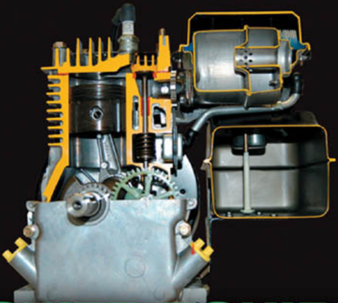
POWER EQUIPMENT ENGINE TECHNOLOGY



Edward Abdo



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Power Equipment Engine Technology
Edward Abdo

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PREFACE

Power Equipment Engine Technology (PEET) is a comprehensive textbook designed to meet the basic needs of students interested in the subject of small engine repair, and to help students become more qualified candidates for shops looking for well-prepared, entry-level technicians.

PEET has been written to make the learning experience enjoyable; the easy-to-read-and-understand chapters and great number of full-color illustrations will assist visual learners with content comprehension. The book is comprised of 17 chapters, starting with a brief history of the internal combustion engine and ending with a chapter on troubleshooting various conditions found on any power equipment engine. Both two-stroke and four-stroke engines are covered in the text.

PEET can be used not only for pre-entry-level technicians but also as a reference manual for practicing technicians, and will be helpful for the general consumer of power equipment engines who has an interest in understanding how they work. Power equipment technicians are currently sought after, and will continue to be in demand in the future as technology advances in the manufacturing of modern power equipment engines. In today‘s world, an education prior to working in the field is becoming more desirable by all shops that hire.

ACKNOWLEDGMENTS

There were many people that played key parts in the development of PEET. The numerous reviews from instructors within the power equipment engine industry offered excellent suggestions that helped to make this a better book for you, the reader. There are also people that I would like to acknowledge whom without their help this book would not have been made possible.

Colin Miller and Beth Syzmanski assisted with the disassembly and reassembly of engines and many of the pictures seen on these pages. Paul Cichocki and Chuck Kelly, – owners of Ashford Small Engine Repair – allowed me to borrow engines from their shop and take numerous photographs at their facilities. They also assisted with questions I had and suggestions pertaining to the content of this book. Their expertise and assistance is greatly appreciated. My life-long friend Mike Krzemien offered me a great deal of input and was always there to offer assistance with his vast technical knowledge from many years of experience working on power equipment engines. Mike's assistance was instrumental throughout the development of each chapter of this text and I cannot thank him enough for all of his help. And finally, I would like to dedicate this book to the two people that mean more to me than anyone, my two boys, Anthony and Nicholas. Their endless love helped me though some very difficult times that occurred during the writing of the chapters to follow and I am proud to not only be their dad but also proud to have them as friends.

REVIEWERS

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Harry Senn
Texas State Technical College
Waco, TX

ABOUT THE AUTHOR

Edward Abdo has been actively involved with working on all types of engines for over 30 years. He has received extensive factory training from all of the major manufacturers and has worked as a Technician, Service Manager and a Service and Parts Director. Mr. Abdo's experience in training includes over eight years as an Instructor, Chief Instructor and Curriculum Development Manager as well as spending 10 years with American Honda – 7 of those years as the Assistant Manager of Service Education in Hondas Motorcycle Division. Currently, Mr. Abdo has his own Powersports Service and Repair shop in his hometown of Springville, NY.

CHAPTER

1 Introduction to Power Equipment Engine Technology

Learning Objectives

- Understand a brief history of the engine
- List job opportunities in the power equipment engine industry

Key Terms

EETC technician certification program
Entry-level engine technician
Equipment & Engine Training Council (EETC)
Franchised dealership
General manager
Internal combustion engine
Otto cycle
Outdoor Power Equipment and Engine Service Association (OPEESA)
Parts department
Parts technician
Sales department
Service department
Service manager
Service writer
Technician

INTRODUCTION

Engines have a long history that dates back hundreds of years, and the power equipment engine is a major factor in that history. But first try to imagine a world without lawn mowers, snow blowers, tractors, cars, cell phones, iPods, electricity, or computers. That is the way it was 200 years ago. All work was done by hand and with the help of animals and water or wind power. Over the years, engines were developed to help us with various types of work, and over time, constant breakthroughs in engine and electronics technology have greatly changed how engines are developed and marketed to today's consumer.

With millions of power equipment engines being sold every year, trained engine technicians will remain in high demand throughout the country. This textbook has been designed to discuss the various types of engines and engine components that a power equipment technician is likely to work with. *Power Equipment Engine Technology* was written for the high school, community college, or trade school level. It can be a valuable addition to the library of the seasoned technician as well as the casual consumer wanting to know more about how an engine operates. The content of this textbook is the result of input from technicians, instructors, and owners of power equipment shops.

A BRIEF HISTORY OF THE INTERNAL COMBUSTION ENGINE

According to Merriam Webster's dictionary, the term **"internal combustion engine"** is defined as "a heat engine in which the combustion that generates the heat takes place inside the engine proper instead of in a furnace." Of course, engines are a bit more complex than this simple explanation suggests.

Internal combustion engines have been in existence for over 200 years and are a direct descendent of the external combustion, steam-powered engine. Steam engines convert potential energy that exists as pressure into mechanical force. An example of a steam engine would be the steam-powered locomotive. Steam engines were designed in many different types but most utilized a reciprocal piston or a turbine device to convert the raw heat built up by the steam into mechanical work. It's argued that the Industrial Revolution came about primarily because of the steam engine. In 1698, Thomas Savery, an English military engineer and inventor, patented the first crude steam engine (Figure 1-1), based on a pressure cooker.

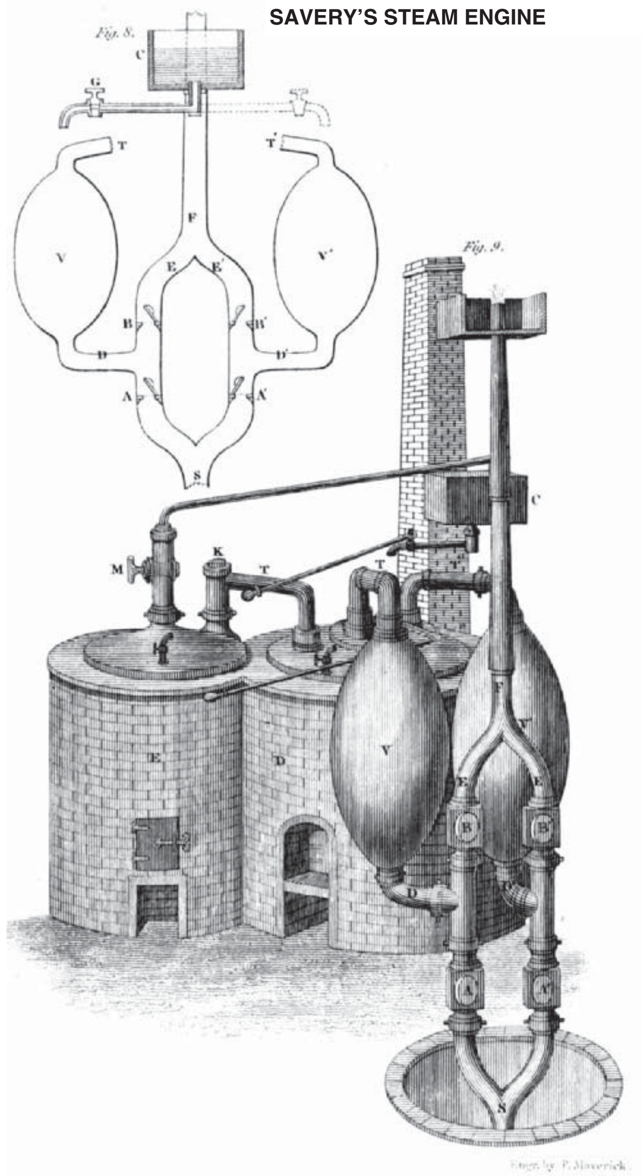


Figure 1-1 Thomas Savery's steam engine (circa 1698) that was used to pump water out of coal mines. Courtesy of Lienhard, John, H. (2006). *How Invention Begins: Echoes of Old Voices in the Rise of New Machines*, pg. 62. New York, NY: Oxford University Press.

Savery worked on this design as a means to solving the problem of pumping water out of coal mines. Thomas Newcomen, an English blacksmith, improved upon Savery's design and, in 1712, built an engine (Figure 1-2) on top of a water-filled mine to pump water out more efficiently. Newcomen's engine used the force of atmospheric pressure to pump steam into a cylinder that was condensed by cold water, which in turn created a vacuum inside the cylinder. This resulted in the operation of a piston that created strokes up and down that would allow the pumping of water.

The first truly practical steam engine was patented by inventor James Watt in 1769 (Figure 1-3). Watt's design was able to save a lot of physical work, like pumping water from mines, and led the way to power steamboats and locomotives. A unit of electrical power, the watt (W), named after James Watt, is equal to 1/746 of a horsepower, expressed as follows:

One volt times (×) one amp equals (=) one watt

The steam engine, however, had its drawbacks. It was a large machine requiring constant monitoring by men who became known as *engineers*. A fire had to be built and maintained in a boiler, and there was always the chance of a boiler explosion.

The Birth of the Internal Combustion Engine

The internal combustion engine emerged in the 19th century as a result of a search for a substitute for steam power. In an internal combustion engine, the fuel is burned inside the engine. A cannon, for example, can provide us with an image of a primitive, single-stroke engine. In fact, people had experimented with gunpowder as a means of driving a piston in a cylinder. Their efforts failed mainly because of their inability to find a suitable fuel and then ignite that fuel in an enclosed space to produce an action that could be easily and quickly repeated. The first problem was solved in the mid-19th century by the introduction of gasoline, which was a by-product of oil wasted during the manufacture of kerosene. The second problem

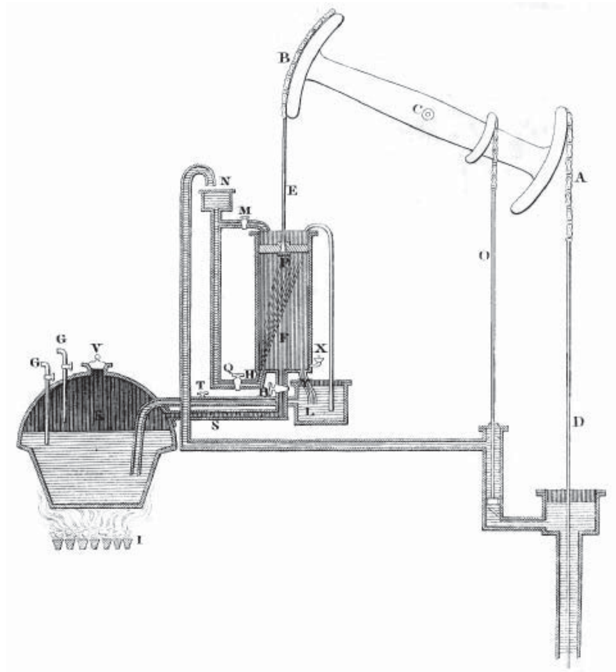


Figure 1-2 The steam engine designed by Thomas Newcomen in 1712 used a piston and was a more efficient design as compared with Savery's steam engine. Courtesy of Lienhard, John, H. (2006). *How Invention Begins: Echoes of Old Voices in the Rise of New Machines*, pg. 64. New York, NY: Oxford University Press.

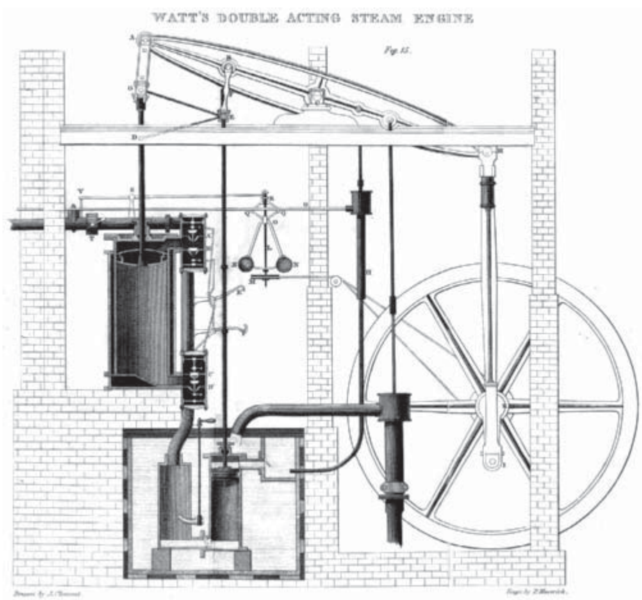


Figure 1-3 James Watt patented the first practical steam engine in 1769 and his design led the way to engines that were used to power boats and locomotives. Courtesy of Lienhard, John, H. (2006). *How Invention Begins: Echoes of Old Voices in the Rise of New Machines*, pg. 69. New York, NY: Oxford University Press.

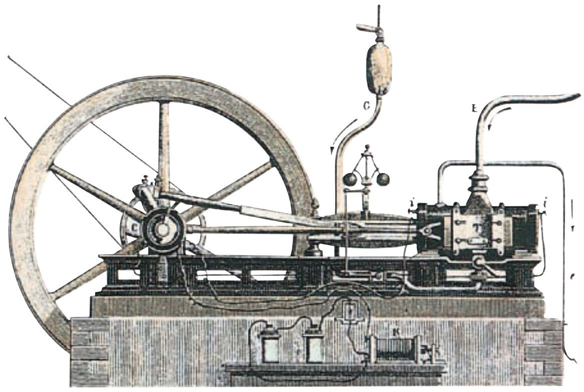


Figure 1-4 The first successful gas-powered engine was built by Etienne Lenoir in France. This design was used as stationary power plants in engineering setups such as printing presses, water pumps, and machine tools. © 2008 Dorling Kindersley Limited.

proved to be more difficult to solve because ignition could not be maintained evenly.

The first successful gas engine was invented by Etienne Lenoir in Paris, France, in 1859 (Figure 1-4). It was a two-stroke design resembling a horizontal steam engine, with its mixture of gas and air ignited by an electric spark on alternate sides of the piston when it was in the mid-stroke position. Most applications of the Lenoir engine were as a stationary power plant, powering printing presses, water pumps, or machine tools. They, however, proved to be rough and noisy after prolonged use. Although technically satisfactory, the engine was expensive to operate.

It was not until a major refinement was introduced by the German inventor Nikolas Otto in 1878 that the gas engine became a commercial success (Figure 1-5). Otto adopted a four-stroke cycle of intake-compression-power-exhaust that

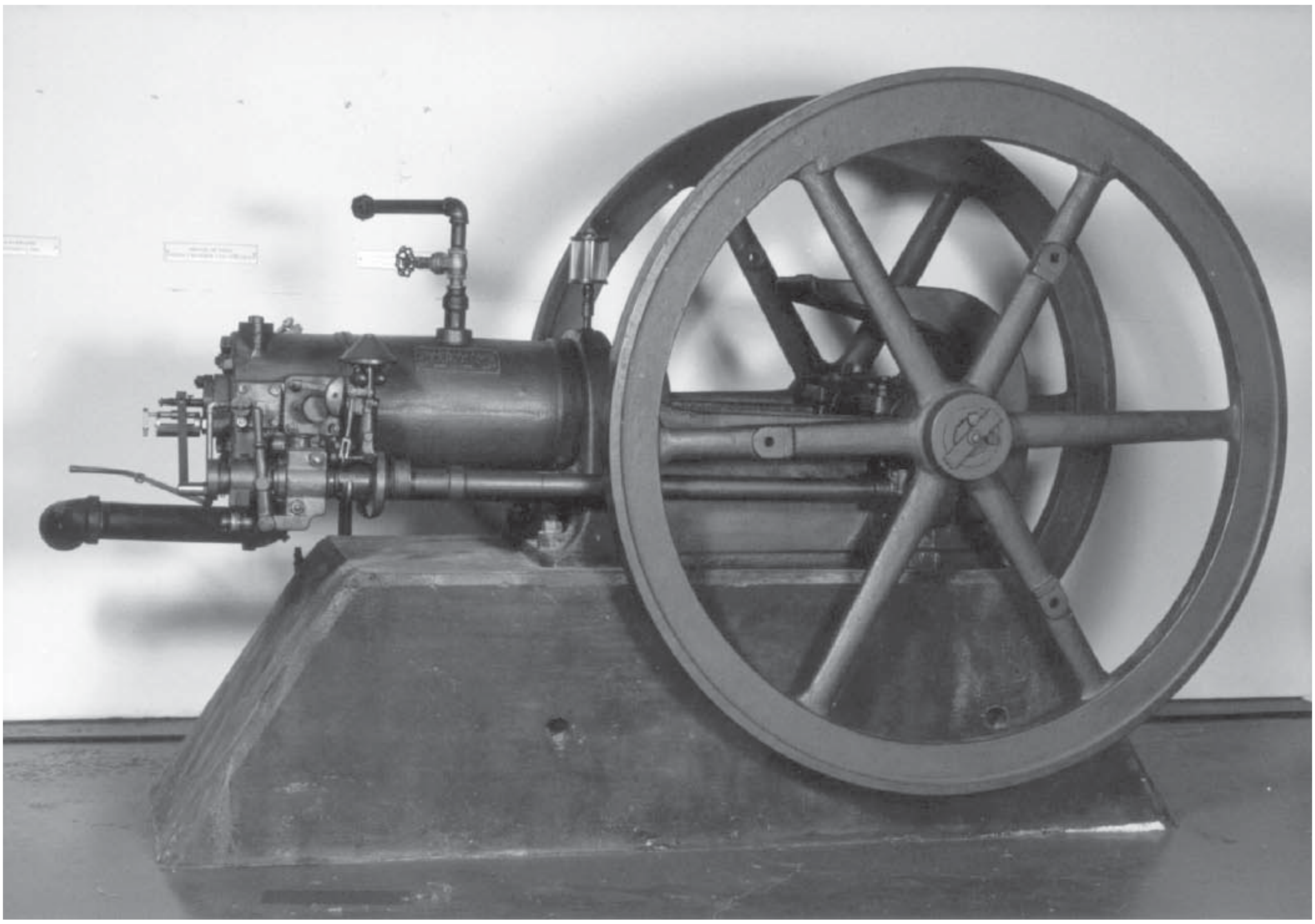


Figure 1-5 German inventor Nikolas Otto designed this engine that allowed gas-powered engines to be a commercial success in 1878. Courtesy of Owls Head Transportation Museum.

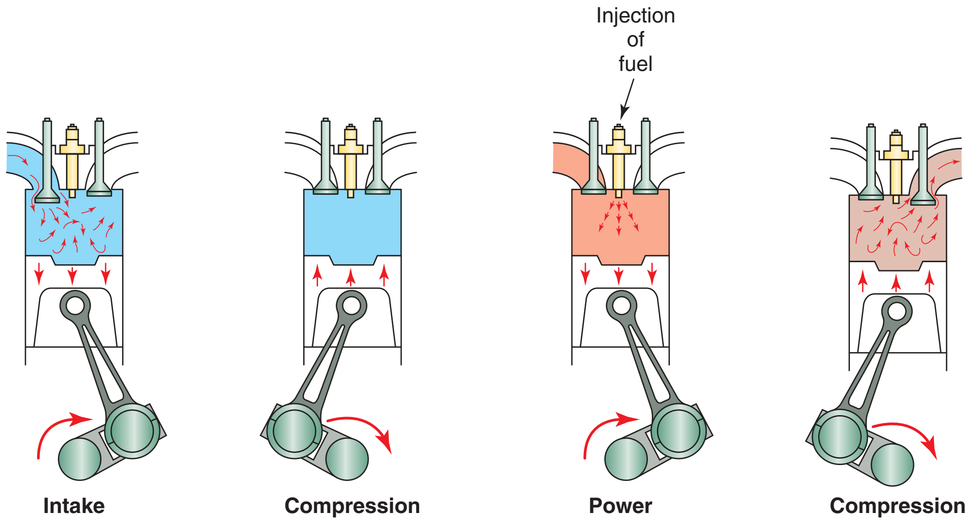


Figure 1-6 The "Otto cycle" was the introduction of the four-stroke engine design of intake-compression-power-exhaust.

has been known as the **Otto cycle** ever since (Figure 1-6). Gas engines came to be used extensively for small industrial factories, which could thus dispense with the upkeep of a boiler necessary in any steam plant, however small. These engines were also of great benefit to farmers. With the purchase of just one small engine, a farmer could run his cream separator, wood saw, butter churn, feed grinder, and gristmill, and pump water too. Everything from small shops to factories could be run on engines now. These engines could usually be started in just a few minutes, without waiting for a head of steam to build up before operating machinery.

So, why is this important? As time passed, companies in the United States, such as Briggs & Stratton, Tecumseh, and Kohler began producing small, lightweight, high-speed, air-cooled engines (Figures 1-7 through 1-8) for portable machinery. Today's power equipment engines use the same basic principles established by these pioneers of the internal combustion engine.

CAREER OPPORTUNITIES IN THE POWER EQUIPMENT ENGINE INDUSTRY

This section outlines career opportunities available in the power equipment industry. Millions of power equipment engines are sold every year, which ensures the need for qualified technicians to keep these machines maintained and repaired. Upon completion of their training, many students obtain their first job as **entry-level engine technicians** at **franchised dealerships.** An entry-level technician has very little hands on experience with engines. A franchised

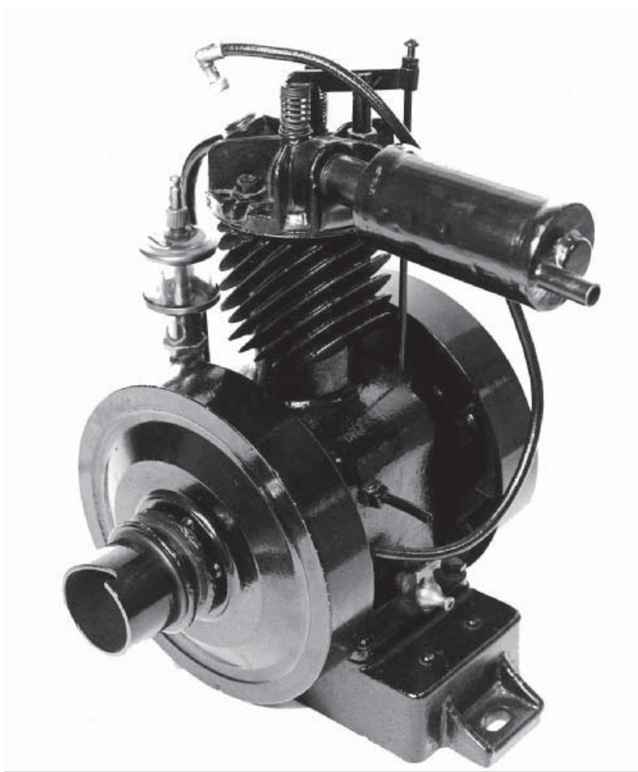


Figure 1-7 An early model of a Briggs & Stratton engine. Copyright Briggs & Stratton Corp. Used with permission.

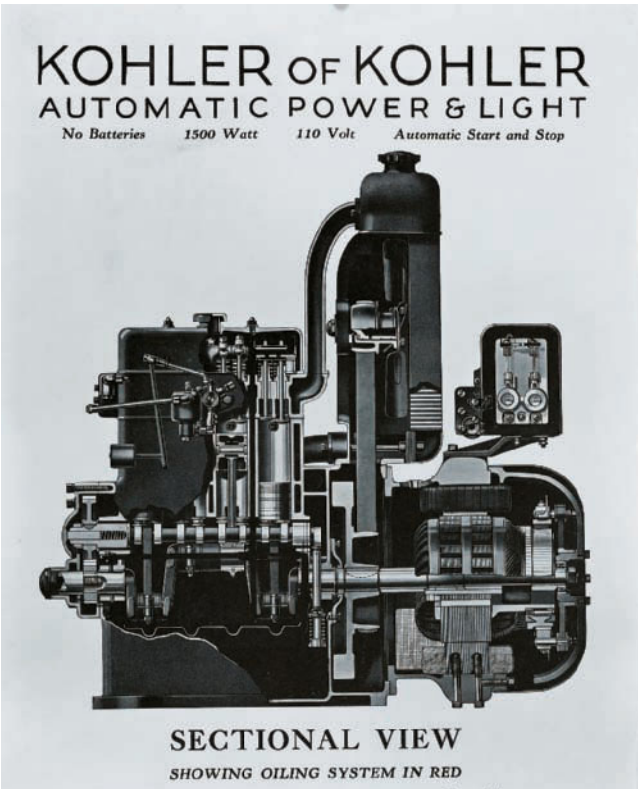


Figure 1-8 The engine manufacturer Kohler was first known for a 1500-W generator powered by a four-cylinder, water-cooled engine built in 1920. Courtesy of Kohler Co.

dealership is authorized to sell a particular engine or component company's products and services in a particular area. Many positions are available at power equipment dealerships for individuals with engine repair backgrounds. Even if you're not interested in a career in the power equipment industry now, this section will give you an idea of what the industry is all about. There are many career opportunities in the field of power equipment engine repair such as working in rental yards, city park departments, school districts, landscape companies, and golf courses. To obtain a better understanding of the positions available at a power equipment dealership, let's take a look at the various positions at the dealership.

Opportunities in Dealerships

A power equipment dealership is an excellent place to begin a career in power equipment engine repair. Often, prospective employees must be willing to start at an entry-level position and work their way up the ladder to higher positions.

Most franchised and independent dealerships have three main departments:

- Sales
- Parts
- Service

Before we discuss the service department, let's take a look at the other two departments. It's possible that your entry-level job may be in the sales or parts department. You can gain valuable experience in these departments as well. The ability to get along with people is a key requirement for working in any area of a power equipment engine dealership. This is particularly true in the **sales department**, where products are displayed and sold. As a skilled salesperson, you must also be able to discuss the technical features of different engines and component attachments with customers. An education in engine repair provides you with a definite advantage as a member of the sales staff. If you possess the ability to deal directly with people, the sales department is an excellent place to learn how a power equipment dealership operates. The sales area provides valuable exposure to business-related activities. The experience can be especially beneficial if you plan to run your own business someday.

The **parts department** is also a great place to use your people skills. Parts departments sell repair parts and accessories. As a member of the parts department, you'll have constant contact with retail customers, the sales department, and the service department. You'll be dealing directly with customers, both in person and on the telephone. The parts department is more closely related to the service department than to the sales department, especially if you work as a **parts technician**. A parts technician is responsible for supplying the service department technicians with the parts they need to complete their service and repair work.

The third department within a power equipment dealership is the **service department**, where power equipment engines are brought in for maintenance and repairs. A small shop may have a service department that employs only one or two technicians. A medium-sized shop might employ three or four technicians plus a service manager. It's not unusual to find a significant number of employees in the service department of a large dealership.

Larger power equipment dealerships typically employ the following personnel in the service department:

- Technicians
- Service writers
- Service managers

The **technician** is frequently considered the backbone of the service department. As a power equipment engine technician, you'll need a technical background, factory training (which the dealership can arrange for you), tools, and usually some prior mechanical experience. Some dealerships require tests of knowledge to be completed by their technicians to become certified. Some job assignments and responsibilities of a technician include:

- Warranty service
- Dealing with customer questions
- Preventive and scheduled maintenance
- General repair activities
- Staying current with new products, accessories, and service procedures
- Maintaining accurate repair records
- Alerting the service manager to actual or potential problems

Another key employee in the service department is the **service writer**. The service writer is responsible for writing the repair orders for service work. He or she should be technically trained and have a complete understanding of the service process. When writing a repair order, the service writer must obtain detailed information from the customer, verify the customer's concern, and then provide the customer with an estimate of the services that might be required to correct the problem. In most dealerships, the service writer creates the repair orders, which are then distributed to the technicians. The service writer also has a hand in job scheduling, ensuring that the repair process flows smoothly.

The **service manager** holds the highest position in the service department. Most service managers are responsible for the following:

- Customer transactions
- Warranty claims
- Product update and information publications
- Technician training
- Employee hiring and dismissal
- Equipment needs
- Building/service area maintenance
- Service policy changes
- Servicing files and records

Service managers usually have an extensive service background and prior management experience, including:

- Technical training
- Factory service school training
- Setup/assembly experience
- Engine repair experience
- Customer relations skills
- Management experience

The service manager has the overall responsibility for the service department. He or she must see that everything in the service department is well organized, that all necessary parts are in stock, and that the service work is performed correctly and completed on time. The service manager must handle all customer complaints and any technical questions from both customers and technicians. The service manager needs an extensive amount of engine repair experience and excellent management skills.

Finally, the top position in many power equipment dealerships is the **general manager**. The general manager has the overall responsibility for the sales, parts, and service departments. He or she oversees the day-to-day operations of the entire business. A general manager is likely to have had experience in all the other departments.

POWER EQUIPMENT INDUSTRY EDUCATION AND CERTIFICATION

Once you decide that you would like to become a power equipment engine technician, you'll need to get the necessary training and experience to do the job. Although it's possible to start out as an on-the-job apprentice, getting formal education in this subject is preferred by many power equipment dealers. Many dealers will start you as an apprentice or an entry-level technician once you graduate, but your abilities will tend to be more advanced if you have the training that formal education provides. There are training programs in high schools, community colleges, and trade schools. Some manufacturers such as Briggs & Stratton offer Master Tech Certification training. One important advantage that the power equipment industry has over many other service industries is the **Equipment & Engine Training Council (EETC)** (Figure 1-9).

Equipment & Engine Training Council

With a goal of raising the competency level of technicians in the power equipment industry, the EETC developed and maintains the **EETC technician certification program** (Figure 1-10). EETC technician certification is recognized as the standard for power equipment servicing. Certified technicians demonstrate a higher level of technical proficiency in their work and this, in turn, increases the level of professionalism at dealerships throughout North America. It's a known fact that consumers seek out dealers employing trained technicians. The technician certification program was initiated in 1995 at the Texas Servicing Dealer Association. The Equipment & Engine Training Council was formed in 1997, and was handed the responsibility of the certification program. The EETC updates certification tests on an annual basis to ensure that the latest technologies are covered.

There are seven tests offered for certification purposes by the EETC. They cover the following subject areas: two-stroke engines, four-stroke engines, electrical, drivelines/hydraulics, compact diesel, generators, and reel technology.

If you desire to document your professional abilities and skills, advance your career, or have a passion for excellence you should consider taking the relevant tests. Certification lasts for 3 years, at which time you must be recertified to maintain your status. The EETC maintains the records and will notify you when you need to be recertified.

The EETC works closely with the **Outdoor Power Equipment and Engine Service Association (OPEESA)**. OPEESA membership includes more than 140 distributors and manufacturers

Figure 1-9 With a goal of raising the competency level of technicians in the power equipment industry, the Equipment & Engine Training Council (EETC) developed and maintains the Outdoor Power Equipment Technician Certification Program. Courtesy of Equipment & Engine Training Council.

Figure 1-10 EETC technician certification is recognized as the standard for power equipment servicing. Courtesy of Equipment & Engine Training Council.

of outdoor power equipment and air-cooled gas and diesel engines. The mission of the OPEESA is to "assist distributors in achieving outstanding channel performance." To fulfill this mission, the OPEESA offers a wide range of services and programs as well as opportunities to share ideas with fellow distributors. In addition, they foster cooperation and proven leadership among manufacturers, distributors, and dealers in the outdoor power equipment industry.

The most current information on both of these organizations can be found on their Web sites: http://www.EETC.org and http://www.opeesa.com.

Summary

- Engines have a long history that dates back hundreds of years. The power equipment engine is a major factor in that history.
- With millions of power equipment engines being sold every year, trained engine technicians will remain in high demand throughout the country.
- There are numerous career opportunities within the power equipment engine industry.
- The industry-recognized standard of power equipment engine certification is obtained through the Equipment & Engine Training Council.

Chapter 1 Review Questions

1. Name the positions mentioned in this chapter that are available in a power equipment service department: _____.
2. Name the three main departments in a power equipment dealership: _____, _____, and _____.
3. Three things that a service writer must do when working with customers are: _____, _____, and _____.
4. The four-stroke cycle of intake-compression-power-exhaust was developed by: _____.
5. What are the seven test subject areas offered for certification purposes by the EETC? _____, _____, _____, _____, _____, _____, and _____.

CHAPTER

2 Safety First

Learning Objectives

- Understand the importance of safety and accident prevention in a power equipment engine shop environment
- Explain the basic principles of personal safety
- Explain the procedures and precautions for safety when using tools and equipment
- Explain what should be done to maintain a safe working area in a service shop environment
- Describe the purpose of the laws concerning hazardous wastes and materials, including right-to-know laws

Key Terms

Alternating current (AC)
Carbon dioxide (CO_2)
Carbon monoxide
Class A fire
Class B fire
Class C fire
Class D fire
Conductor
Contact dermatitis
Direct current (DC)
Fibrillation
Fire extinguisher
Fire triangle
Halon
Headset
Material handling
Material safety data sheets (MSDSs)
Metatarsal guards
National Electrical Code (NEC)
National Fire Protection Association (NFPA)
Occupational Safety and Health Administration (OSHA)
PASS
Personal protective equipment
Power tools
Respirators
Safety glasses

INTRODUCTION

Most people are concerned with safety in and around their homes. They strive to protect their families from accidents and injuries. But accidents in the workplace are often more severe than accidents at home, because workplaces contain more potential hazards. Although working on power equipment engines can be fun and rewarding, if proper precautions are not followed, it can be dangerous as well. You must prevent accidents by working safely, as there is great potential for serious accidents to occur in a power equipment engine repair shop.

THE SAFETY ATTITUDE

Safety is more than just the absence of accidents. *Safety is an attitude* that helps you prevent injuries to yourself and others. Safe working practices should be a way of life. They should be as instinctive as putting on your seat belt or looking both ways before you cross the street. Safety isn't a matter of good or bad luck. It's a predetermined set of mental exercises, including:

- Planning to work safely
- Recognizing potential safety hazards and eliminating them
- Following safety procedures at all times, especially at work

The **Occupational Safety and Health Administration (OSHA)** is the federal agency that publishes safety standards for business and industry. OSHA's regulations affect every business that has employees and sells its products or services. OSHA requires every employer to provide employees with safe workplaces that are free from recognized hazards. Without getting into a long discussion about the legal aspects of OSHA's regulations, suffice it to say that it's the federal government's law enforcer in industrial safety matters. Employers are motivated to adopt and use safe working procedures through OSHA's strict enforcement of the regulations. Safety violators receive harsh penalties and fines. You can find a complete list of OSHA's proven safety methods, practices, and regulations as well as information regarding minors in the workplace at http://www.osha.gov/. Even if you're a one-person operation, you should understand and follow OSHA's safety guidelines. In a power equipment engine service department, safety matters of primary concern are:

- Fire
- Chemicals
- Electricity
- Ventilation of exhaust gases
- Operation of engines and equipment
- Housekeeping practices
- Handling of heavy objects and materials
- Use of personal protective equipment

Now that you have a list of the safety topics and areas that OSHA's regulations cover, let's look at these important safety items one at a time.

FIRE SAFETY

A major safety consideration in the power equipment engine repair business is fire prevention. Many fires occur in private garages every year, and a significant number of these are started by the mishandling of gasoline, such as storing gasoline in unapproved containers or failing to clean up gasoline spills. Gasoline is the fuel for all modern power equipment engines. Because gasoline is one of the most flammable liquids, fire is a serious threat in any power equipment service area.

Gasoline isn't the only flammable liquid used in the service department. Oils, lubricants, paints, cleaning solvents, and other chemicals can create a fire hazard when improperly handled. Despite the fire risk, by following basic safety practices that we are about to discuss, the danger of fire can be greatly reduced, if not eliminated entirely.

The **National Fire Protection Association (NFPA)** is the largest and most influential national group dedicated to fire prevention and protection. Its mission is to safeguard people, property, and the environment from fires. The NFPA publishes the **National Electrical Code (NEC)**, which is the national standard for all residential and industrial electrical installations in the United States and Canada. When you start planning a fire safety program, which is a policy to follow in case a fire occurs in the service area or anywhere else in the store for your business, check with the NFPA. They can provide useful hints and detailed support information. The NFPA can be accessed at http://www.nfpa.org.

The Fire Triangle

There are three conditions that must be present for a fire to start. These conditions are grouped together to form the **fire triangle**. The three components of the fire triangle are:

- Fuel (such as wood or gasoline)
- Oxygen
- An ignition source (such as a spark)

After a fire starts, supply of fuel and oxygen must stay at certain levels to sustain the fire. To extinguish a fire, you must remove at least one of these two legs of the fire triangle. You can put out a fire by removing the fuel source or removing the oxygen.

When analyzing fire prevention, you must always be aware of the ignition sources that could start a fire in your work area. When we consider ignition sources, most of us think of open flames, sparks, stoves, and matches. However, there are several other dangerous, but less obvious, ignition sources.

For example, a common but often overlooked source of ignition is the engine exhaust. A power equipment engine's exhaust system becomes very hot during operation. This heat remains in the exhaust system for a period of time after the engine has been turned off. Therefore, if an engine is still warm when you begin to make repairs, you must take extra precautions to prevent fires.

Another likely source of ignition is cigarette smoking. Smoking-related ignitions are a leading cause of fires. Sparks from lit cigarettes, heat from discarded cigarette butts, and the open flames of lighters and matches can all start fires in flammable and combustible materials. Therefore, smoking should be strictly controlled in a power equipment engine service department. Smoking and nonsmoking areas should be posted with distinct, easily recognizable symbols. Smoking areas should be equipped with adequate receptacles to provide for the safe disposal of smoking materials. Smoking is prohibited in many service departments, and smokers must go to a designated, outside smoking area.

Spontaneous combustion is another potential source of ignition that you should recognize. In a fire caused by spontaneous combustion, the heat for ignition is created by a chemical reaction in combustible materials. One common type of spontaneous combustion occurs when oil- or solvent-soaked rags or papers are discarded in a trash can. The decomposition of the oil or solvent often produces enough heat to ignite the rags or papers. To prevent spontaneous combustion, all oil- or solvent-contaminated rags and papers should be discarded only in designated, fireproof metal safety receptacles. Routine trash material shouldn't be discarded in these special receptacles.

The Four Fire Classes

Let's take a closer look at the different types of fires. The NFPA classifies fires into four categories or classes: Classes A, B, C, and D (Figure 2-1). Each of these four fire classes is defined by, and associated with, a different type of fuel source.

Class A fires involve the burning of wood, paper, cardboard, fabric, and other similar fibrous materials. These materials ignite easily, burn rapidly, and produce large quantities of heat during burning. Some examples of Class A combustible materials that are commonly found in workplaces include:

- Paper business forms
- Company files or records
- Cleaning and polishing cloths
- Work aprons
- Dust covers
- Work area partitions

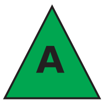
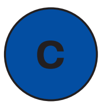
Symbol	Class of Fire	Typical Fuel Involved	Type of Extinguisher
Class  Fires (green)	**For Ordinary Combustibles** Put out a class A fire by lowering its temperature or by coating the burning combustibles.	Wood Paper Cloth Rubber Plastics Rubbish Upholstery	Water Foam Multipurpose dry chemical
Class  Fires (red)	**For Flammable Liquids** Put out a class B fire by smothering it. Use an extinguisher that gives a blanketing, flame-interrupting effect; cover whole flaming liquid surface.	Gasoline Oil Grease Paint Lighter fluid	Foam Carbon dioxide Halogenated agent Standard dry chemical Purple K dry chemical Multipurpose dry chemical
Class  Fires (blue)	**For Electrical Equipment** Put out a class C fire by shutting off power as quickly as possible and by always using a nonconducting extinguishing agent to prevent electric shock.	Motors Appliances Wiring Fuse boxes Switchboards	Carbon dioxide Halogenated agent Standard dry chemical Purple K dry chemical Multipurpose dry chemical
Class  Fires (yellow)	**For Combustible Metals** Put out a class D fire or metal chips, turnings, or shavings by smothering or coating with a specifically designed extinguishing agent.	Aluminum Magnesium Potassium Sodium Titanium Zirconium	Dry power extinguishers and agents only

Figure 2-1 The four categories of fires, per the National Fire Protection Association (NFPA). The symbols shown are placed on fire extinguishers to indicate the types of fires that they're designed to be used on.

Class A fires can be extinguished with water, CO_2 (carbon dioxide), or dry chemical agents. These agents extinguish the fire by quickly cooling the burning material and lowering the temperature in the combustion zone. The symbol used to identify Class A extinguishing equipment is the letter "A" inside a green triangle.

Class B fires involve flammable liquids, gases, and other chemicals. Because many flammable and combustible liquids and solvents are used in a power equipment engine service department, special care should be given to their handling, use, and storage. Some common flammable liquids are gasoline, cleaning solvents, oils, greases, turpentine, oil-based paints, and lacquers. Common flammable gases include natural gas, propane, and acetylene.

Fires involving flammable liquids produce tremendous quantities of heat. Water is ineffective on a Class B fire. The heat from a burning flammable liquid will boil the water that's applied to the fire, turning the water into steam before it can do much good. Most importantly, almost all flammable liquids are lighter than water. The liquids float on top of the water and continue burning. This is a dangerous situation that can cause a flammable liquid fire to spread rapidly. The best way to extinguish a Class B fire is to smother it, removing its source of oxygen. Foams, dry chemicals, and CO_2 are the best extinguishing agents to use on a Class B fire. The symbol used to identify Class B extinguishing equipment is the letter "B" inside a red square. If you routinely keep gasoline (even in small amounts) in your shop, you should have at least one Class B fire extinguisher in the area. You can smother a small Class B fire with a blanket or noncombustible container also. Use this method only if you can do so without risking personal injury. You should always remember that flammable liquid fires have a tendency to flare up rapidly.

Class C fires involve live electrical equipment, such as electrical boxes, panels, circuits, appliances, power tools, machine wiring, junction boxes, wall switches, and wall outlets. Some form of a short circuit or an overloaded circuit usually causes electrical fires. Examples of these causes include:

- Loose contacts or terminals
- Frayed wire insulation
- Improper installations
- Defective equipment
- Overloaded circuits

Electrical system overloads and short circuits can produce arcs, sparks, and heat. This type of electrical problem can ignite nearby combustible materials, such as wire insulation, plastic components, and wall insulation or paneling. Water is a good conductor of electricity, and if it's applied to an electrical fire, the person holding the extinguisher could be severely shocked or electrocuted. **Carbon dioxide (CO_2)** is the most widely used extinguishing agent because it's nonconductive, it penetrates around electric equipment well, it's effective, and it leaves no residue that would have to be cleaned up afterward. Dry chemicals produce a residue that can damage electric equipment.

Halon is another extinguishing agent that's effective on all classes of fire, especially Class C. Halon is stored as a liquid under high pressure and is released on a fire as an oxygen-depleting (smothering) gas. Although halon is effective, it's not readily available. Halon is a fluorocarbon compound that's classified as an ozone-depleting substance. Use of halon is restricted by law for environmental reasons. The symbol used to identify Class C extinguishing equipment is the letter "C" inside a blue circle.

Class D fires involve combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium. Flakes and fine particles of these metals can be ignited at relatively low temperatures. Metal particles are often produced by cutting or grinding operations. If cutting or grinding is done in a typical power equipment engine repair shop, it's usually confined to a designated area that's uncluttered and well ventilated. Greater exposure to Class D fires is found in a "back-of-the-garage" type of operation, where space is limited and conditions might favor the start of this type of fire.

Dry powder compounds and dry chemical extinguishers are the two primary methods to extinguish Class D fires. Dry powder compounds are completely different from dry chemical extinguishers. Dry powder compounds are usually scooped directly onto a fire. Dry chemical extinguishers apply the dry chemical charge under pressure. The symbol used to identify Class D extinguishing equipment is the letter "D" inside a yellow star. The most important reason for introducing you to the four classes of fires is to inform you of what to do and what not to do in a fire emergency. Your reaction to a fire could mean the difference between a minor incident and major loss of property with possible injury or death. Knowledge of the fire classes is also important when you're assessing your work area for fire hazards. Fire prevention isn't just a slogan. Most fires are preventable. Awareness, common sense, and good work habits go a long way toward preventing fires.

Based on the nature of your work environment, the two types of fires most likely to occur in a power equipment engine service department are Class A and Class B fires. But don't be negligent about the possibility of a Class C or Class D fire occurring. Know what to do for all types of fires.

The most common type of fire extinguisher is an ABC dry chemical fire extinguisher, which is capable of handling A, B, or C type fires.

Using a Fire Extinguisher

Fire extinguishers (Figure 2-2) must be properly used to be effective on a fire. You should be familiar with the various extinguishers installed

Figure 2-2 Examples of different types and sizes of fire extinguishers.

Figure 2-3 Be sure to know the locations and types of fire extinguishers available in your service shop.

at your facility before a fire starts. This familiarization step is important for the following reasons:

- To operate a fire extinguisher safely and efficiently, you should know how to use it. You'll lose valuable fire-fighting time if you have to stop and read instructions. Be prepared.
- You could injure yourself or others by using an extinguisher improperly.
- An average fire extinguisher discharges all its contents in just 12–60 seconds. You need to be well prepared in using an extinguisher to make best use of its contents.

To be effective, portable fire extinguishers must be readily available in a fire emergency. Extinguishers must be installed close to all potential fire hazards (Figure 2-3). The extinguishers must contain the proper type of extinguishing agent for those hazards and they must be large enough to protect the designated area. The fire hazards existing in a shop must be identified and evaluated to verify that the proper numbers and types of fire extinguishers are installed at the correct locations.

Take the following steps before you attempt to extinguish any fire:

1. **Evaluate the size of the fire.** A fire in its beginning stages is called an **incipient fire**. A fire is classified as incipient (start-up) if it covers an area no larger than 2–4 square feet, has flames less than 2 feet in height, and produces low levels of smoke. Fire extinguishers can be effective for extinguishing or suppressing a fire at this stage. But it's not safe to use a fire extinguisher after a fire passes beyond the incipient stage. A fire usually remains in the incipient stage only for a short period of time. If the fire goes beyond the start-up stage, the only course of action is to evacuate the building or facility and call the fire department.
2. **Locate the exits and the escape routes you'll need in an emergency evacuation.** To prevent yourself from becoming trapped in a serious situation, keep the locations of the exits in mind as you fight the fire.
3. **Determine which way the flames are moving and approach the fire from the opposite direction.** The flaming side of the fire radiates too much heat, and the fire could overtake you before you have a chance to escape. By attacking the fire from the opposite side, you'll be safer and able to get closer to the combustion zone of the fire.

When you've taken these preliminary steps, you're ready to use an extinguisher. To operate an extinguisher:

- Remove the extinguisher from the wall.
- Grasp the handle of the extinguisher and pull out the safety pin.
- Free the hose and aim the nozzle at the fire.
- Squeeze the handle.
- Move the nozzle in a sweeping motion to distribute the extinguishing agent.

Here's a small hint. You can use the acronym **PASS** to help you remember how to operate a fire extinguisher. The letters in PASS stand for pull (the safety pin), aim, squeeze, and sweep.

Always direct the stream of extinguishing agent at the base of the flames. This is the fire's combustion zone. Cooling this area will extinguish the fire more quickly. Sweep the stream from side to side and work your way around the fire until it's completely extinguished. You should remember never turn your back on a fire until you're absolutely sure that it's completely extinguished. Heat remaining inside partially burned materials can reignite the fire when you're not looking. This could trap you. Portable fire extinguishers should be given a complete annual maintenance check, which may include recharging or pressure testing the extinguisher. Most fire extinguishers require pressure testing every 5 years. You should also inspect all fire extinguishers at least once monthly and answer the following:

- Is the extinguisher in its designated place, close to possible fire hazards?
- Is the extinguisher clearly visible?
- Is access to the extinguisher free of all obstructions?
- Is the extinguisher fully charged?

It's also a good idea (in some localities, it's the law) to install battery-operated smoke detectors and carbon monoxide detectors to cover the entire workplace. Remember, smoke detectors also require maintenance. Check the detectors and their batteries routinely to ensure that they're in proper working order. Replace batteries yearly, and replace all detectors that show signs of malfunction or incorrect operation.

The following are some important fire evacuation procedures that you should commit to memory. Never take fire safety lightly. It's recommended that you practice these procedures in scheduled exercises or fire drills.

- **Get out fast.** Believe the alarm when you hear it. Don't waste time trying to verify that there's a fire or trying to gather things before you leave.
- **Stay low to the floor to avoid smoke and toxic gases.** The clearest air is found near the floor. So crawl if necessary! Cover your mouth and nose with a damp cloth, if available, to help you breathe.
- **Don't open a closed door without feeling the door's surface first.** If you open a door with flames on the other side, the fire could backdraft and severely burn you. Use the back of your hand (don't burn your palm) when you test for heat. If the door feels warm on your side, the temperature is probably far above the safety level on the other side. Don't open the door; use an alternate escape route.
- **Never enter a burning building.** This could be a fatal mistake. Professional firefighters are equipped with special protective equipment and breathing devices that allow them to enter burning buildings. They're also trained in search-and-rescue techniques. Leave these tasks to them.
- **If your clothing catches fire, don't panic.** Stop, drop to the ground, and roll around to smother the flames. If a coworker's clothing catches fire, quickly wrap the person in a blanket or rug to smother the flames. Assist the person with the stop, drop, and roll maneuver if a rug or blanket isn't handy.

HAZARDOUS CHEMICALS

Let's start with a question: Do you work with or near any hazardous chemicals? Before you answer too quickly, continue reading.

Many people are unaware that many materials and products in their work areas indeed comprise hazardous chemicals. Materials such as paints, oils, lubricants, cleaners, degreasers, solvents, and gasoline all comprise potentially hazardous chemicals. Labels on chemical containers normally list the names of the chemicals and any hazards associated with them. The labels also highlight health hazards that the chemicals present, including eye and skin contact irritation, breathing and inhalation dangers, and accidental swallowing or ingestion. Many labels also include first aid procedures in case of accidents attributable to these hazards, the name and address of the chemical manufacturer or importer, and specific ingredients of the hazardous chemical compounds. Some chemicals can cause a variety of serious health problems (or even death) if you're exposed to them.

For example, some chemicals can produce gases and vapors that are poisonous when inhaled. Other chemicals are highly flammable or explosive when exposed to sparks or open flames. And still other chemicals can cause temporary or permanent blindness if they get splashed on the eyes. Everyone should take the potential hazards of chemicals seriously. The intent here isn't to scare you. It's to alert you to possible dangers so that you'll give chemicals the attention they deserve.

Most chemicals in the typical power equipment engine shop workplace are not life threatening but can cause minor injuries or illnesses. If you work with chemicals in your service department, always follow the safety precautions on the chemical's label and protect yourself with gloves and safety goggles. A common problem that chemicals can cause is a skin inflammation called **contact dermatitis** or eczema. Contact dermatitis usually starts as redness in the area of chemical contact or exposure and may progress to blistering, scaling, and cracking of the skin surface. People who regularly expose their hands to materials such as detergents, cleaners, degreasers, oil, and gasoline are susceptible to dermatitis. Although contact dermatitis isn't a life-threatening condition, it's uncomfortable and could lead to more serious health complications, such as infections. Contact dermatitis is much easier to prevent than it is to cure, so it's important to wear industrial rubber gloves whenever you're using chemicals that could come in contact with your skin. Exposing the skin to stronger chemicals can cause more serious injuries. For example, exposure to acids and strong bases can cause immediate and painful burns.

The batteries used in all types of power equipment contain strong and dangerous acids. The sulfuric acid found in batteries is a particularly dangerous acid you should be aware of. It can eat through clothing or burn your skin. And more importantly, it can easily cause blindness if splashed on the eyes. Be aware that storage batteries give off dangerously explosive hydrogen gas when they're being charged. Always use extreme caution when handling, storing, replacing, charging, or adding distilled water to storage batteries. Follow these safety guidelines when handling batteries:

- Keep batteries upright to prevent the acid from spilling or leaking.
- Always wear gloves, an apron, and safety goggles when handling batteries, to protect your skin and eyes.
- Charge batteries in a well-ventilated location to prevent the buildup of hydrogen gas.

Right-to-Know Laws

An important part of a safe work environment is knowledge of potential hazards. Right-to-know laws protect every employee in a power equipment engine dealership. These laws were placed in effect when OSHA's Hazard Communication Standard was published back in 1983. This was originally intended for chemical companies and manufacturers who require employees to handle potentially hazardous materials in the workplace. Since then, most states have enacted their own right-to-know laws and these laws now apply to all companies that use or sell potentially hazardous chemicals or materials. The general intent of right-to-know laws is to ensure that employers provide a safe working place for their employees when hazardous materials are involved. Specifically, there are three areas of employer responsibility.

First and foremost, all employees must be trained about their rights under the legislation, the nature of the hazardous chemicals around them, and the contents of the labels on the chemicals. Second, all the information on each chemical must be posted in **material safety data sheets (MSDSs)** and must be easily accessible to every employee (Figure 2-4). Third, the manufacturer must give these sheets (Figure 2-5) to customers if requested to do so. The sheets detail the chemical composition and precautionary information for all products that can present a health or safety risk.

Figure 2-4 Right-to-know laws were created to protect employees' rights and give them access to all information regarding potentially hazardous materials in the workplace.

ELECTRICAL SAFETY

We take electricity so much for granted that we often lose sight of its potential to cause serious injury or death. The main hazards of electricity are electrical shocks and burns. Electric shocks and burns usually result from:

- Faulty power tools or equipment
- A disorderly and untidy work environment
- Human error (the misuse of an electrical device)

Even if you don't work with electrical equipment on a routine basis, you should be aware of how shocks can occur. Generally, you must be in contact with or in proximity to a conductor or a conductive surface. **Conductors** are generally metals that readily pass, or conduct, electricity. If you're in proximity to a conductor and you contact a source of electricity, the electricity can pass through your body to the conductive material and then to ground. In such a situation, your body acts like a switch, closing the electrical circuit. The sensation that you feel is an electric shock. The shock may range from mild to severe, depending on the circumstances and the source of the electricity. If you're lucky, you may experience only a brief unpleasant sensation. If you're unlucky, you could be seriously injured, or worse.

There are two types of electric power sources: **alternating current (AC)** and **direct current (DC)**. AC flows in alternating cycles and is used to run lighting circuits and appliances in most households and workplaces. DC is continuous and steady and is found in batteries and battery-powered electric systems, such as power equipment engine electrical systems.

Each type of electrical source has its own set of hazard characteristics. The AC found in the typical repair facility can be hazardous if the path of the shock run from one hand to the other. This puts your heart in line with the alternating current flow and can cause **fibrillation** (erratic, non-rhythmic heartbeat).

Always keep your work area clean and orderly to prevent electrical accidents. Keep floors clean and dry, because a wet or damp floor will make anyone standing on it more conductive to electricity. All portable electrical equipment (tools that have plugs and cords) should be inspected before each use to ensure that the equipment, cord, and plug are in good condition. If you feel the slightest tingle or shock while using electrical equipment, stop immediately. That slight tingle is an indication that there's a fault in the equipment's electrical wiring or ground circuit. When unplugging any electrical power tool, don't pull the cord but instead pull the plug itself, to eliminate any possible problems in the plug.

Avoid wearing conductive metals such as rings, watches, and chains when working with electricity. These metal objects significantly increase your risk of being electrically shocked. You can increase your resistance to electric shock by wearing rubber gloves, standing on an insulating rubber mat, and using tools with insulated handles.

EXHAUST GAS SAFETY

When an engine is running, exhaust gases are created that are hazardous if inhaled. The most dangerous of these gases is carbon monoxide

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HEXANE
===========================================================
MSDS Safety Information
===========================================================
Ingredients
===========================================================
Name: HEXANE (N_HEXANE)
% Wt: >97
OSHA PEL: 500 PPM
ACGIH TLV: 50 PPM
EPA Rpt Qty: 1 LB
DOT Rpt Qty: 1 LB
===========================================================
Health Hazards Data
===========================================================
LD50 LC50 Mixture: LD50:(ORAL,RAT) 28.7 KG/MG
Route Of Entry Inds _ Inhalation: YES
Skin: YES
Ingestion: YES
Carcinogenicity Inds _ NTP: NO
IARC: NO
OSHA: NO
Effects of Exposure: ACUTE:INHALATION AND INGESTION ARE HARMFUL AND MAY BE FATAL.
INHALATION AND INGESTION MAY CAUSE HEADACHE, NAUSEA, VOMITING, DIZZINESS, IRRITATION
OF RESPIRATORY TRACT, GASTROINTESTINAL IRRITATION AND UNCONSCIOUSNESS. CONTACT
W/SKIN AND EYES  MAY CAUSE IRRITATION. PROLONGED SKIN MAY RESULT IN DERMATITIS (EFTS
OF OVEREXP)
Signs And Symptions Of Overexposure: HLTH HAZ:CHRONIC:MAY INCLUDE CENTRAL
NERVOUS SYSTEM DEPRESSION.
Medical Cond Aggravated By Exposure: NONE IDENTIFIED.
First Aid: CALL A PHYSICIAN. INGEST:DO NOT INDUCE VOMITING. INHAL:REMOVE TO FRESH AIR. IF
NOT BREATHING, GIVE ARTIFICIAL RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN.
EYES:IMMED FLUSH W/PLENTY OF WATER FOR AT LEAST 15 MINS. SKIN:IMMED FLUSH W/PLENTY
OF WATER FOR AT LEAST 15 MINS WHILE REMOVING CONTAMD CLTHG & SHOES. WASH CLOTHING
BEFORE REUSE.
===========================================================
Handling and Disposal
===========================================================
Spill Release Procedures: WEAR NIOSH/MSHA SCBA & FULL PROT CLTHG. SHUT OFF
IGNIT SOURCES:NO FLAMES, SMKNG/FLAMES IN AREA. STOP LEAK IF YOU CAN DO SO W/OUT
HARM. USE WATER SPRAY TO REDUCE VAPS. TAKE UP W/SAND OR OTHER NON-COMBUST MATL &
PLACE INTO CNTNR FOR LATER (SU PDAT)
Neutralizing Agent: NONE SPECIFIED BY MANUFACTURER.
Waste Disposal Methods: DISPOSE IN ACCORDANCE WITH ALL APPLICABLE FEDERAL, STATE AND
LOCAL ENVIRONMENTAL REGULATIONS. EPA HAZARDOUS WASTE NUMBER:D001 (IGNITABLE
WASTE).
Handling And Storage Precautions: BOND AND GROUND CONTAINERS WHEN TRANSFERRING LIQUID.
KEEP CONTAINER TIGHTLY CLOSED.
Other Precautions: USE GENERAL OR LOCAL EXHAUST VENTILATION TO MEET
TLV REQUIREMENTS. STORAGE COLOR CODE RED (FLAMMABLE).
===========================================================
Fire and Explosion Hazard Information
===========================================================
Flash Point Method: CC
Flash Point Text: _9F,_23C
Lower Limits: 1.2%
Upper Limits: 77.7%
Extinguishing Media: USE ALCOHOL FOAM, DRY CHEMICAL OR CARBON DIOXIDE. (WATER MAY BE
INEFFECTIVE).
Fire Fighting Procedures: USE NIOSH/MSHA APPROVED SCBA & FULL PROTECTIVE
  EQUIPMENT (FP N).
Unusual Fire/Explosion Hazard: VAP MAY FORM ALONG SURFS TO DIST IGNIT SOURCES & FLASH
BACK. CONT W/STRONG OXIDIZERS MAY CAUSE FIRE. TOX GASES PRDCED MAY INCL:CARBON
MONOXIDE, CARBON DIOXIDE.
===========================================================
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Figure 2-5 Material safety data sheets (MSDSs) are an important part of working in a power equipment dealership and should be readily available. They contain important information to let you know the dangers of working with hazardous materials.

(CO). **Carbon monoxide** is a by-product of burning hydrocarbon fuels. It's often present in garages and around heating equipment. It's colorless, odorless, and tasteless, so you can't detect when it's present. When inhaled, carbon monoxide passes into the bloodstream and prevents red blood cells from carrying oxygen. As a result, the body suffocates from the lack of oxygen to the brain. Even small amounts of carbon monoxide can make you very ill. Adequate ventilation is necessary to prevent the buildup of carbon monoxide fumes. Also, carbon monoxide detectors should be installed in your work area. These devices are similar in appearance to smoke detectors and can be purchased at most hardware or discount stores. These detectors sound an alarm when a predetermined level of carbon monoxide is sensed in the air. They don't detect smoke and can't be substituted for smoke detectors. Each type of device has its own function. Always follow these precautions when operating an engine:

- Never operate an engine in an enclosed area. Make sure your workshop has proper ventilation. Use exhaust pipe extensions to direct the exhaust gases outside. OSHA can provide detailed information about ventilation safety requirements for buildings and work areas. You can find information on OSHA at http://www.osha.gov
- When you're operating an engine (even if your shop is well ventilated), avoid breathing the fumes.
- Never operate an engine too close to a residential building. Exhaust gases could seep in and jeopardize the well-being of those inside.
- Don't pour gasoline into a hot or running engine.

SAFE OPERATION OF EQUIPMENT

All power equipment engines have moving parts that can be potentially hazardous. The careless operation of these vehicles when they're in for service can cause serious injuries and damage your workshop and your tools. To avoid accidents, follow these safety guidelines:

- Read the manufacturer's instruction manual carefully before operating any unfamiliar equipment.
- Never start a vehicle unless the transmission has been shifted into neutral or is in the "park" position.
- Turn off the ignition system before you start working, to prevent the engine from starting accidentally while you're working on it.
- Keep your hands, fingers, and sleeves clear of all hazardous moving parts.
- Keep visitors and customers (especially children) away from all risk areas and post appropriate signs to warn customers of hazards.
- Remember that the exhaust system gets very hot during operation. Keep your hands, feet, and loose clothing away from the exhaust components whenever the exhaust system is hot.
- Allow the exhaust to cool before adding fuel to the engine.

GOOD HOUSEKEEPING PRACTICES

Now that we've discussed some of the hazards that may be present in a power equipment engine service department, let's look at some of the things that can be done to prevent accidents. One of the most important considerations of any accident prevention and safety program is good housekeeping. Good housekeeping is more than just cleaning up. Housekeeping is a reflection of your organization and your work habits. A neat, well-organized work area allows for good inventory control of parts and materials. A tidy work environment provides the basis for proper waste disposal. Your neatness can prevent parts, tools, work records, and other important items from being lost in the clutter and thrown out with the trash. Finally, a neat work area is less likely to contribute to accidents. Here are some specific rules related to good housekeeping:

- Keep your workbenches and your work areas clean and organized at all times. You should clean your work area daily, preferably after each job is completed. If a job spans several days, clean up at the end of each day. Don't allow combustible debris such as paper, cardboard, string, or rags to accumulate on or under the bench. If you must use combustible materials or flammable liquids, use only the quantity needed to complete the task and immediately return the remainder to its proper storage area. Clean up any spilled materials from floors and benches immediately. Sweep the floors every day to eliminate the buildup of dirt, dust, and other litter.
- Store flammable liquids such as gasoline and solvents in approved safety cabinets and in cool, dry areas away from ignition sources (Figure 2-6). Avoid storing flammable liquids or other chemicals in direct sunlight, heat, or humidity. Ensure that the storage area is well ventilated, to prevent the buildup of potentially explosive fumes. Check all storage areas frequently for rusted containers, corroded caps or lids, and leaking containers.
- Label all flammable liquids and other hazardous materials properly. It should be noted that many chemicals should never be stored in anything other than the original container that they come in. If a substance is transferred from its original container, the second container must also be properly labeled. Use portable safety cans for transporting small quantities of flammable liquids (Figure 2-7). These cans are fire resistant and have self-closing lids. Never leave cans of flammable liquids lying around when they're not in use.
- Small amounts of flammable liquids sometimes leak or spill from machines and equipment. Place drip pans under leaking engines and vehicles to prevent the floor from becoming slippery. Drip pans should be noncombustible and should be large enough to contain any anticipated spill. If a vehicle has a persistent leak, place an absorbent, noncombustible material in the pan to soak up the liquid. Empty the drip pans regularly and dispose of the oil-soaked compounds. Oil-soaked materials are hazardous waste that must be disposed of properly. Don't include hazardous waste with normal trash.
- Proper garbage disposal (Figure 2-8) is another important concern for power

Figure 2-6 Always store flammable liquids in a cool, dry area away from ignition sources.

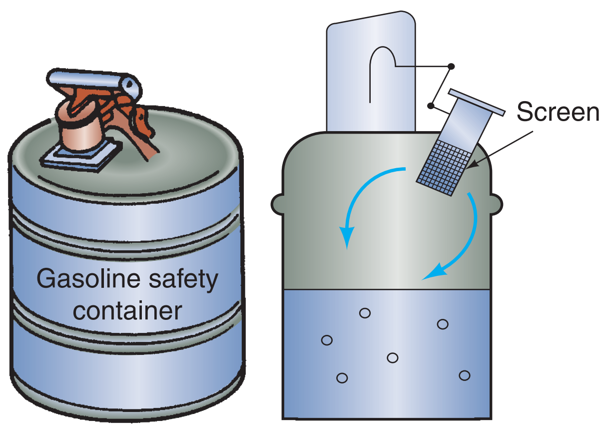

Figure 2-7 Flammable liquids should be stored in safety-approved containers. This gasoline container prevents the fumes from escaping while in storage.

Figure 2-8 Place oil rags and other combustible waste in an approved container.

equipment engine service departments. Discard dry combustibles on a regular basis and never allow them to accumulate. Place combustibles in metal containers with lids. Lids help to contain and snuff out any fire that might start inside the containers. When you empty the smaller containers, store the accumulated waste in a large metal refuse bin with a lid. These refuse bins should be located in a remote area away from heat sources.

- It's a good housekeeping practice to separate clean combustible wastes from dirty combustible wastes. Examples of "dirty" combustibles include papers, rags, and work clothes that are soaked with oil, grease, or solvents. These contaminated materials are more flammable than clean materials. Place all contaminated materials in separate metal containers with tight-fitting lids. Do you remember our discussion about spontaneous combustion earlier? This is a good example of the use of a special discard container for disposing of contaminated material. Have oily rags and work clothes laundered by a professional industrial cleaning service. Used liquids contaminated with dirt, grease, oils, solvents, or degreasers are classified as hazardous wastes and must be disposed of accordingly. Never empty such liquids into a sink or dump them on the ground. Federal, state, and local laws regulate the handling and disposal of hazardous wastes. Always follow authorized procedures when disposing of waste liquids.

HANDLING HEAVY OBJECTS AND MATERIALS

Material handling (moving materials from one place to another) is a concern for all occupations because this task has serious hazards associated with it. Every workplace requires some form of material handling. In a power equipment engine service department, you may be required to remove or lift complete engine assemblies, packages of supplies, or pieces of equipment. Poor material-handling techniques and practices can lead to a variety of injuries, including back injuries, twisted or sprained muscles and joints, hand injuries, and foot injuries. Improper material-handling procedures can also result in damaged equipment, tools, and facilities. Because they happen so frequently, back injuries are the costliest of all injuries in terms of medical costs and lost work time. Back injuries are often the result of poor material handling and improper lifting. Most back injuries occur when workers don't know (or ignore) proper lifting techniques. Back injuries can also result from preexisting back problems that are worsened by lifting. Some workers know how to lift heavy items correctly but ignore proper techniques to get the job done faster. To prevent injuries, always use the following lifting techniques (Figure 2-9):

- Be sure that the weight of the load isn't beyond your capacity to lift. Usually, loads of more than 50 pounds require the assistance of a second person.
- Ensure that the path of travel from pickup to drop-off is clear of obstacles.
- Get a good grip on the item to be lifted. If needed, wear gloves to improve your grip.
- Stand close to the load you're going to lift.
- Bend from the knees (squat) when lifting and setting down a load. Bending from the waist places more strain on the lower back.
- Lift with a smooth, controlled motion.

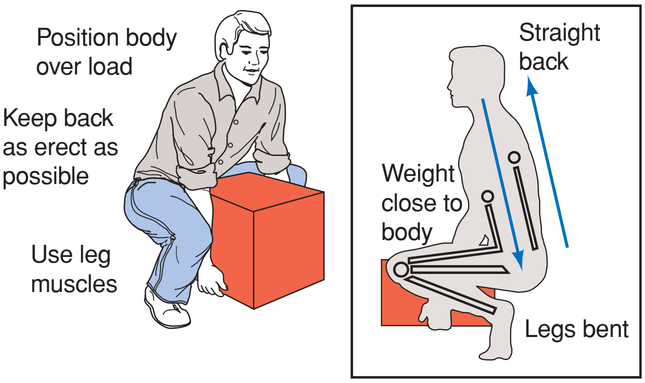

Figure 2-9 Always lift heavy loads using your leg muscles rather than your back muscles, and get close to the object to make lifting easier.

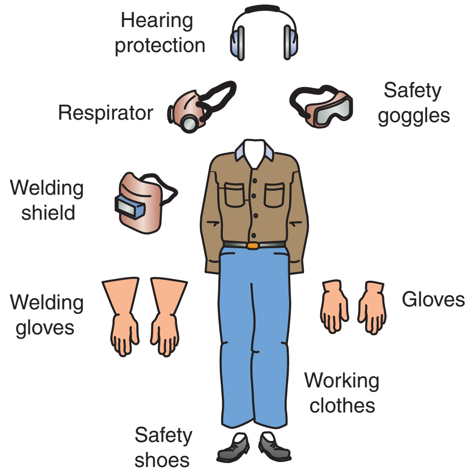

Figure 2-10 Always wear appropriate personal protective equipment when working in a shop environment.

- Don't twist from the waist to place the load after lifting it. Instead, turn your entire body to set a load in place.
- Use caution when placing a load above chest height or below knee height. You put more strain on the lower back in these positions.

Here are some other suggestions to prevent back injury when lifting materials:

- Use hoists, hand trucks, carts, or dollies to lift or move heavy items. These lifting devices free you from heavy lifting and protect you from injury.
- Wear a back support belt to protect the back muscles.
- Always get help to move loads that are heavy or awkward in size or shape.
- Stretch your back and arm muscles before lifting. Stretching warms up the muscles and helps prevent muscle strains, pulls, and tears.
- Keep your back and stomach muscles in good shape. Lack of good muscle tone could contribute to a severe lifting-related injury.

USING PERSONAL PROTECTIVE EQUIPMENT

To protect yourself from injuries in the workplace, use **personal protective equipment (PPE)** when appropriate. PPE includes items such as dust masks, safety glasses, gloves, and special footwear (Figure 2-10). Remember that any task can be hazardous, even if the equipment is operated properly and all safety procedures are followed. Always wear personal protective equipment wherever the potential for injury exists. The type of PPE you need varies depending on the tasks you perform.

Protecting Your Eyes and Face

Protective **safety glasses** and goggles (Figure 2-11) are available in a wide variety of styles to meet specific needs. Safety glasses with side shields provide more protection from impact and flying particles. Most safety glasses and goggles may be worn alone or over a worker's own prescription eyeglasses.

Splash goggles protect the eyes from dust particles and chemicals. They may contain ventilation holes to provide air circulation. Welding glasses have tinted or darkened lenses to protect the eyes from the bright flashes of welding arcs. A face shield is a cap-like device that holds a clear plastic shield over the face. The face shield protects the entire face from chemical splashes and flying particles.

Many people wear contact lenses as a replacement for glasses. Contact lens wearers must

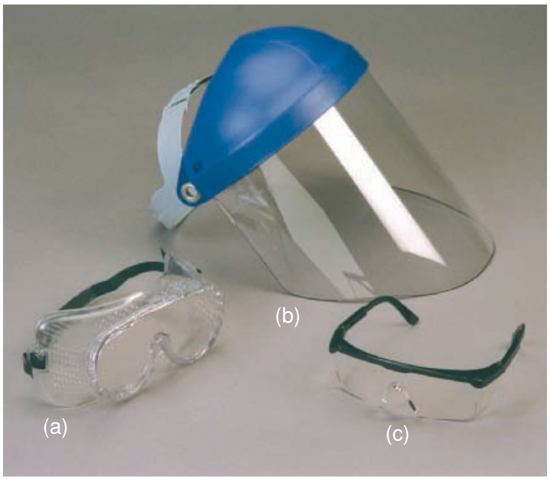

Figure 2-11 These eye protectors have specific uses (see text): (a) splash goggles, (b) face shield, and (c) safety glasses.

determine when it's appropriate for them to wear their contacts on the basis of their working environment. Wearing contact lenses aren't recommended if the workplace has significant amounts of flying dirt or dust particles, when welding, or if chemical fumes are present. Remember that the only function of contact lenses is to correct your vision. They don't provide any eye protection from dust, impact, or splashes. You must still wear eye protection devices such as goggles or face shields over your eyes whenever your activity warrants such protection.

Sometimes, even with the best safety practices, people somehow get foreign objects in their eyes. Many shops have eyewash stations or safety showers (Figure 2-12), which should be used whenever you have been sprayed or splashed with a chemical such as battery acid, fuel, or cleaning solvent. Contact a doctor and get immediate medical attention.

Protecting Your Lungs

Respiratory protection devices can protect you from harmful dusts, gases, or vapors. Any employee with exposure to chemical fumes, dust, or any other irritants in the air should wear appropriate respiratory protection devices. A typical dust mask is a small, fabric-like filter with straps that slip over the face to cover the nose and mouth. Dust masks are designed to shield the mouth and nose from dust particles. They don't filter out vapors, fumes, or gases.

Figure 2-12 Eyewash stations are available in properly equipped power equipment service shops. If you need to use an eyewash station, you should follow up with a visit to a doctor to ensure no permanent damage to the eyes has occurred.

Respirators (Figure 2-13) are more substantial devices than masks. Firefighters use a form of respirator device when they're called upon to enter a burning building. Respirators are made of heavy plastic, metal, and safety glass. The respirator provides the best respiratory protection available.

Figure 2-13 Whenever there is a danger of breathing harmful fumes, use a high-quality respiratory breathing protector.

Protecting Your Hearing

Question: How can you tell that you're in a high-noise area without using a sound-level meter? If another worker is standing 3 feet away and you can't have a conversation unless you shout, the work area is too noisy. Hearing protection should always be worn in areas with a high–noise level. If you work 8 hours a day in a high-noise environment without wearing hearing protection, you'll most likely experience a hearing loss over a period of years. If the noise level is extreme, you may suffer a hearing loss more quickly. You should always wear earplugs or a **headset** (Figure 2-14) in noisy areas or when you're using tools that produce a lot of noise.

Remember, there's no cure for noise-induced hearing loss. The prevention of excessive exposure to noise is the only way to avoid hearing damage. Some earplugs are disposable (Figure 2-15), meant to be used once and thrown away. Others are intended to be cleaned and used repeatedly. A professional hearing specialist would individually fit preformed or molded plugs.

Proper Attire

When working in a shop, remove hooded sweatshirts, ties, bracelets, necklaces, watches, and other jewelry. They can be caught in drive systems or possibly cause electrical shock if placed across an electrical circuit. To maintain a professional appearance, many shops have uniforms for their employees to wear when at work. These uniforms include long pants and button up shirts. Never wear shorts while working in a service shop as there will be no protection for your legs from hot surfaces, such as an exhaust system.

Figure 2-14 Protect yourself from permanent hearing damage from excessive noise by using high-quality headsets when you're working in high-noise areas.

Figure 2-15 A typical pair of disposable earplugs with a small storage container. In a power equipment engine shop environment, these may be all that is needed to help protect your hearing in most cases.

Protecting Your Feet and Legs

Foot injuries represent another type of injury associated with material handling. These injuries usually occur when heavy materials or tools are dropped. To prevent foot injuries, it's a good idea to wear steel-toed safety shoes or boots. Various types of steel-toed safety shoes are available to provide different levels of protection. You can also attach **metatarsal guards** (special covers that go over the instep of boots) to your shoes to protect your feet. Open-toed shoes or sneakers are not considered appropriate footwear. Avoid wearing shorts and wear full length pants when working in the service area to protect your legs from injury.

Protecting Your Hands and Arms

Gloves, gauntlets, and sleeves protect the arms and hands from chemical splashes, heat,

Figure 2-16 Rubber gloves protect your hands when working with cleaning solvent.

cuts, and tool-related injuries. In addition to standard leather and heavy-cotton construction, work gloves are also made from a variety of plastics and rubbers for use when working with solvents (Figure 2-16). Special gloves may also be designed to resist tears, cuts, and punctures. Gloves come in a variety of lengths to cover the hand, wrist, elbow, or entire arm, depending on the requirements of the job.

USING TOOLS SAFELY

According to the National Safety Council (NSC), more than 500,000 disabling, work-related finger and hand injuries occurred in a recent 1-year period. The careless use of simple hand tools such as screwdrivers, wrenches, and hammers was found to be the cause of many of these injuries. The most common hand and finger injuries were impact injuries (bruises, sprains, broken bones), cuts, and puncture wounds caused by improper use of hand tools. Here, improper use means using the wrong tool for the job, holding or using the tool incorrectly, or using a damaged tool.

Using Hand Tools Safely

Power equipment engine technicians use dozens of different hand tools daily. By giving your tools proper care, you'll extend their useful life and also lessen the possibility of accidents and injuries. To keep your tools in top working condition and prevent injuries to yourself and your fellow workers, observe the following safety precautions:

- Always use the right tool for a job. Don't try to substitute one tool for another.
- Inspect hand tools often for defects. If you find a defective tool, repair it or replace it.
- When using a tool, comply with the manufacturer's instructions.
- Never toss a tool to someone. Hand tools should be passed from one person to another by hand.
- Keep all tools clean. Protect the tools from corrosion. Wipe them clean when you're finished using them. Lubricate all tools with moving parts to prevent wear and binding. Store tools in a dry and secure location.
- Keep the cutting edges on tools sharp. Sharp tools perform better and they save time.

Using Power Tools Safely

Power tools have certain additional hazards associated with them. Common power tools that are used by a power equipment engine technician include drills, power impact wrenches, and grinders. Electric power tools have three properties that contribute to their potential danger: electrical charge, high-speed movement, and momentum. The most important area of concern when using power tools is the electric charge. To avoid an electric shock when using an electric power tool, you must isolate and insulate yourself from the electric current by following these guidelines:

- Make sure that all electric power tools are properly grounded.
- Inspect electric power tools often for defective wiring. Visually inspect all power cords, plugs, and receptacles. Have qualified electricians replace all defective cords and plugs.
- Always unplug tools before replacing bits, blades, or grinder wheels.
- Never operate an electric power tool in a wet or damp area.
- Wear gloves to protect yourself from shocks.

- Use only extension cords that are rated to carry the current required by the power tool. An undersized extension cord can cause damage to the tool and can be a fire hazard if it overheats because of electrical overloads.

High-speed movement is another area of concern when operating electric and air power tools. Avoid contact with any rotating tool parts because they could grab your hands, hair, or clothing. Keep all safety guards in their proper positions when operating power tools such as grinders and drills. When drilling metal, remember that friction due to the high speed involved produces sharp, hot shavings that could cut or burn you. Also, note that if a drill becomes jammed in a piece of material, the momentum of its moving parts may cause it to spin out of control. To avoid being injured by a tool's momentum, remember the following guidelines.

- Hold all tools firmly. Pay attention to any sounds that may indicate that a tool is about to jam.
- Use only sharp cutting bits. A dull bit will frequently jam.
- Clamp or block all workpieces tightly to a firm work surface. Don't use your hands to hold the materials in position.
- Wear appropriate personal protective equipment when operating power tools.
- Check tools for potential mechanical failure. For example, check for broken drill bits. Also, check for faulty triggers and control switches that could cause unexpected start-ups and stops. Make sure the tools have all their guards in place.

Compressed Air Safety

Virtually all service shops use compressed air to assist with the day-to-day activities within the shop environment. Air compressors can be useful, but it's important to use safety precautions when working with compressed air.

- Never point a compressed air nozzle at another person.
- Never use compressed air to clean off clothes.
- Never use compressed air to rotate engine components such as bearings.
- Air pressure can cause metal particles or even water droplets to penetrate skin.
- Air pressure can be regulated with the use of an air pressure regulator.

Summary

- It's important to understand the importance of safety and accident prevention in a power equipment engine shop environment.
- You should know the basic principles of personal safety.
- There are procedures and precautions for safety when using tools and equipment.
- You must maintain a safe working area in a service shop environment.
- There are laws concerning hazardous wastes and materials, including right-to-know laws.
- You have rights as an employee (and/or student) to have a safe place to work.

Chapter 2 Review Questions

1. The three elements of the fire triangle are _____, _____, and _____.
2. A Class B fire involves live electrical equipment. (True/False)
3. Name the federal agency that publishes and enforces safety standards for business and industry. _____
4. What are some of the key safety areas of primary concern in a power equipment engine service department? _____, _____, _____, _____, _____, _____, _____, _____, _____, and _____.
5. _____ is a type of fire created by a chemical reaction with combustible materials.
6. Safety is an _____ that helps you prevent injuries to yourself and others.
7. There are two types of electric power sources: _____ and _____.
8. The letters PASS are used as a fire safety acronym. They stand for _____ (_____ _____ _____), _____, _____, and _____.
9. To prevent foot injuries, it's a good idea to wear _____.
10. When an engine is running, it creates exhaust gases that are hazardous if inhaled. The most dangerous of these gases is _____.

CHAPTER

3 Tools

Learning Objectives

- Identify common hand, power, and special tools
- Know how to select the correct tool for a repair
- Understand advantages and disadvantages of various types of tools
- Identify and select the right measuring tool for different jobs
- Understand the importance of having an up-to-date service information library

Key Terms

Adjustable wrench
Allen wrench
Basic hand tools
Bench grinder
Bench vise
Chisel
Clamp
Clearances
Compression gauge
Dial indicator
Die
Drill bit
Drill press
Feeler gauge
File
Hacksaw
Impact screwdriver
Micrometer
Multi-meter
Plier
Precision measuring tools
Puller
Punch
Specification manuals
Tap
Test light
Timing light
Toolbox
Torque
Torx wrench
Vernier caliper
Vise
Wrench

INTRODUCTION

Power equipment engine technicians use hundreds of tools to perform a wide variety of repair activities. In addition to the standard hand and power tools that you may already be familiar with, there are specialized and precision repair tools that will probably be new to you. The assortment of tools that you'll use depends primarily on the types of machinery you'll encounter and the specific systems that you'll be responsible for. As an example, if you were to specialize in lawn mowers, your tools would be different from those of someone who specializes in tractors.

Skilled professionals, no matter what their trade or field, know how to use tools correctly and safely. Knowing exactly which tools to use for each task is essential for completing quality repair jobs quickly, safely, and efficiently. When you gain experience in the power equipment engine repair field, you'll acquire the skills to do jobs faster and more efficiently. A large part of this skill development will focus on your ability to use the tools of the trade correctly.

Power equipment engine repair tools can be divided into the following groups:

- Basic hand tools
- Power tools
- Special tools

It would be virtually impossible for us to discuss every type of power equipment engine repair tool in this chapter. For this reason, we'll limit our discussion to the tools that you'll use most often. You've probably used many of the standard hand tools that we'll cover. But you may be totally unfamiliar with some specialized tools and measuring/testing instruments that we're going to discuss. It's recommended that you take your time as you read about the various tools and instruments and familiarize yourself with their use. Caution: Always wear eye protection when working with tools.

BASIC HAND TOOLS

Basic hand tools are the common tools that are found in just about every workshop toolbox. Some of these are screwdrivers, hammers, pliers, wrenches, and socket sets. Because they use these tools so frequently, most power equipment engine repair technicians own a complete set of hand tools, similar to the one shown in Figure 3-1. Undoubtedly, most of the basic hand tools would be familiar to you.

You've probably used them and may even own many of them. To be sure, however, that you understand the proper use of these tools, we'll take a brief look at each of them. Let's begin with the most commonly used hand tool, the wrench. The largest portion of your current tool collection probably consists of different types of wrenches.

Wrenches

Wrenches are used to tighten or loosen nut-and-bolt-type fasteners (Figure 3-2). As you probably know, wrenches come in a variety of sizes, from very small to very large.

Figure 3-1 A typical set of hand tools that a power equipment engine technician would own. This assortment of tools could be used for different applications and isn't limited to power equipment engine repair. Courtesy of Snap-on Tools Company.

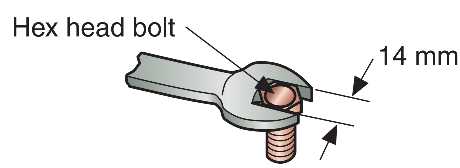

Figure 3-2 The size of a wrench is determined by the width of the opening at the end of the wrench.

Metric and SAE (Society of Automotive Engineers) are the general classifications of the wrenches found in a power equipment engine technician's toolbox. Metric wrenches use millimeters, such as 10 mm, 11 mm, or 12 mm. SAE wrenches use fractions of an inch, such as 1/2 inch, 9/16 inch, or 5/8 inch. As a rule of thumb, American-made power equipment engines require SAE tools (keep in mind that this is only a rule of thumb as some American-made engines now use metric components) and foreign-made power equipment engines require metric tools. More information on different measuring systems will be provided in Chapter 4.

Wrenches are forged from strong, tempered steel. Each wrench size is designed to fit one particular-sized fastener. A common mistake when using wrenches is to use the wrong size (where the wrench "almost fits"). Using a wrong-sized wrench can, in many cases, damage the fastener and the wrench as well. In addition to varying sizes, wrenches are available in different styles (Figures 3-3 and 3-4). The five most common styles are the

- Open-end wrench
- Box-end wrench
- Combination wrench
- Adjustable wrench
- Socket wrench

Open-End Wrenches

Open-end wrenches have U-shaped openings at both ends and are designed so that the length of each wrench is proportional to the size of its opening. The larger the opening, the longer the wrench's handle, so that more rotational force can be applied. Rotational force is referred to as **torque**. Caution: Because of the open-end wrench's design, you should *never* use an extension on a wrench handle to increase the torque. Using any type of handle extension could break the wrench and possibly cause an injury. There are different types of open-end wrenches. Two common examples are:

- The standard wrench (Figure 3-5) has a 15° head angle with a different-sized opening on each end.
- The flare nut or line wrench (Figure 3-6) is used for fuel and oil line fittings or brake lines. The head contacts 270° of the nut for a secure grip while allowing for access around fuel, oil, and brake lines.

Figure 3-4 A typical socket wrench set.

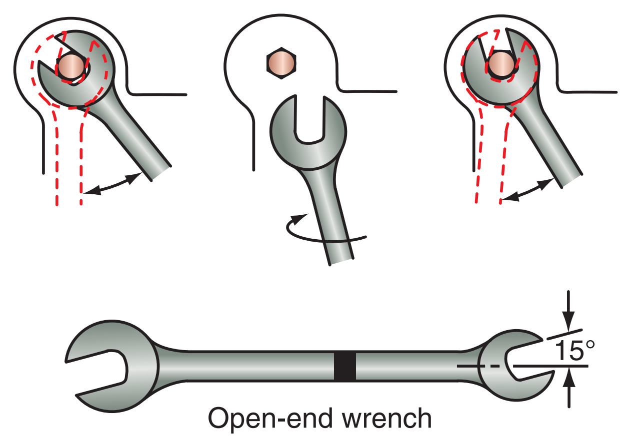

Figure 3-5 The standard wrench has a 15° head angle with a different-sized opening on each end.

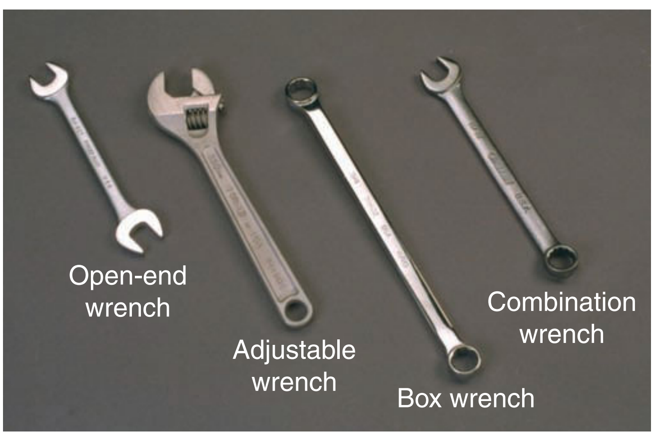

Figure 3-3 Four different styles of wrenches.

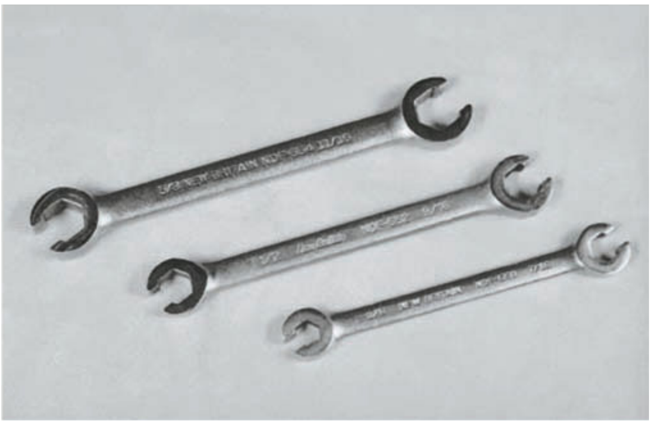

Figure 3-6 The flare nut or line wrench is used for fuel, oil, or brake line fittings. The flare nut wrench head contacts 270° of the nut for a secure grip.

Figure 3-7 A typical box-end wrench.

When using an open-end wrench, always place it squarely on the nut or bolt and pull toward you. Using this position reduces the chance of injury. Open-end wrenches have a tendency to slip when high torque is applied. If you must use a pushing motion, push with the palm of your hand. Don't grip the wrench with your fingers. You've probably heard the term "knuckle buster." Guess where that phrase came from? And always keep your wrenches clean to help prevent slipping.

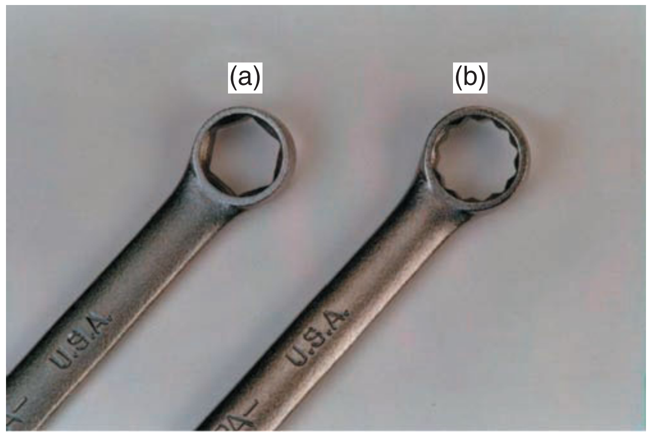

Figure 3-8 Box-end wrenches are available with (a) 6-point and (b) 12-point openings.

Box-End Wrenches

Box-end wrenches (Figure 3-7) should be used to loosen very tight bolts or nuts. The end of a box-end wrench encircles a nut or bolt head, providing more contact surface than an open-end wrench. Box-end wrenches have thin heads. This makes box-end wrenches useful in tight places, where there's limited access space around the nut or bolt head.

Box-end wrenches are available with 6-point and 12-point openings (Figure 3-8). The number of points refers to the inside shape of the box end. A 6-point box-end wrench provides more support to the head of a bolt than the 12-point box-end wrench.

You should use a 6-point wrench on bolts and nuts that are very tight. The 6-point wrench is less likely to slip than a 12-point wrench. The main disadvantage of the 6-point wrench is that its head is thicker than that of a 12-point wrench. Also, a 6-point wrench can be placed on a bolt or nut in only six different positions.

Because its head is thinner and can be placed on the bolt or nut in 12 different positions, the 12-point style wrench is the better choice to use in tight places. You frequently can't get enough wrench travel in tight places to advance a 6-point wrench to the next turning position. With a 12-point wrench, the travel required to turn to the wrench to the next position is only half that required for the 6-point wrench. Remember, a 6-point box-end wrench is stronger and grips the fastener more securely, whereas a 12-point usually works better in tight spaces.

Figure 3-9 Combination wrenches are among the most popular wrenches found in a power equipment engine technician's toolbox.

Combination Wrenches

Combination wrenches (Figure 3-9) combine the open-end wrench and the box-end wrench into one tool. In most cases, both ends of the combination wrench are of the same size. This allows you to use the box end to loosen bolts or nuts that are tight and the open end to quickly remove them when they're loose.

Adjustable Wrenches

Adjustable wrenches (also called crescent wrenches) have movable jaws that allow you to adjust the opening to fit almost any size nut or bolt (Figure 3-10). But adjustable wrenches don't grip the fastener as tightly as other types of wrenches.

Adjustable wrenches have a tendency to slip and round off the corners of nuts and bolt heads. Because of this limitation, adjustable wrenches should be used to remove only bolts or nuts that are already loosened. Adjustable wrenches can be used in a pinch, when the correct size of wrench isn't available. Remember that adjustable wrenches can slip. When using them, always pull toward you to save your knuckles, by using the method shown in Figure 3-11.

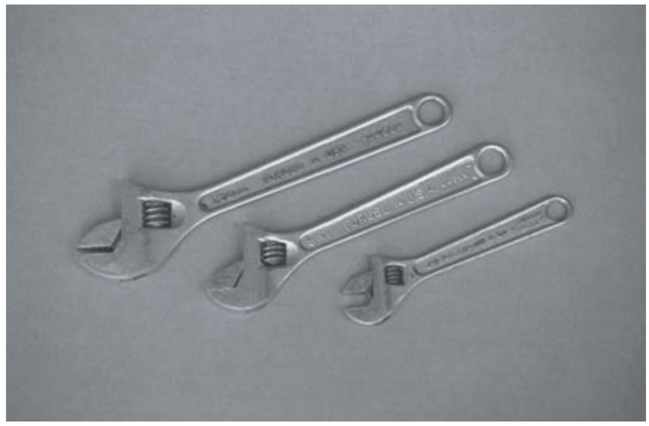

Figure 3-10 Adjustable wrenches are commonly called crescent wrenches and have movable jaws that allow you to adjust the opening to fit a nut or a bolt of almost any size.

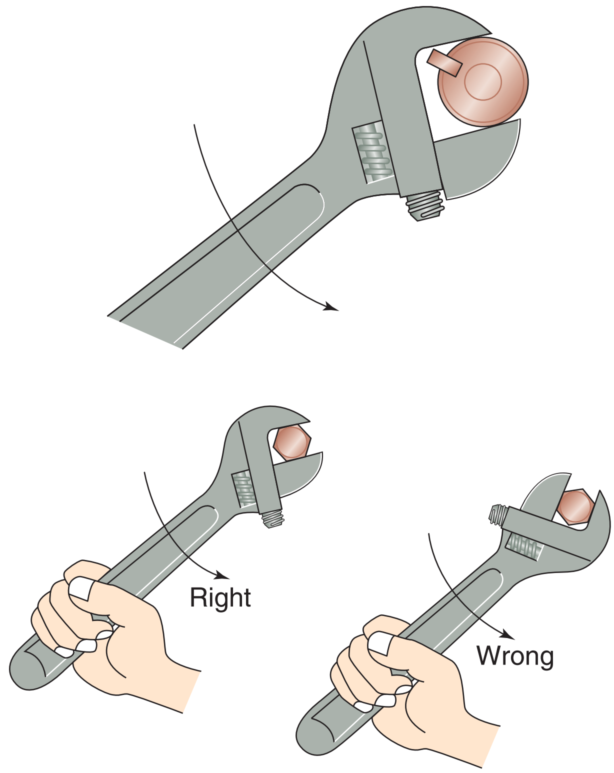

Figure 3-11 Proper use of an adjustable wrench.

Note that there is a right and wrong way to use the adjustable wrench and using it incorrectly can cause the wrench to break.

Socket Wrenches

Socket wrenches are among the more frequently used tools and are usually purchased in sets (Figure 3-12). The individual sockets contained in a set are in graduated sizes. The size of the socket refers to the size of the bolt head or nut that the socket fits. Socket sizes range from small to very large, to match the largest available bolt and nut sizes.

There are two basic depths of sockets: standard and deep well (Figure 3-13). Deep well sockets allow access to recessed fasteners or nuts that are threaded onto studs.

Sockets are available in 6- and 12-point configurations, just like box-end and combination wrenches (Figure 3-14). The 6-point socket is stronger. The 12-point is good for tight areas but is more likely to round off the nut or bolt. Some sockets have fluted corners designed to place stress on the sides of the fastener. Sockets of this design tolerate higher torque with less chance of rounding off the nuts or bolt heads.

Sockets come in various degrees of hardness. The strongest are made for use with impact drivers and are usually black in color. Hand-type sockets are usually chrome plated and are not meant to be used with hand, air, or electric impact drivers (Figure 3-15).

Sockets can be installed onto different types of handles (Figure 3-16). The drive lug on the socket handle fits into the drive hole in the socket. Sockets come with different drive hole sizes: typically 1/4 inch, 3/8 inch, and 1/2 inch.

Figure 3-12 A wide range of different types of sockets.

Figure 3-13 A standard socket (left) and a deep well socket (right).

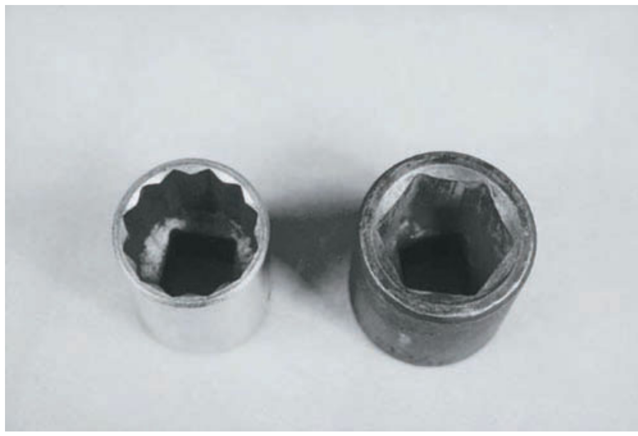

Figure 3-14 Six- and 12-point sockets. Whenever possible, it's recommended that a 6-point socket be used as it's stronger.

Figure 3-15 You can easily tell the difference between hand and impact sockets. The impact socket is black in color and the hand socket is chrome plated.

The most common handle is the reversible ratchet handle. A lever on the handle allows you to change direction to either tighten or loosen fasteners (Figure 3-17). Reversible ratchet handles are great for removing and installing fasteners quickly, but they can be damaged if too much torque is placed on them. Ratchet handles can have a swivel or flex head to allow easier access to difficult to reach fasteners.

If you're using a socket to loosen an exceptionally tight fastener, use a breaker bar, not a ratchet handle, to turn the socket. A breaker bar is a non-ratchet solid handle with a socket drive fixed on its end. Because a breaker bar has no ratchet mechanism, it can withstand much more torque than a ratchet handle.

Along with the breaker bar, other popular handles are speed handles and sliding T-handles (Figure 3-18). These handles are often used to turn sockets in tight spaces. Most socket sets also contain a variety of extension bars and adapters. These accessories allow the sockets to be used in different situations.

Allen and Torx Wrenches

The **Allen wrench** or hex wrench is a short, six-sided rod that is used to tighten screws and bolts that contain similar six-sided (hex) indentations (Figure 3-19). A typical Allen wrench has a right-angle bend near one end. The bend forms a convenient handle. Certain special Allen wrenches are equipped with T-handles or screwdriver-style handles, and others are designed to be used with socket wrench drive handles. Allen wrenches can be purchased individually, but they're normally sold in sets that contain all the commonly used sizes.

The **Torx wrench** is similar to the Allen wrench, except the end of the Torx wrench is star-shaped (Figure 3-19). Because they can handle more torque without slipping or stripping, Torx wrenches and bolts are used where higher fastening strengths are required. Torx bolts are ideally suited for use with impact

Figure 3-16 Different styles and sizes of ratchet handles for socket wrenches.

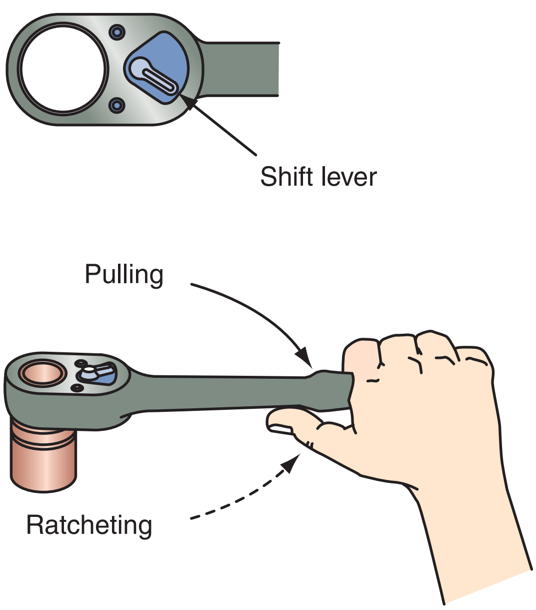

Figure 3-17 A reversible ratchet handle. Note that it has a shift lever that is used to change the direction of the ratchet action.

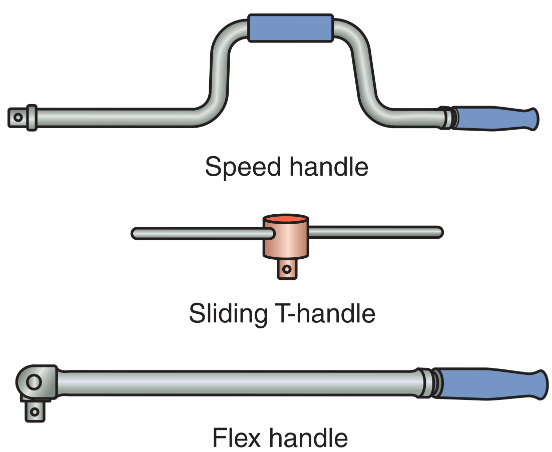

Figure 3-18 Popular types of socket drivers.

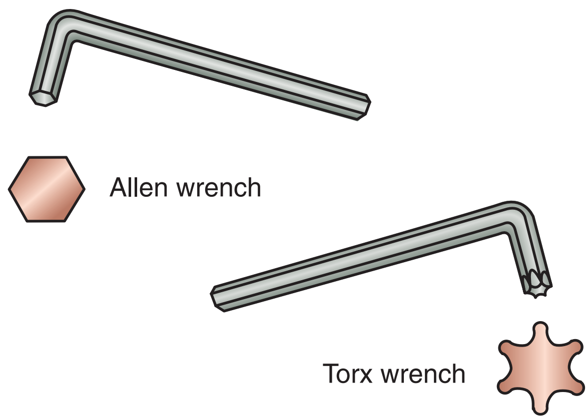

Figure 3-19 An Allen and a Torx wrench.

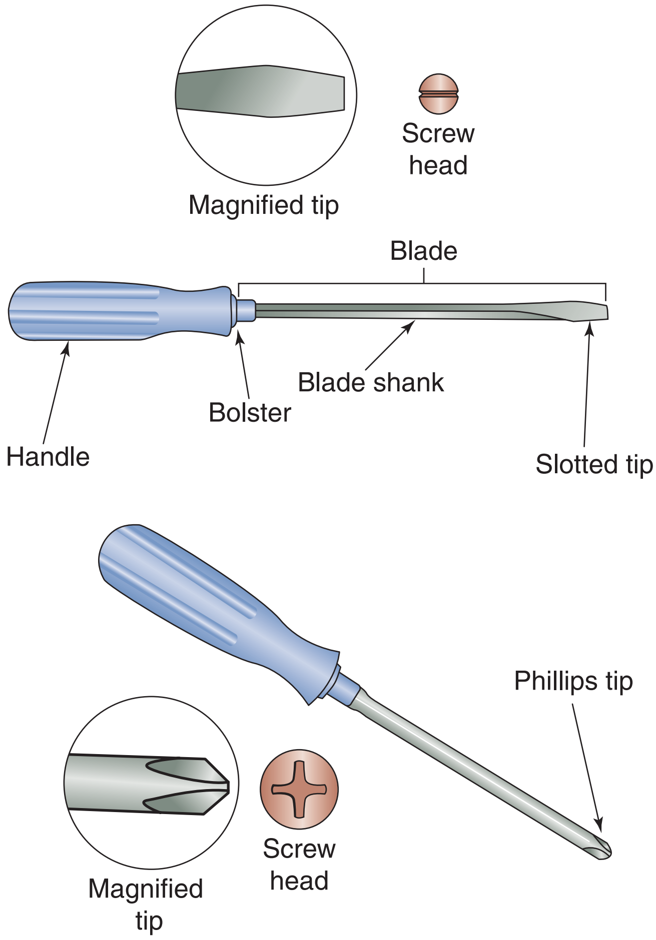

Figure 3-20 The basic parts of a screwdriver.

tools. Torx wrenches are also available with screwdriver-type handles or attachable to socket wrench drive handles.

Screwdrivers

Although just about everyone is familiar with the standard screwdriver (Figure 3-20), let's have a quick review. A standard screwdriver has the following parts:

- A handle, which is usually made out of plastic or wood
- A blade shank, which can be round, square, or hex. If it's square or hex, you can use a wrench on the screwdriver to increase torque.
- A bolster, which some screwdrivers have, allows you to use a wrench
- A tip or blade, which you insert into the screw head slot, which is commonly a straight tip or Phillips head

The screwdriver is one of the most abused hand tools. Have you ever:

- Used a screwdriver as a pry bar or chisel?
- Used a screwdriver handle as a hammer?
- Hammered directly on a screwdriver handle?
- Used the wrong-sized screwdriver?
- Used the wrong type of screwdriver?

See what I mean? There are so many opportunities to misuse screwdrivers. Almost every one of us has done one or more of these things at one time or another. If used improperly, the screwdriver can cause damage, even serious injuries to you.

Types of Screwdrivers

Screwdrivers are available in a variety of shaft lengths and tips. Here are the most common:

- **Flat (or slot) tips.** These range in size from very small (1/16 inch wide) to large (3/4 inch or wider). Be sure to always choose a screwdriver of correct thickness and width, as required by the fastener (Figure 3-21).
- **Phillips screwdriver tips.** (Figure 3-22) These have a crossed point but a somewhat blunt end. These tips have good holding power and are less likely to slip than slotted tips. The common sizes of Phillips screw head slots used in power equipment engines work are #1, #2, and #3.
- **Reed & Prince tips.** These tips are similar to Phillips tips but have a sharper tip. Reed & Prince tips are not interchangeable with Phillips-tipped screwdrivers.

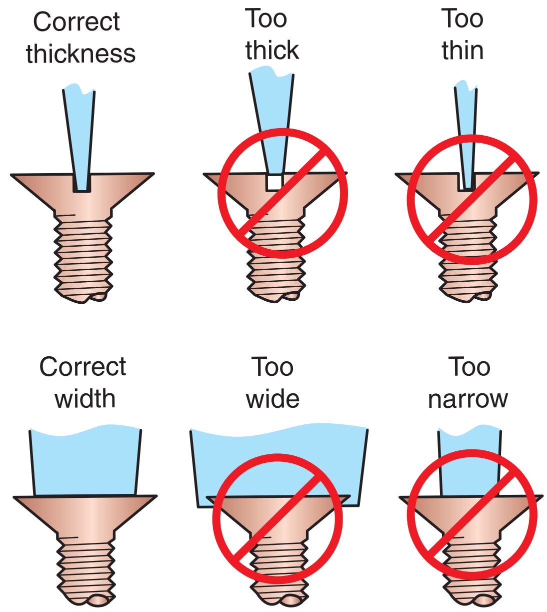

Figure 3-21 The blade of a screwdriver should fit the screw slot snugly to prevent slipping or slot damage.

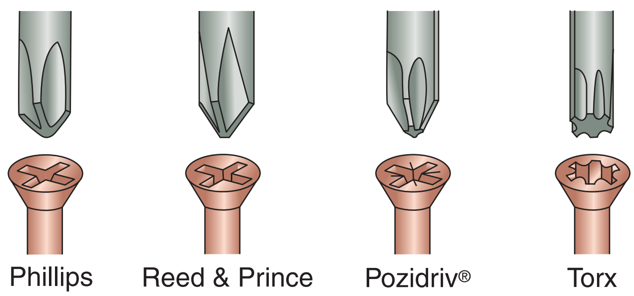

Figure 3-22 These screw head shapes are used in many applications on power equipment engines.

- **Pozidriv tips.** These are similar to the Phillips tips but allow for a more positive fit of the tool, which in effect allows more torque to be applied. Pozidriv screws can easily be distinguished from other tips, by a line embossed on the screw head at 45° to the slots.
- **Torx tips.** This type of tip is used when higher fastening strengths are required, because Torx tips can handle more turning force without slipping.

Special Purpose Screwdrivers

Screwdrivers are also available in special shapes to provide access in restricted areas. Several of the special-shaped screwdrivers are described here.

- **Offset screwdrivers.** These are special-purpose tools with an angled tip to allow access where space is limited. The offset screwdriver comes with either slotted or Phillips tips and is available in different sizes.
- **Stubby screwdrivers.** These have a short shaft and a short, fat handle. Like the offset style, the "stubby" is used in cases where there's limited access space. The stubby screwdriver is available with either slotted or Phillips tips.
- **Angled or remote screwdrivers.** These have a hollow tube with a handle on one end and a bit on the other end. They're used for jobs where you can't get hand access. Some are curved or angled. Deluxe versions may have a 1/4-inch square drive end to accommodate interchangeable tips.
- **Impact screwdrivers.** These are used often on power equipment engines to remove and install fasteners where hand or wrench torque is insufficient (Figure 3-23). The drive mechanism of the impact screwdriver converts the impact force of a hammer blow to rotational torque, which is transferred to the screwdriver tip.

The end of the impact screwdriver is designed to accept a variety of tips. When using the impact screwdriver, always:

- Use the correct size bit.
- Use a bit that was designed for impact use.
- Use eye protection equipment.

To use the impact screwdriver, first install the tip onto the fastener and twist the tool in the desired direction. Hold the tool firmly and keep the tip squarely on the fastener; then strike the tool sharply with a hammer (Figure 3-24).

Observe the following rules when you're using any screwdriver:

- Always clean the slot(s) in a screw head before attempting to remove the screw.
- Always hold a screwdriver so the shaft is at a 90° angle to the screw slot. Don't hold it at an off angle as the screwdriver may slip out of the screw and may damage the screw.
- Make sure that the screwdriver blade fits a screw slot snugly to prevent slipping and possible damage to the screw and/or screwdriver.

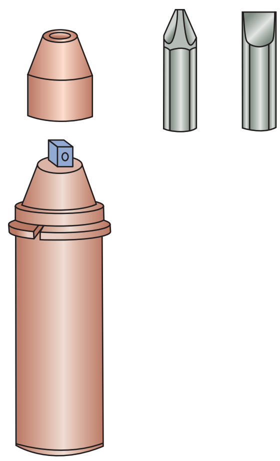

Figure 3-23 A typical impact screwdriver. Note the removable cap that would allow a socket wrench to fit on the end of the tool.

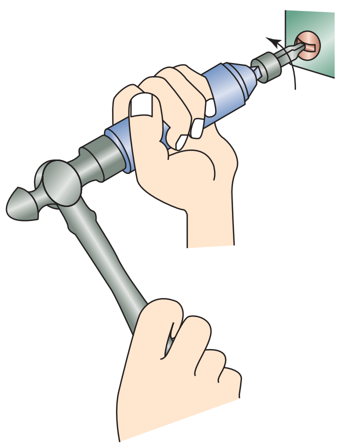

Figure 3-24 Recommended grip when using an impact screwdriver.

- Never use a screwdriver to cut or remove metal, punch holes, pry, or for any other unintended purpose. This could damage the tool and cause injury.
- Never hammer on the handle of the screwdriver (except, of course, for impact screwdrivers).
- Never use a screwdriver to work on an object that you're holding in your hand. The screwdriver could slip and cause a painful injury. Use a bench vise to support the object that you're working on.

Pliers

Pliers are another commonly used hand tool. There are a variety of pliers (Figure 3-25). They vary in size and shape, depending on their intended function. Certain pliers are designed for holding or gripping, others are designed for shaping, and others are used for cutting.

Types of Pliers

Combination and **rib-joint pliers.** Also known as slip joint pliers, these are used generally to hold parts when you work on them or to twist and bend materials. Rib-joint pliers have a slip joint that lets you open the jaws wide to grip large-diameter items. The jaws have gripping teeth. The outside end of the jaw set is for grasping flat objects and the middle for grasping curved objects.

Locking or "vise grip" pliers. These are functionally similar to combination and rib-joint pliers. Locking pliers are used to get a firm holding grip on items. They can be locked in place to hold parts tightly while keeping both your hands free. They can function as a small, portable vise. For example, you can use locking pliers to hold two metal parts in position while you install screws, washers, or bolts.

Needle nose pliers. These are useful for gripping or twisting small parts and for reaching parts in limited-access spaces. The jaws of needle nose pliers are smaller and thinner than those of long nose pliers. Needle nose pliers allow you to easily move and position parts that are too small to be handled properly with your fingers. Use of these pliers for heavy work can easily damage them. The tips of the jaws will break if you apply too much pressure on them. Needle nose pliers are often found with bent jaws to help get to tight spaces.

Cutting pliers. These come in different shapes and sizes, with the most popular being diagonal and the end cutter designs.

Retaining-ring pliers. These (Figure 3-26) are used to spread or compress retaining

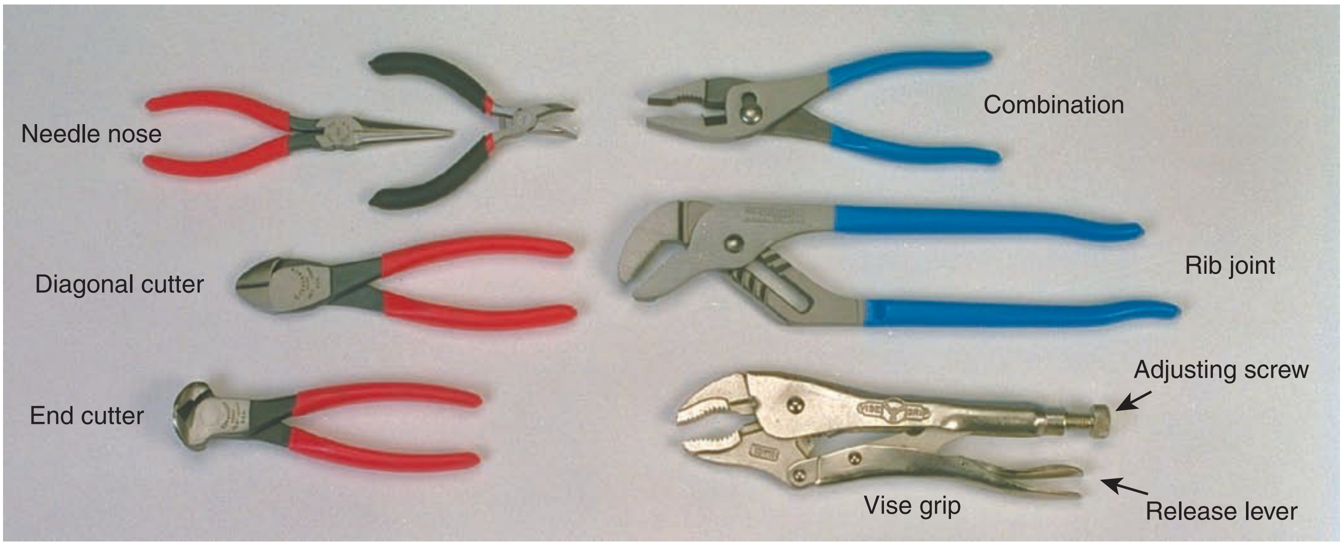

Figure 3-25 A wide variety of pliers are available; shown are just a few that would typically be found in a power equipment engine technician's collection.

rings when these rings are being removed or installed. There are two main types of retaining-ring pliers: those used for internal retaining rings and those used for external retaining rings. These pliers are of generally either long nose type or angle nose type to allow for varying access angles. Some models of retaining-ring pliers come with replacement tips. External retaining rings fit into grooves machined in the outer surfaces of shafts. Internal snap rings are used to retain components on the inside of hollow shafts.

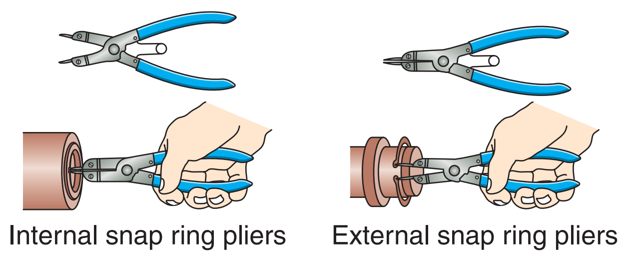

Figure 3-26 Internal and external retaining ring pliers in use.

Special Purpose Pliers

The following types of pliers are also often used when working on power equipment engines.

- **Hose clamp pliers.** These have grooves cut into the jaws to provide positive gripping when removing or installing wire hose clamps.
- **Wire stripper/crimper pliers.** Commonly referred to as electrical pliers (Figure 3-27), these are used to remove insulation from wire and install crimp-type electrical connectors.

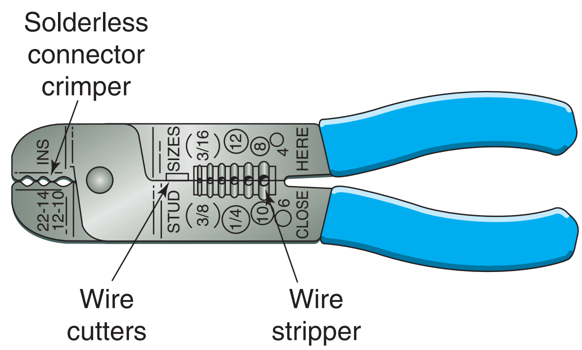

Figure 3-27 Wire stripper/crimper pliers, also known as electrical pliers.

Snips or shears are used for cutting sheet metal and metal gasket material. They come in several styles and sizes to match the material being cut. Aviation snips are used for cutting sheet metal and come in left, right, and straight cutting styles.

Hammers

Power equipment engine technicians use a wide variety of hammers, which range in size from 2 to 48 ounces (Figure 3-28). Ball peen and mallet (or soft-faced) hammers (Figure 3-29) are two of the most common types.

The head of a ball peen hammer has two opposing striking surfaces, a flat-faced surface and a rounded surface. The flat-faced surface is used for regular hammering. The ball end is used primarily for shaping cold metal.

You should use a mallet or soft-faced hammer if a ball peen hammer might damage the part that you're working on. Several types of soft-faced hammers are commonly used in a power equipment engine repair shop.

Figure 3-28 Types of hammers.

Figure 3-29 The ball peen hammer (left) and rubber mallet (right) are among the most commonly found in a power equipment engine technician's toolbox.

- **Rubber hammers.** These are used to help seat tire beads and to carry out sheet metal work. If you're concerned about damaging a part, use a plastic-faced hammer.
- **Plastic-faced hammers.** These are available with replaceable heads of varying densities (hardness). Almost all dead blow hammers are made out of high-impact plastic. The plastic shell is filled with lead shot that helps direct the force from the hammer blow and prevents the hammer from bouncing on impact. They're frequently used where a heavy, non-damaging blow is needed, such as while installing a bearing.
- **Brass/bronze hammers.** These hammers are soft faced and prevent damage to the part and sparks when using them.

Here are a few things to remember when using a hammer:

- Make sure that the head is securely attached to the handle.
- Wooden hammer handles should be replaced if damaged. Be sure that the handle fits the hammerhead securely. The handle requires the correct-sized wedge to properly retain the head.
- You can't repair fiberglass or steel hammer handles. Replace the hammer if the head becomes loose or damaged or if the handle is cracked.
- Grip the hammer close to the end of the handle to provide better control of the tool and strike a stronger blow.
- Always ensure that while striking, the hammer face is parallel to the object being hit.
- Always wear safety goggles to protect your eyes.

Punches and Chisels

You'll use an assortment of **punches** and **chisels** when working on power equipment engines (Figure 3-30). Punches are used for aligning and driving items, whereas chisels are used for cutting.

Punches

- **Center punches.** These have tempered ends with sharp points. They're used for punching indentation marks on metal. These marks are

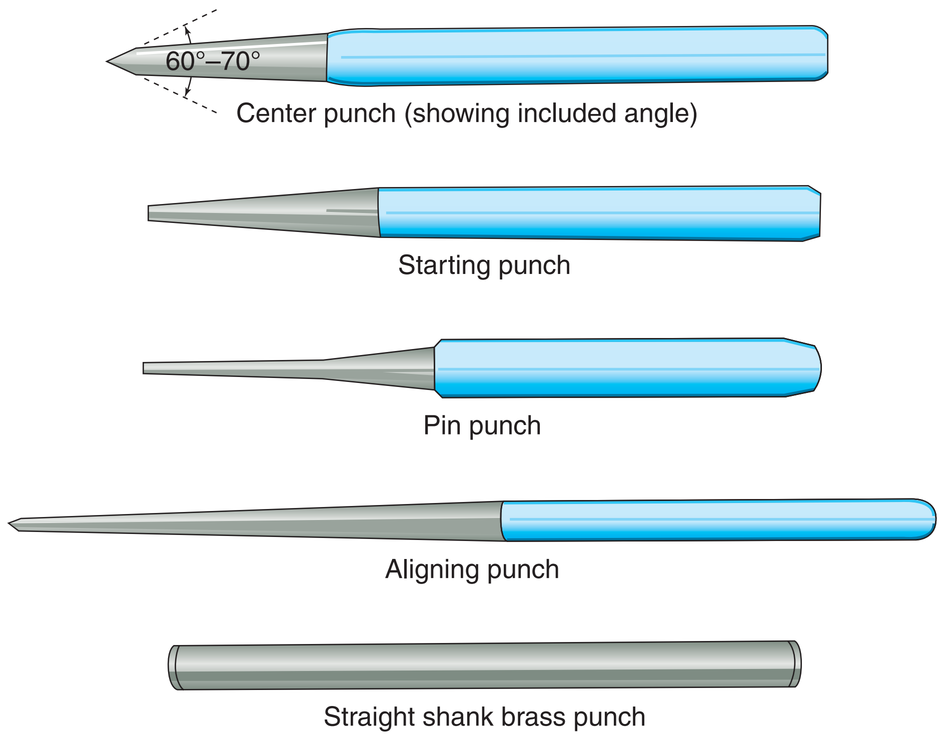

Figure 3-30 Punches used in power equipment engine repair.

used as reference points for measuring or as starting points for drilling.

- **Starting** or **aligning punches.** These have tapered shafts with flat tips. They're used to align holes or to start pins moving.
- **Pin and straight shank punches.** These have no taper. They have a flat tip and are used to drive out pins. If you use the correct-sized drift punch, you won't enlarge the hole and damage the end of the pin.

Here are a few points to remember when using a punch:

- Hold the punch with a firm but not overly tight grip.
- Use a punch holder when possible to prevent possible injury to your hand (if the hammer misses the punch when striking).
- Hold the pointed end of the punch in place while striking the other end with a ball peen hammer.
- Strike the end of the punch squarely.
- Always wear approved eye protection equipment when using punches.
- The ends of punches wear or get misshapen with use. When the end surface enlarges beyond its normal size or mushrooms, you should grind the bit end back to its original shape.

Chisels

Chisels (Figure 3-31) are another of those often abused tools. They're not meant for opening paint cans, tightening or loosening screws, or prying things apart. Unfortunately, many a chisel has met an early end because of its use for one of these unintended functions! Chisels are meant to be used for cutting, shearing, and chipping.

The flat chisel is the most common type of chisel used in a power equipment engine repair shop. The chisel has a bevel on both sides of the cutting edge. Like the punches that we just covered, the striking head on the chisel is softer than the cutting edge.

Here are a few things to remember when using a chisel:

- The chisel head diameter should be approximately one half the diameter of the hammerhead that you use for striking the chisel.

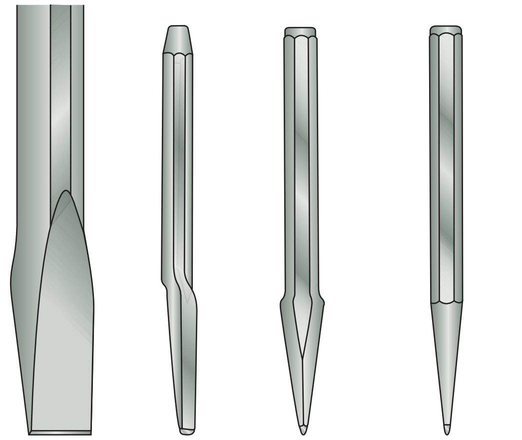

Figure 3-31 Different types of chisels.

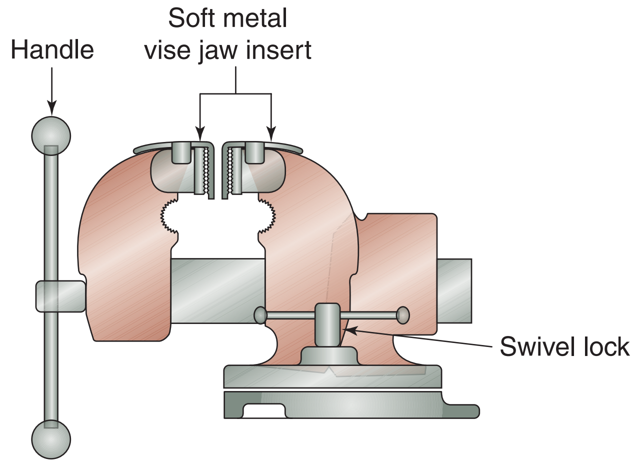

Figure 3-32 The bench vise is a useful holding device that mounts onto a table edge. Note that the jaws are covered with a soft metal insert to protect the item being held.

- Hold the chisel the same way you would hold a punch. Don't hold it too tightly, but use a firm grip.
- Chisels wear with use. You should grind the head when it shows signs of mushrooming.
- Always keep the cutting edges of chisels sharp. Grind the cutting edges to the original contours and angles.
- Always wear eye protection.
- Use a chisel holder when possible to prevent possible injury to your hand (if the hammer misses the chisel when striking).

Clamps and Vises

Clamps and **vises** are used to hold workpieces securely. This frees up both your hands so that you're better able to handle tools. Clamps and vises are often referred to as an extra pair of hands. Proper and timely use of a vise or clamp can help prevent injuries and eliminate damage to expensive parts and components. If you're ever in doubt as to whether or not you should use a vise, use it! It only takes one slip or accident to make you wish you did.

C-clamps are basically portable vises that you can use to hold pieces of material together while you work on them. They're available in a variety of sizes, to accommodate a wide range of applications. Most power equipment engine repair shops have a collection of C-clamps, with multiples of each size.

The **bench vise** (Figure 3-32) is a useful holding device that clamps onto a workbench or table edge. The jaws of a vise are opened and closed by turning a handle. The jaws are usually covered with soft metal. This covering protects the piece being held in the vise from scratches and dents. There are also jaw protectors made of soft materials to better protect items placed in a vise.

Cutting Tools

Various types of cutting tools will be found in a power equipment engine service shop. The most common are covered here.

Hacksaws

Hacksaws are used to cut metal stock that's too heavy to be cut with snips or cutting pliers (Figure 3-33). Hacksaws are available with adjustable frames to accommodate different-length blades. A wing nut on the blade retention bracket is used to tighten the blade to the correct tension. An improperly tensioned blade doesn't cut well and dulls quickly. Hacksaw blades are available in a variety of lengths, hardnesses, and tooth patterns for cutting different materials.

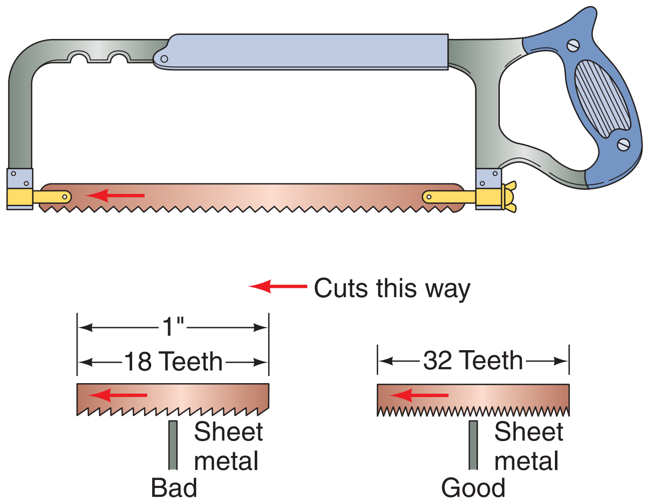

Figure 3-33 A standard hacksaw with two types of blades. A thin material requires more saw teeth, as seen in the example here.

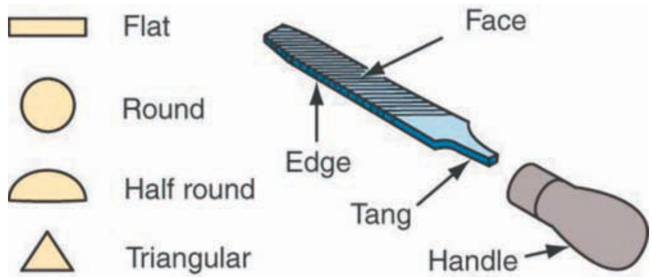

Figure 3-34 The parts of a file and the different edge shapes used by a power equipment engine technician.

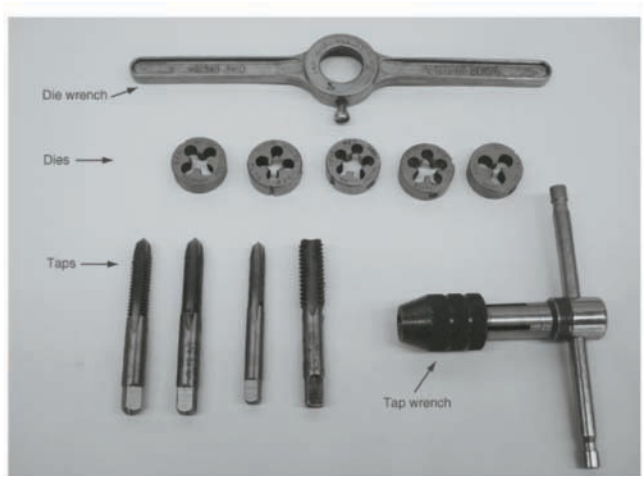

Figure 3-35 Taps and dies are used to cut threads.

Generally speaking, harder and thicker materials require coarser, harder hacksaw blades.

When using a hacksaw, it's important to apply pressure only on the forward stroke. Use little to no pressure on the backstroke.

Files

Files are cutting tools used to smooth surfaces and edges. Files are classified by their cross-sectional shapes and types of teeth (Figure 3.34). The main parts of the file are the face, edge, and tang.

Taps and Dies

Taps and **dies** (Figure 3-35) are used to cut threads in metal stock. A tap cuts "female" threads (equivalent to the threads in a nut). A die cuts "male" threads (like the threads on a screw or bolt). There are different types of taps for various uses. A popular tap used on power equipment engines is the bottoming tap, which allows material to be removed (i.e., "threaded") down to the very bottom of the hole. The tap is turned using a special wrench called a tap wrench. Dies are turned using a die wrench.

Here's a quick overview for using taps and dies. To use a tap, insert the proper-sized tap into a predrilled hole in the metal stock. Screw in the tap about a third of a turn and then back (to break the excess material from the newly cut thread) until the hole is threaded. To use the die, clamp the bolt or screw stock into a vise, and screw down the die using a back-and-forth motion to cut the threads (Figure 3-36). Note that the actual use of these tools is complex, precision work that requires skill and experience. We've simplified the description so that you can distinguish between using a tap and using a die.

Screw Extractors

The screw extractor (Figure 3-37) falls under the cutting area and is a valuable tool that's similar in operation to the tap and die. If a bolt or screw head has been accidentally sheared

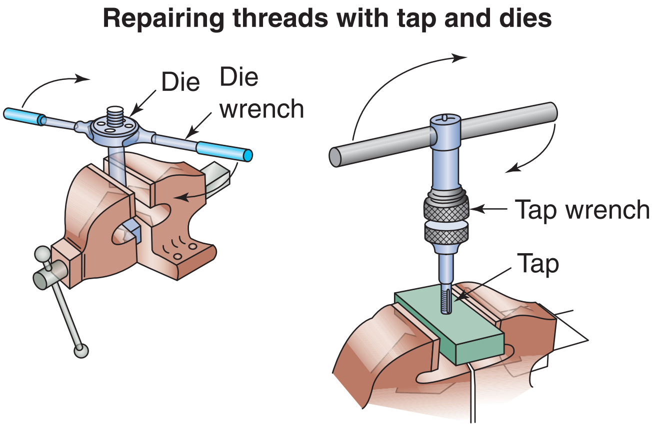

Figure 3-36 Use of a tap and die to repair threads in different types of fasteners.

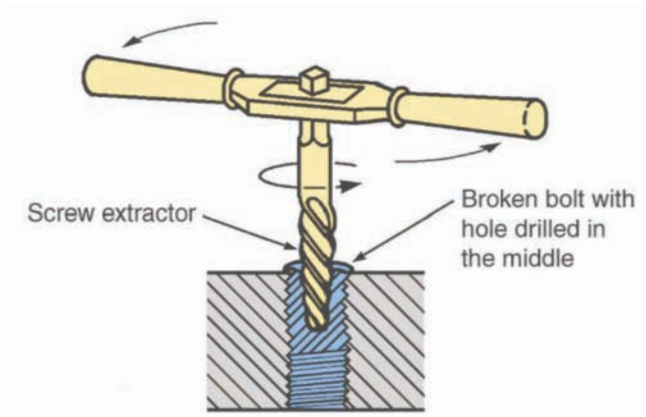

Figure 3-37 A screw extractor is a handy tool to assist in the removal of broken fasteners.

off, you can use a screw extractor to remove the screw. To use a screw extractor, start by drilling a small hole in the center of the broken screw. Then thread the screw extractor into the hole and twist it in a counterclockwise direction. The screw extractor self-taps into the broken screw. Continue turning in the counterclockwise direction and the broken screw or bolt will be extracted.

POWER TOOLS

Power tools are essential to the power equipment engine technician. Proper use of power tools will help to make you more efficient at your job. You must, however, exercise extreme care when using power tools. Not only can they cause severe injuries (covered in Chapter 2), they can also break fasteners, warp covers, and strip threads and permanently damage components. The power-operated hand tools that we'll cover are either driven by air pressure or powered by electricity.

Drills

One of the more common power tools is the **drill**. A power drill, sometimes referred to as a drill motor, is a handheld device that's used to drive a drill bit.

The **drill bit** is a tool that bores through the material. The end of the bit that attaches to the power drill is the shank, and the power drill's socket that holds the drill bit is the chuck.

Power drills come in a variety of speeds. Speed is measured in rpm (revolutions per minute). You should consider rpm values before selecting a drill. Lower-speed drives are well suited for drilling large holes in certain types of metal. Higher-speed drives are better for drilling smaller holes. Drills with lower rpm values are often equipped with gripping handles. These handles are necessary because of the high rotational torque produced by these tools.

Some drills are equipped with variable-speed motors that are controlled by movable triggers. These variable-speed drills are handy for day-to-day use. Many drills also have a reverse feature that allows you to back a drill bit out of the material you're drilling.

Power drills come in two common shop sizes: 1/2 and 3/8 inch (Figure 3-38). These measurements refer to the maximum diameter of the drill bit shank that the chuck will accept. The larger 1/2-inch power drill is used for special low-speed, high-torque situations. The 3/8-inch drill is more commonly used for general-purpose applications in the shop. 3/4 inch drills are not as common in power equipment engine repair shops but are available for drilling larger holes.

Drill bits (Figure 3-39) are manufactured from hardened steel rod stock and are available in a variety of shapes and lengths. They're frequently sold in graduated-size sets, but each size is available separately.

Drill bits are available in both SAE and metric sizes. A well-equipped repair shop has at least one complete set of each. The drill bits used in a

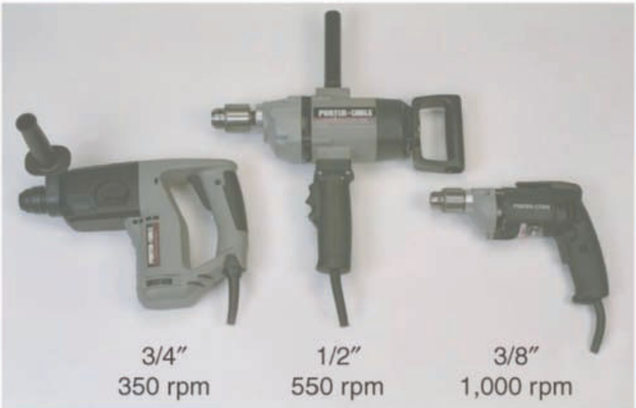

Figure 3-38 Different types of drill motors. The most common drill found in a power equipment engine technician's tool collection is the 3/8-inch drill.

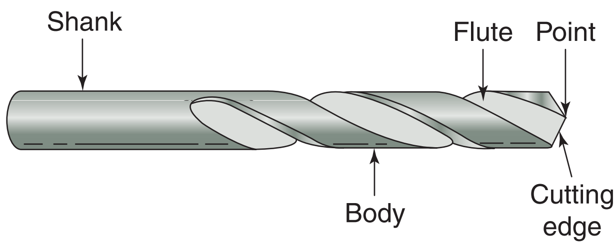

Figure 3-39 The parts of a typical drill bit.

handheld power drill are the same as those used in a shop-style drill press. You must consider the type and thickness of the material you'll be drilling and the type and size of the power drill you'll be using when making a drill bit selection. Not all bits are made for cutting metal. Some are made for wood, plastics, and concrete.

Here's a safety tip when drilling metal. When the bit starts to break through the other side of the metal, the bit may catch and twist the power drill. That's why you should be sure that the piece you're drilling is properly secured and you have a firm grip on the power drill. This will help avoid damaging the part or the drill and will reduce the risk of injury.

Rechargeable cordless drills are popular (Figure 3-40). These drills are quite powerful and allow you to work in difficult places without being restrained by an electrical power cord. This is particularly handy if you have to work in a remote location where normal power isn't available. Rechargeable batteries are the power source for cordless drills. A fully charged battery

Figure 3-40 Self-powered drill motors are popular and can also be used as a powered screw driver, as seen here.

may provide several hours of drill usage. Because they must be recharged periodically, you may want to keep spare batteries handy. That way, when you're busy, the only time you'll lose is the time it takes to swap batteries. Be sure to read the instruction manual for proper use and maintenance of these batteries. Some types should be used until they're completely discharged, and other types may be recharged at any time during use. If you recharge the first type before it's completely discharged, the battery's quality will be compromised and its useful life shortened.

Always be cautious when using power drills. Be sure to follow these guidelines:

- If you're using corded drills, use only grounded power equipment.
- Determine if there are any obstructions or wiring in the path of the bit before drilling.
- Select the correct drill-and-bit combination to perform the drilling task effectively and safely.
- Don't apply too much pressure on the drill bit.
- Use bit lubricants where required.
- Ensure that the bit is tightly clamped in the chuck.
- Never leave the chuck key in the chuck.
- Use sharp bits. A dull bit could bind, causing the drill to grab. An unexpected twist of the drill could injure your wrist.
- To drill a large hole, start by drilling a smaller hole and gradually increase the hole size by selecting increasingly larger bits.

Drill Press

Another power tool you may need from time to time is the **drill press.** The drill press is a large, floor-standing device that can drill precisely located and angled holes. Because the drill press holds the drill bit in an exact position, it can cut at precision angles and depths. Drill presses use many of the same drill bits that are used with the handheld power drill.

Bench Grinder

The **bench grinder** is another useful tool in the power equipment engine service department. The typical bench grinder (Figure 3-41) has two rotating wheels, one with an abrasive grinding surface and the other with a buffing wire surface. The wheels can be used to sharpen tools, buff or polish metal, and remove rust from parts. Also popular are handheld grinders, which are more flexible to use as they're not stationary tools.

It can't be overstated that caution should be used every time you use any type of grinder. Always use eye protection equipment and heavy gloves. Gloves will protect your hands from the heat caused by grinding and abrasives. Always keep a firm grip on the piece you're grinding or buffing. Finally, make sure that all guards, guides, and shields are in place before you operate a grinder.

Air Tools

The air ratchet (Figure 3-42) is similar to the standard hand ratchet wrench but is larger than the hand ratchet. The size of the air ratchet drive restricts the places where it can be used directly. With a selected set of shaft extensions and universal joint couplers, the air ratchet can be used for most applications. There are 1/4-inch and 3/8-inch drive lug models. The air ratchet turns at a much higher speed than a handheld ratchet and lets you remove nuts and bolts more quickly.

Power impact wrenches are driven by compressed air. They come in either 3/8-inch or 1/2-inch sizes (Figure 3-43). Power impact wrenches are useful for component disassembly but aren't recommended for reassembly. Caution: It's easy to apply too much torque using a power impact wrench, which could easily shear the fastener and/or damage the part or assembly that you're working on.

As mentioned earlier, special, heavy-duty impact sockets are designed for use with air or impact wrenches. If you recall, they're the ones that generally have a black finish. Here's a handy hint: never start a bolt or nut with a power impact wrench. The fasteners can cross thread, causing damage to the fastener or component. Remember to always use approved eye protection equipment when using power tools.

Figure 3-41 A typical bench grinder has a grinding wheel as well as a wire brush attachment.

Figure 3-42 An air ratchet can aid in the speed of removal of fasteners, but should not be used to tighten fasteners.

Figure 3-43 A typical air–power impact wrench. These types of tools should be used only to remove items and not used to install, as they're so powerful that they could break or over-torque the fastener in question.

When using compressed-air power tools, never exceed the recommended air pressure rating of the tools.

SPECIAL TOOLS

The basic hand tools that we described are often used to repair power equipment engines. But many repair activities involve procedures that can't be performed with standard tools alone. You'll need various special tools (Figure 3-44), especially when rebuilding engines. As you learn more about power equipment engine repair, you'll discover that there exists a special tool for almost every purpose.

You should be aware that some special tools are designed to be used on only one make or model of engine, whereas other special tools can be used on a variety of engines. In most cases, these special tools are owned by the service department and controlled by the service manager, but many technicians opt to purchase all the special tools that they utilize, to ensure that they know that they have the right tool at hand whenever they're in need of it. We'll review the names and uses of some special power equipment engine repair tools now. You're not expected to understand how to use these tools yet; you're expected just to become somewhat familiar with them. In later chapters, we'll cover the use of specialized tools in detail. Now, let's take a look at some more common special tools.

Pullers

Pullers are used to safely remove gears, flywheels, or various such components from shafts. A puller can easily separate machined parts that are tightly pressed together without damaging the parts. There are different types of pullers used in power equipment engine repair (Figure 3-45). For safety reasons and protection of precision parts, you should use pullers whenever possible. A type of puller called a bearing splitter is popular as it features knife-like edges that are easily placed behind the part to be removed to secure a gripping surface when clearances are limited.

Figure 3-44 An assortment of special tools used in power equipment engine repair.

Figure 3-45 Different types of pullers related to power equipment engines.

Precision Measuring Tools

Precision measuring tools are used to make exact measurements of parts or distances between parts. Measuring tools are used primarily to check for wear of components and specific, part-to-part clearances when reconditioning or rebuilding an engine. The measuring instruments used during power equipment engine repair can range from standard rulers to precision instruments. They're designed to measure thickness, clearances, pressure, and fastener tightness. Let's take a quick look at some of the common measuring tools.

Vernier Calipers

The **vernier caliper** is one of the most commonly used precision measuring tools in power equipment engine repair work (Figure 3-46). They can be used to measure inside, outside, or depth measurements, which makes them versatile.

To operate vernier calipers, place the jaws of the caliper around the part (Figure 3-47). The caliper indicates the size of the object on its display scales. You can use the jaws of most sliding calipers to measure both outside and inside dimensions.

Individual styles of vernier calipers display their measurements differently. Some of the more common styles include the printed beam and vernier scale, the dial gauge, and the digital display to allow quick readings. Our caliper example has a printed beam and vernier scale. You must read the numbers on the scale and perform minor calculations to obtain the actual measurement.

In contrast, digital calipers (Figure 3-48) are considered by many to be much easier to use. The caliper displays the true measurement directly on the digital display screen and most will show in SAE or metric measuring systems.

Figure 3-47 A vernier scale caliper is shown being used here.

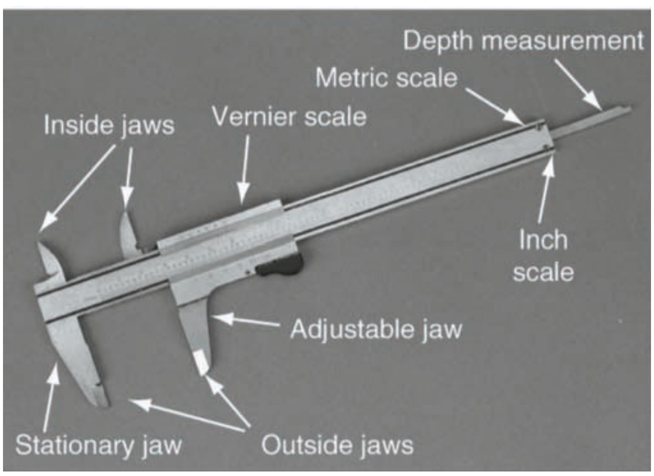

Figure 3-46 The vernier caliper is a versatile tool that can be used to measure inside and outside diameters as well as depth.

Figure 3-48 Some people feel that reading a digital caliper is easier than reading the standard vernier scale. As you can see here, that point is hard to argue!

Micrometer

As mentioned, vernier calipers can be quite accurate, but they're less accurate than **micrometers**. In those cases when exact precision is needed, micrometers should be used. The micrometer is used to measure the size of a part or component. The basic components of a micrometer are shown in Figure 3-49.

Micrometers come in a variety of sizes and styles (Figure 3-50a). Some micrometers are designed to measure the outer dimensions of an object, whereas others are made to measure inner dimensions, such as the inside diameter of a cylinder. Another type of micrometer measures depth. Many micrometers use an electronic readout that allows quick and easy-to-read measurements, whereas many other micrometers can be read using a vernier scale on the tool itself. Just like vernier calipers, micrometers with digital displays can be purchased, which also allow for easy conversion from SAE to metric denominations (Figure 3-50b).

To use a micrometer, place the object between the anvil and the spindle, and then turn the thimble until the anvil and spindle contact the object with a light resistance. You can read the measurement on the thimble and sleeve of the gauge (Figure 3-51).

Micrometers are often used during the engine-rebuilding process. During a rebuild, you'll completely disassemble an engine and inspect and measure all the engine parts to determine if they're worn or damaged. Because the micrometer can measure thickness so accurately, it can easily detect small changes in part sizes, which indicates wear. Using a micrometer is a typical procedure performed during engine reconditioning.

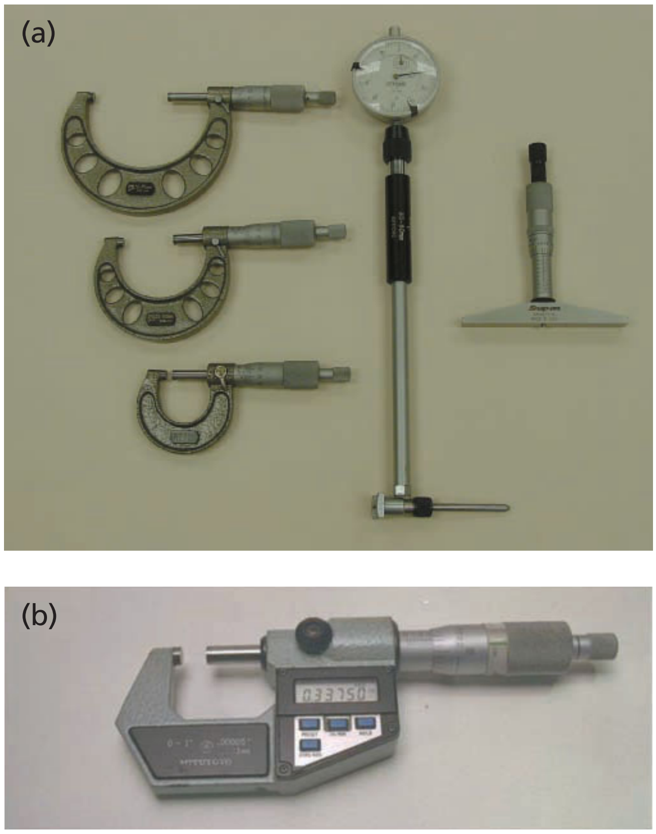

Figure 3-50 (a) The three primary types of micrometers used in power equipment engine repair. (b) Just like the vernier caliper, micrometers also come in versions that can be read digitally.

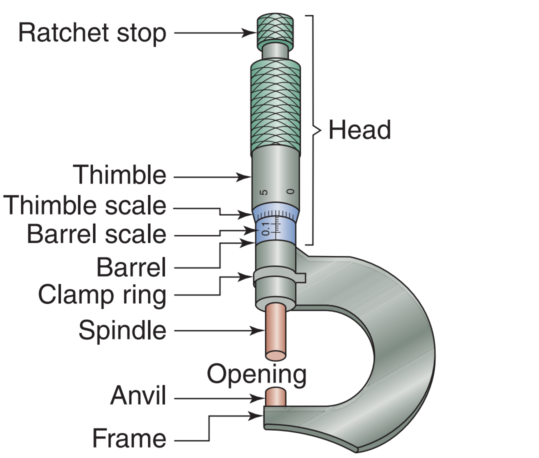

Figure 3-49 The components of a typical micrometer.

Dial Indicator

So far, with precision measuring tools, we've looked at tools that measure the sizes of parts. However, there are times when you'll need to measure the distance that a part moves, such as the in-and-out movement (travel) of a shaft. The most common way to measure this type of movement is to use a **dial indicator**, which is simply a dial gauge with a plunger that sticks out from one side (Figure 3-52) and can be used in numerous positions. Dial indicators are held in place by a magnetic base or a flexible shaft that

Figure 3-51 Measurement using a micrometer.

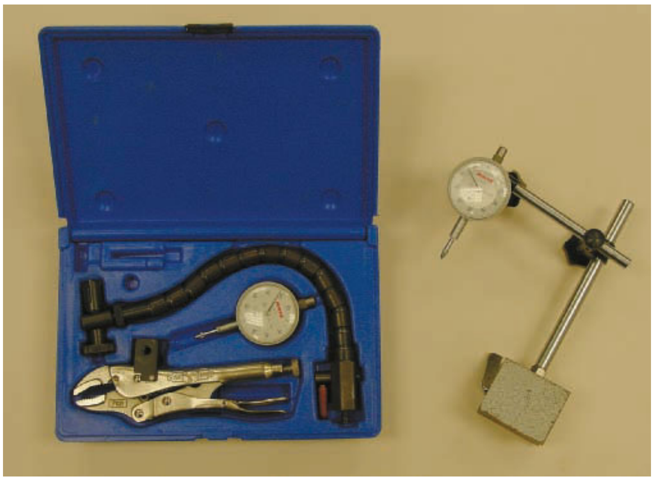

Figure 3-52 Two dial indicators. The one on the right uses a magnetic base to hold it in place, whereas the one on the left uses a flexible shaft that locks in place.

can be locked in place once the desired location has been determined.

To use the dial indicator, attach it to a solid object (usually by means of a magnetic base or a clamping device) next to the item you're going to measure (Figure 3-53). Position the dial indicator so that the plunger contacts the object whose movement is to be measured. Move the object back and forth. The dial indicates the distance that the plunger has traveled. Dial indicators are often used in engine and transmission rebuilding.

Torque Wrenches

Accurate tightening of fasteners is a key consideration in the proper operation of engines

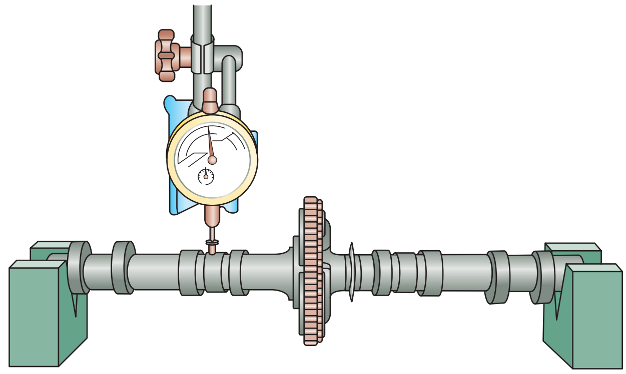

Figure 3-53 A dial indicator in use measuring a camshaft from a power equipment engine.

and other power equipment engine components. In shop repair and service manuals, manufacturers specify the exact amount of torque that should be used to tighten fasteners, such as head bolts (note that most torque figures given by manufacturers are "dry torque" readings, meaning that no lubrication is used). Because it's almost impossible to accurately tighten a bolt by hand to a specified torque, special tools called torque wrenches are used. A torque wrench allows you to apply an exact amount of tightening force (torque) to a fastener. Frequently, the torque wrench is a modified socket drive handle that has a torque-measuring device built into it. This allows you to use standard interchangeable sockets when you're setting the torque on fasteners.

A torque wrench contains a measuring dial or scale. As you tighten a nut or bolt with the wrench, the dial or scale indicates how much torque you're applying. These scales are usually calibrated in SAE foot-pounds (ft-lb), inch-pounds (in-lb), or metric newton-meters (N-m). There are two common types of torque wrenches used in the power equipment engine service shop (Figure 3-54).

- The beam-type torque wrench contains a metal pointer rod. As you tighten a bolt, the rod points to the measured torque value (Figure 3-54a).
- The click-type torque wrench is somewhat easier to use than the beam type (Figure 3-54b). With a click-type torque wrench, you preset on a calibrated dial the desired amount of

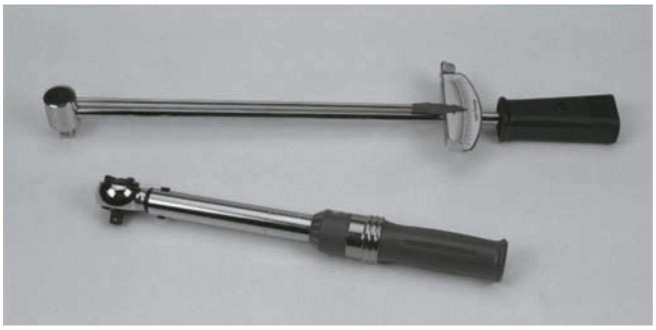

Figure 3-54 The two most popular types of torque wrenches found in a power equipment engine technician's tool collection are the (a) beam and (b) click types.

torque before tightening the bolt. When you reach the preset torque value, the wrench clicks and no more torque is required to be applied. At low torque values, the click is inaudible and therefore you must feel the wrench flex. To preserve the calibration of the click-type torque wrench, you must release the adjustment after each use.

Feeler Gauges

Feeler gauges are another type of precision measuring tool. They're typically used to measure very small spaces between two parts, such as spark plug gaps. These small spaces are often called **clearances**. A typical feeler gauge is actually a set of gauges, made up of a large selection of metal blades that can spread open like a fan (Figure 3-55). The blades vary in thickness to provide a complete range of precise measurements. Each blade is marked with its thickness, in some cases marked in both metric and SAE sizes.

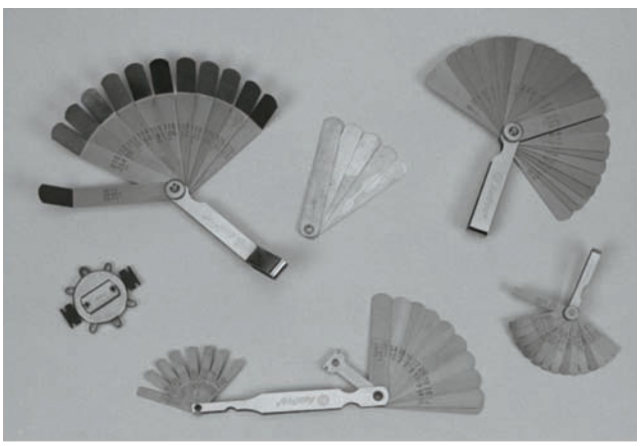

Figure 3-55 A wide array of feeler gauges.

To measure the distance between two parts, insert one blade at a time between the parts until you find the blade that's an exact fit. The marked size of that blade indicates the measured clearance between the two parts. In some cases, a combination of two or more blades is used to precisely measure the clearance. In these cases, the total of the individual blade thicknesses gives the clearance.

Test Instruments

Troubleshooting and repairing power equipment engines require a wide variety of special test instruments. These test instruments are designed to test the condition of various systems. For example, there are different instruments that you can use to test an engine's ignition and electrical systems. Let's take a brief look at some of the common test instruments.

Multi-meter

You can use different special instruments to test or measure parameters in electrical circuits within a power equipment engine's electrical system. The most common electrical testing instrument is the **multi-meter** (also called a volt-ohmmeter or VOM). This one instrument can measure voltage, current, and resistance. The multi-meter is a box-like device that has two flexible wire test leads connected to it (Figure 3-56). The ends of the wire leads hold probes that are used to contact the electrical circuitry. When the readout on the display is digital, the meter is referred to as a digital volt-ohmmeter (DVOM).

The probes can be of either needle-point or alligator-clip design. Most comprise a combination to allow you to either probe or connect the test leads, depending on what component is being tested. To make measurements, the probes are made to touch different areas of an electrical circuit. The multi-meter has a display face to provide the circuit measurement information to the user. The display can be of either an analog type, which uses a moving needle (Figure 3-57), or a digital display type (Figure 3-56). Both types of multi-meters are popular in the power equipment engine technician's tool collection.

Figure 3-56 A typical digital multi-meter.

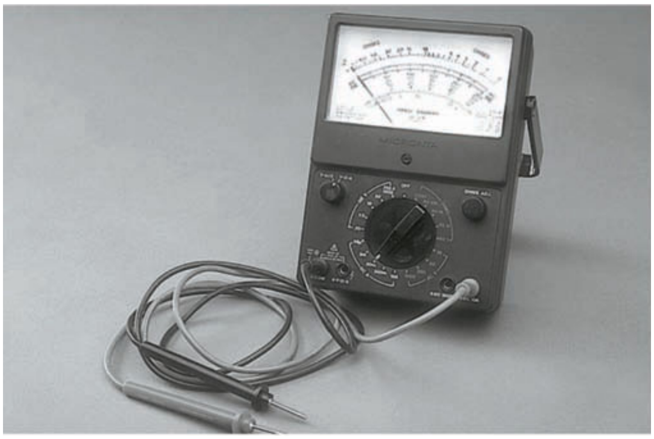

Figure 3-57 A typical analog multi-meter.

The circuit information displayed by the multi-meter helps you determine where problems, such as broken wires, faulty connections, or defective components, may exist in an electrical system. Note that this is a brief and basic description of the multi-meter's operation. The actual operation of a multi-meter is more complex. You must always observe electrical safety precautions when using the multi-meter. You could damage the multi-meter and the electrical circuit if you use it improperly. More important, you could receive a severe electrical shock. We'll discuss in detail where to use a multi-meter in Chapter 13.

Timing Light

Although not used much today, a special device called a **timing light** (Figure 3-58) may be used to determine if the timing of the spark impulse is correct.

Figure 3-58 Timing lights are still popular and are used to determine if the engine's spark timing is correct.

You connect the timing light device between the spark plug and the plug wire, start and run the engine, and watch the timing light flash against a rotating timing mark. Every time the plug fires, the timing light will produce a flash of light (strobe) that freezes the mark. The illuminated timing mark is compared with a fixed reference mark to verify correct timing. If the timing is wrong, the two marks (fixed and rotating) will not line up. You then adjust the timing until the marks come into alignment. Most of today's power equipment engines don't have adjustable timing; therefore, you may conclude that if the timing isn't correct, there is a problem in the system that will require a component to be replaced. Another tool that can be used with the spark plug is a spark tester, which allows you to actually see the spark of the ignition. In many cases, you would be able to adjust the spark plug gap to verify that the ignition coil is working well.

Test Lights

A **test light** (Figure 3-59) is used to determine if electrical power is available to a particular circuit. It's often used in the diagnosis of failed lighting systems. Test lights come in two styles: self-powered, which is used to verify that a circuit is complete, and non-self-powered, which is used to verify that power is being supplied to the circuit. Both types have various uses in the service shop environment.

Before using a self-powered test light, ensure, with the help of the service manual, if it's likely

Figure 3-59 A test light is a handy tool when diagnosing a problem in an electrical system. There are two types of test lights, self-powered and non-self-powered. Shown here is a non-self-powered test light.

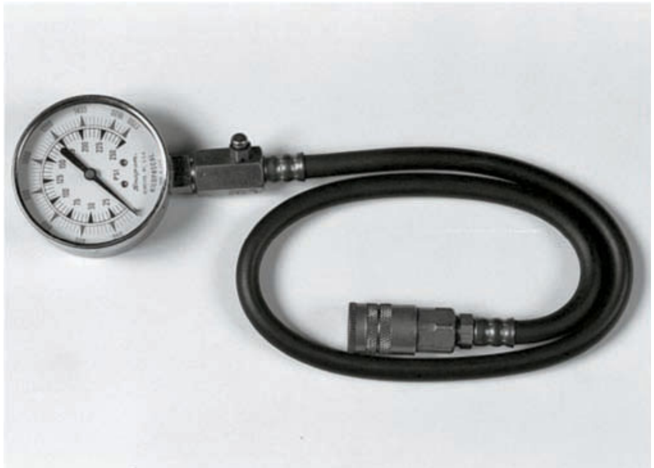

Figure 3-60 Compression testers measure the amount of pressure inside an engine cylinder and are used often on all types of power equipment engines.

to damage the circuit board being tested, because some applications of self-powered test lights can do so. In these cases, use a multi-meter.

Compression Gauge

The **compression gauge** is used to measure pressure in an engine cylinder (Figure 3-60). You may know that a mixture of air and fuel is compressed inside of the engine's cylinder, after which the mixture is ignited. The higher the cylinder compression, the better the fuel mixture burns. As engine components wear, the compression in the cylinder decreases. By measuring the cylinder's compression pressure, you can determine if the engine is mechanically sound.

To use the compression gauge, unscrew the spark plug from the cylinder head and install the compression tester gauge adapter into the cylinder head in place of the spark plug (Figure 3.61). When you turn the engine over a number of times, the amount of pressure that's developed in the cylinder is displayed on the gauge.

Many technicians use another tool in conjunction with a compression tester to determine the condition of a four-stroke engine—a leak-down tester. This type of tester is used to check the amount of air pressure that is allowed to escape under pressure. More information on this type of special tool will be discussed in Chapter 12 (on the four-stroke engines).

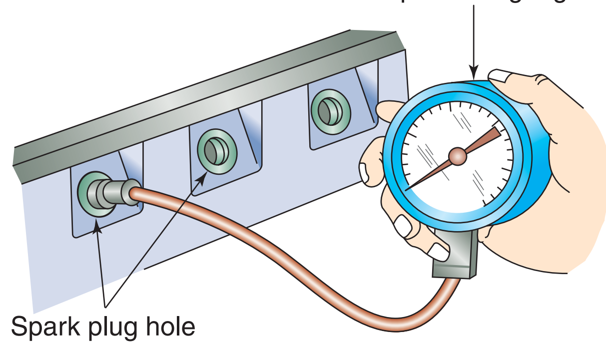

Figure 3-61 Proper placement of a compression tester.

PURCHASING TOOLS

Few power equipment engine technicians own every type of available repair or diagnostic tool. This is because most technicians don't perform every type of repair. Exactly what tools you'll need depends on your repair specialty area and the availability of equipment at the service department where you work. In most power equipment engine service departments, technicians are required to buy their own basic hand tools and possibly some diagnostic tools. The service department usually provides only specialized tools and expensive test equipment.

When you buy tools, remember that you'll use these tools almost every day. You must be able to depend on them. For this reason, the tools you buy should be of high quality to provide you with many years of service. It's a good idea to buy professional quality tools with a brand name. These tools are usually of the highest quality and are often backed by lifetime warranties. If a tool under warranty is damaged or fails in normal use, you can return it to the manufacturer for a replacement. You can purchase most tools individually or in sets. If you intend to enter the power equipment engine repair field, you may want to consider purchasing a complete starter set rather than dealing with individual tools. Although in most cases purchasing tools in sets works out to be less expensive than buying them individually, if you already own a reasonable assortment of quality tools, you may need to purchase only a few additional items to meet your tool needs.

As you perform more repairs and gain experience, you can add more tools to your starter set. Remember that it's better to avoid buying too many tools until you're reasonably established in your field. Before purchasing an assortment of tools that you may never use, stop and analyze your situation. When you determine the types of repairs that you'll be doing routinely, you can purchase extra tools on the basis of your specific needs. This planning will help you avoid spending a lot of money on tools that you may never need in the future. Tools aren't cheap, but they're a sound investment in your future. Invest wisely!

STORING TOOLS

Proper tool maintenance and storage should be an important part of your daily routine. Professional technicians always take care of their equipment. Because you'll probably own a large collection of tools one day, it's important to establish good work habits and housekeeping practices early in your career. One of the most important first steps is to organize your tools so that you can find them easily. You wouldn't want to spend a lot of time looking for a tool each time you need it. And equally important, tools are an expensive investment. You should keep them locked up when you're not using them. The best way to store and organize your tools is to keep them locked in a sturdy, professional-quality **toolbox**. Toolboxes come in a variety of sizes and price ranges. They can be small and portable units (Figure 3-62) or large, floor-standing units with wheels (Figure 3-63). When choosing a toolbox for storage, always

Figure 3-62 A typical portable toolbox.

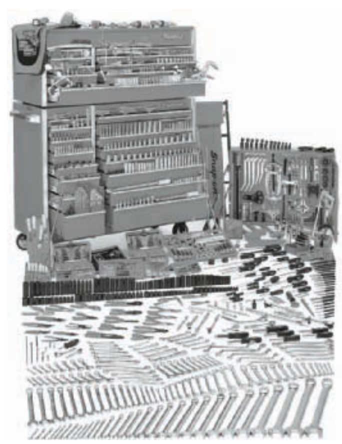

Figure 3-63 Many long-term power equipment engine technicians go all out and purchase large, floor-standing toolboxes, such as this one. Courtesy of Snap-on Tools Company.

consider your future needs and plan ahead. As a professional technician, you'll continue to add tools to your collection as the need arises. So, when you choose a toolbox or cabinet, select one that will allow room for future expansion.

SERVICE INFORMATION LIBRARY

Whenever you're repairing or rebuilding a power equipment engine, the correct service reference material is a must. Because each make and model is different, you'll frequently need to look up manufacturer's information and specifications about the particular machine you're working on. An up-to-date, service information library is as essential to your work as proper tools. Franchised power equipment engine dealerships are required to keep a variety of reference books and service manuals on hand. Service manuals can be a printed copy or a CD that is used in a computer. These collections of service documentation grow every time new models and features are introduced to the market. Service manuals contain a great deal of helpful information, such as engine identification information, engine specifications, reconditioning specifications, and recommended repair procedures. Many manufacturers are making manuals and other service information available online also, as it's easier to access and update specifications online.

Most manufacturers also send out **specification manuals**, known as "spec" manuals. Use of the term *specification* here focuses on certain precision measurements made on parts of the vehicle, particularly in the engine. The exact measurements are determined by the manufacturer and are listed in the vehicle's service manual or spec manual. When you're working on a major rebuild of a power equipment engine, many of the engine specifications must be checked with precision measuring instruments we had discussed earlier in this chapter. These measurements are compared with the specifications listed in the service manual. Any deviations from the listed, acceptable tolerance limits indicate a problem that should be corrected as part of the repair process. An engine must conform exactly to its specifications to operate properly. Some common engine specifications include:

- **Spark plug gap.** The width of the gap between the spark plug's electrodes.
- **Cylinder bore.** The inside diameter of the engine's cylinder.
- **Torque specifications.** Tightness of fasteners, usually measured in foot-pounds, inch-pounds, or newton-meters.

Some technicians attempt to make repairs on a vehicle without using service manuals, but this isn't a good practice for several reasons. First, even the most experienced technicians can't remember every specification for every make and model vehicle. If you were to work on only one type of power equipment engine, you could probably handle most repairs without the use of outside references. But in almost all power equipment engine service departments, technicians are required to work on a large variety of models, often from different manufacturers. Second, manufacturers constantly make changes and improvements to their vehicles. Each year, new vehicles are introduced and more features are added to existing models. An up-to-date service information library will help you stay current with the latest changes to the vehicles you service. And finally, service manuals are often necessary in those cases where you weren't the person who disassembled a particular component. You may be picking up work left unfinished by someone else. With a service manual at hand, you can quickly determine how the component should be assembled and how it should be adjusted once it's installed.

Service manuals are useful tools, but they can't tell you everything. Most manuals, written with the assumption that you already know the basics of power equipment engine repair, concentrate on specifications and repair procedure sequences. Therefore, service manuals can never take the place of good training. Service manuals are simply additional tools to help you make repairs correctly and efficiently.

Summary

- You should be able to easily identify common hand, power, and special tools.
- It's important to know how to select the correct tool for a particular type of repair. Use of the correct types of tools, as required by the job at hand, ensures that you're an efficient and effective technician.
- There are different special tools needed to properly disassemble and reassemble power equipment engines.
- There are different types of precision measuring tools and each has a specific purpose.
- A proper service information library is among the most important tools that you can use.

Chapter 3 Review Questions

Fill in the blanks in each of the following statements.

1. A _____ is a test instrument that's commonly used to measure voltage, resistance, and other electrical parameters.
2. Power equipment engine tools can be classified into these three categories: _____, _____ and _____.
3. A _____ is used to tighten a nut or bolt with the exact required amount of pressure.
4. One of the most commonly used precision measuring tools in power equipment engine repair can measure inside and outside diameters as well as depth. This tool is called a _____.
5. The _____ measuring system uses millimeters.
6. A short, six-sided rod used to tighten screws with similar indentations is the _____.
7. Which type of wrench would be a better choice in tight places?
   a. 6-point box wrench
   b. 12-point box wrench
8. An air ratchet is suitable for tightening fasteners. (True/False)
9. Franchised power equipment engine dealerships have service libraries that include _____ and _____.
10. _____ combine the open-end wrench and the box-end wrench into one tool.

CHAPTER

4 Measuring Systems, Fasteners, and Thread Repair

Learning Objectives

- Identify the basic measuring systems used on power equipment engines
- Identify common fasteners used on power equipment engines
- Describe the four most important bolt dimensions
- List the three basic types of threads used on fasteners
- Understand how to identify and record bolt grade/tensile strength
- Determine the appropriate tightening torque for a threaded fastener
- Describe common ways to remove damaged fasteners
- Describe how to clean and repair damaged threads

Key Terms

Axial tension
Bolt
Bolt head markings
Conventional system
Elastic range
Metric system
Nut
Plain flat washer
Plastic range
Preload
Stretched bolt
Stud
Tensile strength
Threads per inch (TPI)
Yield point

INTRODUCTION

Power equipment engines use two systems of weights and measurement. Most power equipment engines made in the United States use the U.S. or conventional system of weights and measurement. Virtually all power equipment engines built in the rest of the world use the metric system, which is considered by many to be easier to use.

Power equipment engines have hundreds of parts held together by threaded fasteners. Unlike permanent fastening methods like welding, riveting, or gluing, threaded fasteners establish a non-permanent connection that can be disassembled when necessary.

A competent power equipment engine technician must know the different measurement systems as well as about fasteners, including how to properly install and tighten the various fasteners to correct manufacturer specifications and how to repair and remove fasteners when they break. A technician must be able to use a torque wrench to complete most tightening procedures to ensure a quality reassembly. In doing so, the technician must be able to use factory-specified torque values and recommended tightening methods and sequence of operations. An improperly tightened fastener can fail by loosening (backing out) or breaking, causing a dangerous condition for the operator of the power equipment engine. In this chapter, we will review measurement systems, fastener identification and classification, removal of broken and seized fasteners, thread repair procedures, and fastener reinstallation guidelines.

MEASUREMENT SYSTEMS

For power equipment engine systems to operate properly, the parts must fit together securely. Fasteners, parts, and the tools needed to work on them are made to specific sizes or measurements.

Power equipment engine manufacturers use the two most common weights and measurement systems: the conventional system and the metric system.

The Conventional System

Use of the **conventional system**, also known as the standard or United States Customary system, requires knowledge of different combinations of numbers. For example, 1 foot contains 12 inches. One inch can be divided into equal units, as in halves (1/2"), quarters (1/4"), or eighths (1/8") of an inch. Rulers and other measuring instruments divide each inch into units of 16, 32, 64, or 128 equal parts.

Sizes of fasteners, tools, and parts are stated in inches or parts of inches. The parts of inches are expressed either as fractions or as decimal numbers. For example, a fastener diameter of one-half inch can be written as 1/2" or as a decimal, 0.5", and a fastener diameter of 1/8" would be 0.125" as a decimal number.

The Metric System

The **metric system**, also called the International System of Units (SI), is used in virtually all countries around the world. It's easier to use because it uses a simple decimal system to determine different base units of measurement. There is no need to memorize, for example, that 12 inches make a foot or 3 feet make a yard. Power equipment engines generally use the following metric increments, the meter being the base point of measurement:

- A millimeter equals one thousandths (1/1000) of a meter.
- A centimeter equals one hundredth (1/100) of a meter.

The metric system uses only decimal numbers. It's easy to remember that each metric unit of measurement is 10 times the size of the previous unit. For example, 10 millimeters (10 mm) equal 1 centimeter (1 cm), and 10 centimeters (10 cm) equal 1 decimeter (1 dm). A meter (39.37 inches) equals 1,000 mm or 100 cm. Each metric unit of measurement smaller than the meter equals 1/10 (0.10) the size of the previous unit. Thus 1 centimeter equals 0.01 meter and 1 millimeter equals 0.001 meter.

FASTENERS

Fasteners are devices that hold the parts of a power equipment engine together. Hundreds of fasteners are used in today's modern vehicles. Figure 4-1 illustrates some of the most common types.

The Nuts and Bolts of Bolts and Nuts

A **bolt** is a metal rod with external threads on one end and a head on the other. When a bolt is threaded into a part other than a nut, it can also be called a cap screw. A **nut** has internal threads and usually is made with a six-sided outer shape. Figure 4-2 shows examples of bolts, nuts, and washers. When a nut is threaded onto a bolt, a powerful clamping force can be produced.

In power equipment engine technology, many bolts and nuts are named after the parts they hold. For instance, bolts holding the cylinder head on the block are called *cylinder head bolts.* Bolts on an engine-connecting rod are called *connecting rod bolts.*

When more turning force, or torque, is applied, the greater force exerted on the nut creates a tension in the bolt, which clamps the mating parts together. **Preload** is the technical term for the tension caused by tightening the fastener that holds the parts together. The common term used for this is *torque*. Producing sufficient preload force is the key to strong and reliable bolted joints that will not loosen or break under load. Figure 4-3 illustrates the forces that act on a bolted component. We will discuss these forces later in this chapter.

Figure 4-1 Many of the common types of fasteners used on today's power equipment engines.

Fastener Anatomy

Bolts and nuts come in various sizes, grades (or strengths), and thread types. A good technician must be familiar with the differences. The four most critical bolt dimensions (Figure 4-4) are:

- **Bolt diameter.** The outside diameter of the bolt threads.
- **Head size.** The distance across the flats or outer sides of the bolt head. This is the same

Figure 4-2 Examples of nuts, bolts, and washers.

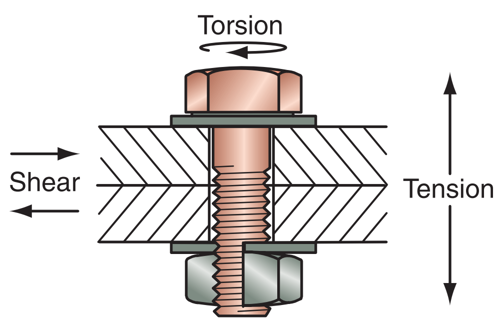

Figure 4-3 The forces acting on a threaded fastener: axial tension, torsion, and shear. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

as the size of the wrench that would be used to install or remove the bolt.

- **Bolt length.** The distance from the bottom of the bolt head to the threaded end of the bolt.
- **Thread pitch.** Sometimes referred to as thread coarseness, thread pitch for metric fasteners is the distance from the top of one thread to the top of the next (Figure 4-5). The International Standards Organization (ISO) sets these specifications. This is also the distance the bolt moves in one complete revolution. Standard or U.S. Customary (USC) fastener thread pitch is determined by the number of **threads per inch (TPI)** (see Figure 4-6 for thread pitch measurement using the conventional system).

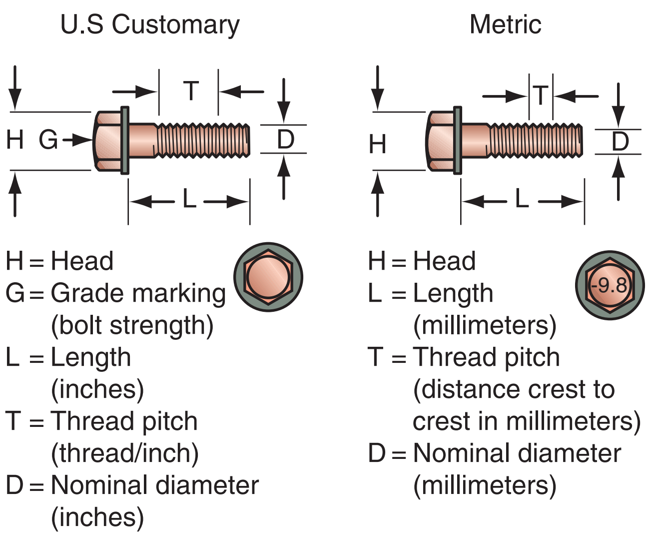

Figure 4-4 Critical bolt dimensions, in the United States Customary (USC) and metric systems.

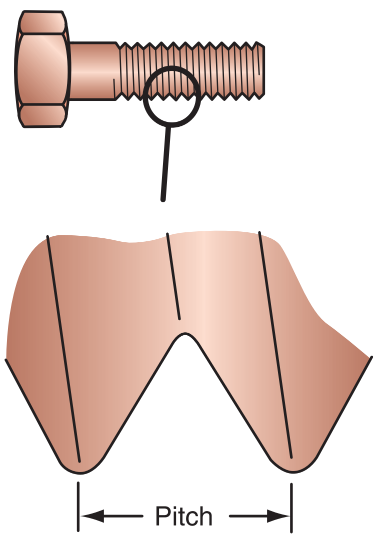

Figure 4-5 Thread pitch is the distance from the top of one thread to the top of the next. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Thread Types

With respect to thread standards, there is a metric thread (SI), a parallel thread for piping (PF), a taper thread for piping (PT), and a unified thread [unified national coarse (UNC), unified national fine (UNF)].

The three most common types of threads used on fasteners are:

- Coarse threads (UNC)
- Fine threads (UNF)
- Metric threads [System International (SI)]

An additional thread is used on power equipment engines but in limited applications. For example, threads on oil pressure switches and coolant temperature sensors may use a PT (tapered pipe) or a PF (standard pipe) thread.

Note that PT and PF threads are *not* compatible with each other or any other threads previously mentioned.

Never substitute thread types or else thread damage will result. To prevent damage to fasteners, always thread the bolt or nut by hand (or fingers) for the first 3–5 complete turns. If the fastener only threads a turn or two and then starts to bind, there may be a mismatch. Don't continue to tighten using a big wrench, air tool, or impact wrench as damage will likely occur.

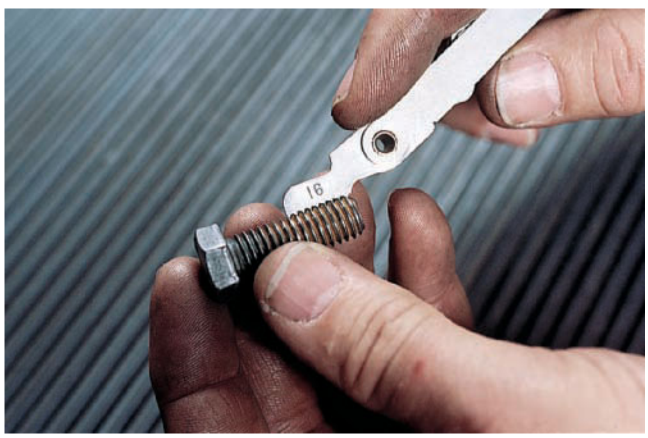

Figure 4-6 A thread pitch gauge that measures threads per inch.

Bolts and nuts come in right-hand and left-hand threads. With right-hand threads, the fastener must be turned clockwise to tighten. This is the most common style of thread. A left-hand thread requires turning the fastener in a counterclockwise direction to tighten. Left-hand threads are not common. The letter "L" may be stamped on fasteners with left-hand threads.

Bolt Grades

Tensile strength, or grade, refers to the amount of pull a fastener can withstand before breaking. Bolts are made out of different metals. Some are better than others.

Tensile strength of bolts can vary. **Bolt head markings**, also called grade markings, specify the tensile strength of the bolt. Standard or USC bolts are identified with lines or slash marks (Figure 4-7). Count the lines and add 2 to determine the strength of the bolt. These are known as Society of Automotive Engineers (SAE)-type and are evaluated by the American National Standards Institute (ANSI).

Metric bolts are *numbered*: The higher the bolt number, the greater the strength of the bolt (Figure 4-7). The ISO defines fastener quality in terms of tensile strength and yield strength. This standard is used for metric fasteners and may someday eventually replace all other grading standards. Metric fasteners classified as 8.8 or higher are required to have the markings.

When replacing any bolt, always replace with the *same* grade markings. A weaker bolt may easily snap causing part failure and a dangerous condition. Replacing a bolt with a stronger one isn't always safe. Harder bolts tend to be more brittle and may fail in specific applications.

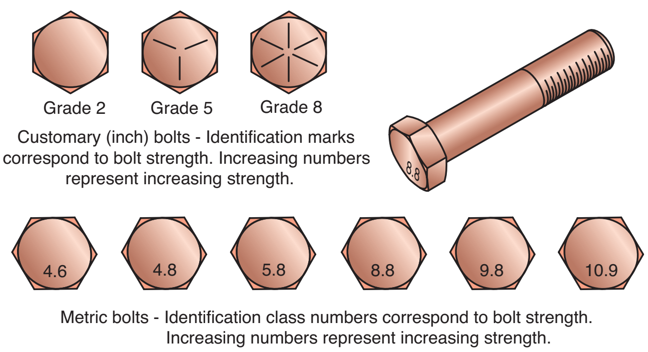

Figure 4-7 Typical bolt grade markings.

Bolt Types

There are various types of bolts found on power equipment engines. Here, we will cover a few of the most commonly found.

Deep Recess-Type Bolts

Deep-recess (DR)-type bolts without strength markings (flange bolts with hex-heads and weight reduction recess in them) are classified by outer flange diameters (Figure 4-8). Their outer flange diameters are larger than those of standard bolts with a flanged head. Install these bolts in the correct location with the correct torque.

Uniform Bearing Stress Bolts

Uniform bearing stress (UBS) bolts (Figure 4-9) are designed to resist loosening. A small angle of 5–60' is rolled or forged on the underside of the bolt head. This causes the flange to flex as the bolt is tightened and provides additional friction to hold the bolt tight. UBS bolts can be identified by an undercut

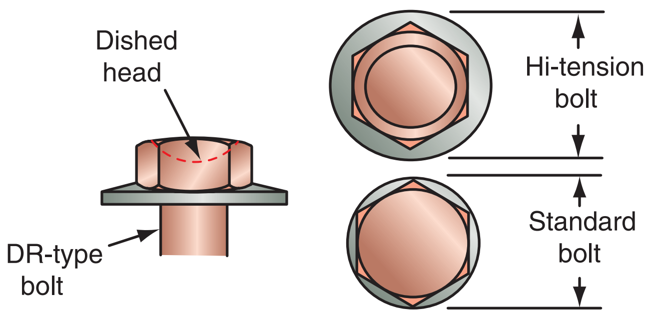

Figure 4-8 A deep recess (DR)-type bolt. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

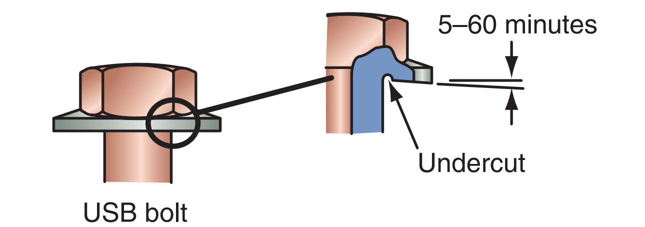

Figure 4-9 Uniform bearing stress (UBS) bolts have flanges that flex to resist loosening. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

radius under the bolt head. UBS bolts may or may not be marked with strength marks.

Torx Bolts

Torx bolt heads (Figure 4-10) have a patented shape. Bolts of this design carry a greater torque from the socket to the bolt. These bolts come in both external and internal types. The external Torx is classified as an E type and the internal as a T type. These are used on many ATV differentials.

Combination Bolts

The combination (CT) bolt is a type of self-tapping bolt (Figure 4-11). It forms the female threads when it's screwed into the unthreaded pilot hole by deforming the walls of the hole. The lower half of the CT bolt features the combination of the standard threads and the low threads. Fewer chips and shavings are produced while using a CT bolt.

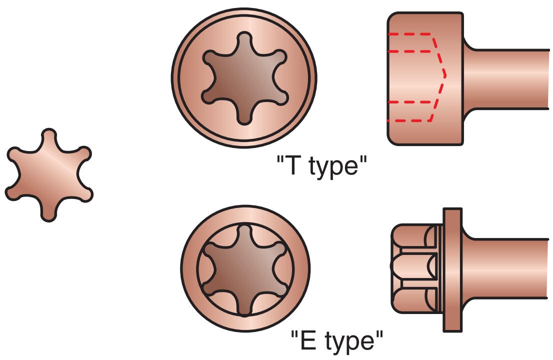

Figure 4-10 The two types of Torx bolts. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

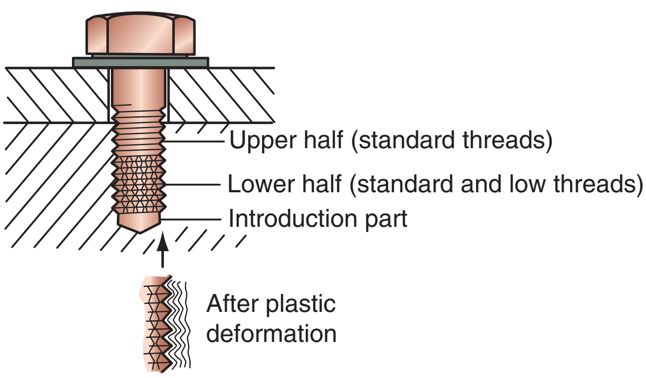

Figure 4-11 Combination (CT) bolts are self-tapping. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Note: When the CT bolt is reinstalled, be sure that the male threads drop into the female threads in the component before tightening to prevent forming another set of threads. When replacing a CT bolt (Figure 4-12), use a new CT bolt or a standard bolt of shorter length.

Studs

A **stud** (Figure 4-13) is a fastener with external threads on each end. To hold parts together, a stud first is tightened into a threaded hole in a part (such as an engine case). A second part (a cylinder head) fits over the exposed end of the stud. Finally, a nut is fitted to the exposed end of the stud and is tightened. Studs generally come in two thread sizes, to enable the user to be sure which side of the stud should be inserted into the threaded hole. Studs are removed by the use of a puller, also seen in Figure 4-13.

Tension Bolts

Certain areas of the power equipment engine are subjected to repeated and severe external forces, such as vibration or expansion due to heat. Special bolts (Figure 4-14) with greater elasticity are used in these areas. These fasteners stretch further than common bolts without permanently stretching. They're used on cylinder heads, connecting rods, and crankcases.

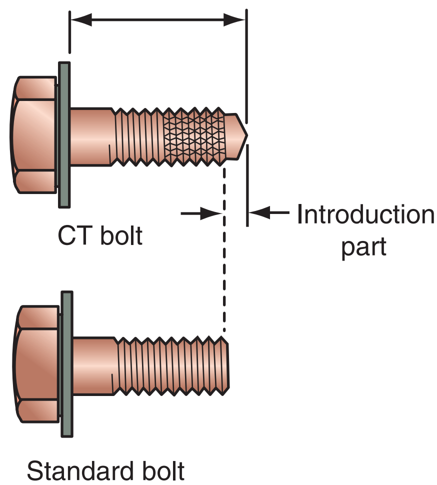

Figure 4-12 When replacing a CT bolt with a standard bolt, use a shorter bolt or else you could damage the component. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

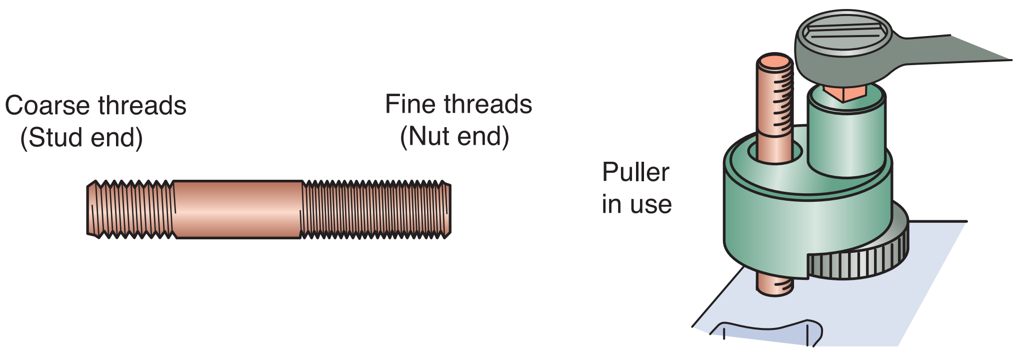

Figure 4-13 Studs have external threads on both ends.

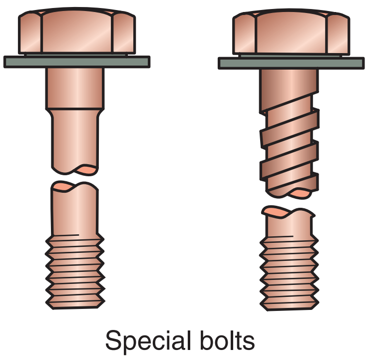

Figure 4-14 Special bolts are used in various places on a power equipment engine. Be sure to use the correct bolt when reassembling! Copyright by American Honda Motor Co., Inc. and reprinted with permission.

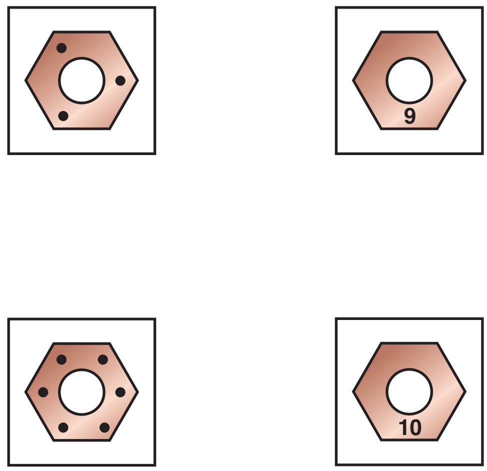

Figure 4-15 Grade markings on nuts are used in the same fashion as on bolts.

Nuts

A nut has internal threads and usually a six-sided outer shape. The grade of nut used must match the grade of bolt that it's used with. Manufacturers use different nut markings for grade identification (Figure 4-15). Some marks are on the top and others are marked on the sides.

Self-Locking Nuts

A self-locking nut (Figure 4-16) has a spring plate on the top. This spring plate presses against the thread, making it difficult for the nut to loosen. This type of nut, which can be used again after removal, can be found on the frame, in suspension pivot bolt/nut applications, and the axle. Points to consider when working with self-locking nuts are:

- The bolt head must be held during nut installation and removal because of the resistance of the nut spring plate against the bolt.
- If the bolt length is too short, the spring plate portion of the lock nut will not engage the thread fully. Therefore, the nut will not lock.

Castle-Headed Nuts

The castle-headed nut allows a cotter pin (Figure 4-17) to be installed through a nut and bolt to prevent loosening. Applications include important safety points on the frame, axle nut, and brake torque rod. Points to consider when working with castle nuts are:

- Always use new cotter pins during assembly.
- Tighten the nut to the specified torque. Align the next possible pin hole while tightening the nut just beyond the specified torque.
- Don't align the holes in a position where the nut torque is less than the specified torque.

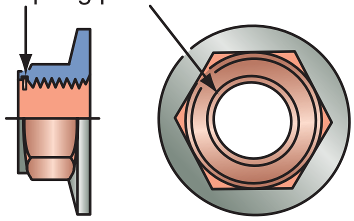

Figure 4-16 A self-locking nut with a spring plate. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

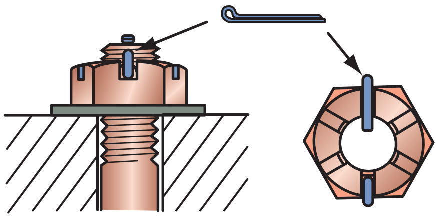

Figure 4-17 Castle-headed nuts are used with cotter pins to prevent loosening. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Stake Nuts

The stake-type lock nut (Figure 4-18) incorporates a metal collar at the top of the nut. A punch is used to stake (bend or indent) the collar of the nut to match a groove in the shaft that it's being used on. Applications include the clutch center lock nut, shift drum stopper plate, and wheel bearing retainers. Points to consider when using stake nuts are:

- During disassembly, eliminate the staking point before the nut is loosened.
- Replace the nut if the old staked area of the nut aligns with the groove of the shaft after tightening the nut to the specified torque.
- After tightening the nut to the specified torque, stake the nut collar using a drift punch. Ensure that the staking point has entered into the grove at least 2/3 of the groove depth.

Well Nuts

Well nuts are rubber fasteners with a brass-threaded sleeve installed in the center (Figure 4-19). A screw normally threads into the brass insert. When tightened, the insert causes the rubber to expand and hold it in place. Well nuts are used on body panels, fairing parts, and windshields/windscreens. Don't use excessive force to tighten well nuts.

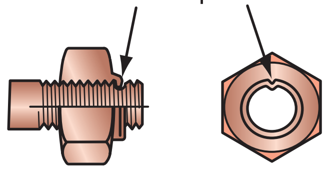

Figure 4-18 Stake-type lock nuts are usually used inside engines. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

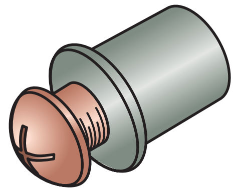

Figure 4-19 Well nuts are used mainly on plastic parts like windshields. They expand when tightened. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Acorn (Cap) Nuts

An acorn nut or cap nut (Figure 4-20) is a decorative nut with a finished or plated surface and is used often to cover the threaded end of a bolt or stud. Many are made of stainless steel to prevent corrosion or chipping. Bolts (or studs) must be of proper length or else the nut may bottom on the stud before the clamping action can occur. Applications include head nuts and engine covers.

Washers

There are several types of washers common to the power equipment engine industry.

Flat Washers

A **plain flat washer** is used under bolt heads and nuts. Use of correct-sized washers is necessary to achieve correct loads on bolts. A washer increases the clamping surface under the fastener and prevents the bolt or nut from digging into the part. The latter advantage is especially useful when the material to be clamped is soft, such as aluminum, magnesium, or other metals softer than steel.

Figure 4-20 Acorn or cap nuts are used to cover threaded ends of bolts or studs. Install them correctly or else the nut will bottom out and not tighten properly.

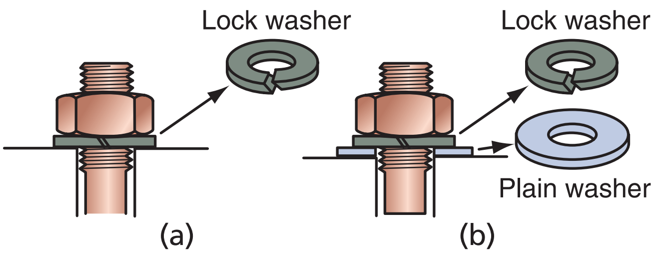

Figure 4-21 (a) A typical split-ring-type lock washer. (b) The correct installation of a plain (or flat) and lock washer. (Parts [a] and [b]: Copyright by American Honda Motor Co., Inc. and reprinted with permission.)

Split-Ring-Type Lock Washers

A split-ring-type lock washer (Figure 4-21a) is compressed under the pressure exerted by the surface of the nut. The elasticity of the spring and the edges of the ring ends prevent loosening. Applications that include various points on frame- and bolt-incorporating washers are also used. When using with a plain (flat washer) washer, always put the lock washer between the nut and plain washer (Figure 4-21b).

Cone-Type Lock Washers

The cone-type lock washer (Figure 4-22) is a dished washer made from spring steel. When installed, the center of the washer sits up from the surface. The bearing surface (of the nut) presses on the cone spring washer and the spring reaction presses against the nut to prevent it from loosening. Applications include the clutch lock nut and primary gear lock nut as well as the drive sprocket center bolt.

Tongued Lock Plate Washers

The tongued lock plate (Figure 4-23) serves the purpose of a washer and a locking device. Simply bend the tongue (claw) to the flat face of the nut or into the groove of the nut to lock the nut or bolt head. Applications include clutch locking nuts, some flywheel and starter nuts, and important safety points on the chassis. Replace the lock plate washer with a new one whenever the lock plate is removed.

Thread-Locking Agents and Sealers

Under some conditions, special chemical compounds called thread-locking agents may be needed to help threaded fasteners do their

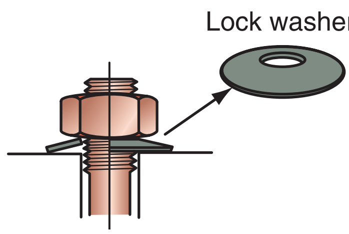

Figure 4-22 Cone-type washers must be installed correctly to function properly. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

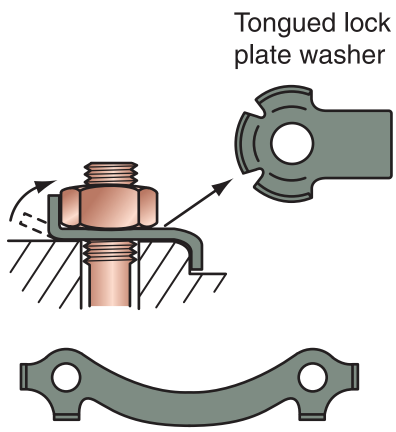

Figure 4-23 Tongued lock plate washers can be seen often to hold rotating components such as sprockets. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

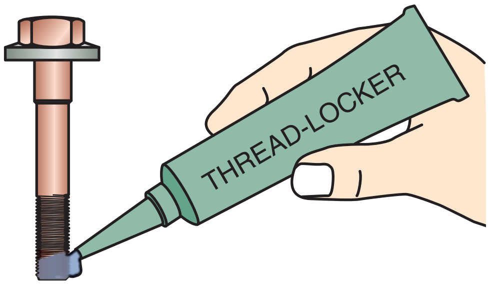

Figure 4-24 Thread-locking agents are often used on power equipment engines to help prevent loosening of fasteners. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

job. Thread-locking agents (Figure 4-24) can be used where vibration would cause the fastener to loosen. These compounds are anaerobic adhesives that set up in the absence of air. These products come in several grades, depending on the desired strength, with the most popular being high-strength red and medium-strength blue. Applications include frame components, fork socket bolts, brake disc bolts, and fasteners inside the engine such as the stator coil bolts, bearing retainer bolts, and shift drum stopper plate bolt.

Consider the following when using thread-locking agents:

- Application of a locking agent increases loosening torque. Take care not to damage the bolt during removal. However, sometimes heat (using a heat gun) is needed to soften the material when higher-strength compounds are used.
- Before applying the locking agent, clean off all oil and/or residual adhesive remaining on the threads and dry them completely.
- Applying a small amount of adhesive to the end of the bolt threads distributes the adhesive as it's threaded in.
- Excessive adhesive may, during loosening, damage the thread or cause the bolt to be broken.
- Locking agents may cause plastic parts to crack.
- Some bolts have a locking agent already installed. Never reuse this type of fastener as they're designed to be used only once.

Along with thread-locking agents, thread sealants are used for the same purpose, in locations where the threads of a bolt or another fastener protrude into an area where liquids such a coolant or oil could cause corrosion or leak past the threaded area.

INSPECTION AND CLEANING OF THREADED FASTENERS

Before any reassembly process, threaded fasteners must be inspected, cleaned, and sometimes repaired to be made ready for normal functioning. It's critical to review the service manual specific for the power equipment engine to determine if specific bolts, nuts, or washers can be reused or must be replaced. Failure to replace specific fasteners such as crankshaft-connecting rod bolts/nuts or cylinder head bolts or nuts, as recommended by the manufacturer, could cause future fastener failure that would be expensive as related components also would certainly be damaged.

Upon inspection of a bolt before use, what is referred to as a stretched bolt may be identified. If a bolt had been overtightened, it would have stretched (Figure 4-25). A **stretched bolt** can be identified when a nut threads down the bolt easily but binds when it reaches the stretched area. At that point, it becomes hard to turn. A stretched bolt must be discarded.

Always clean fasteners thoroughly. Installing fasteners with dirt or other foreign matter

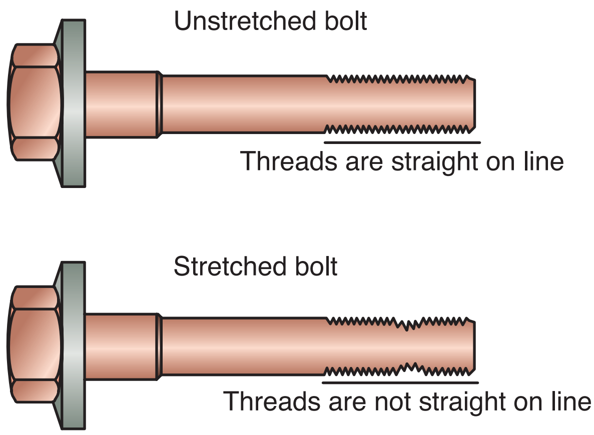

Figure 4-25 A stretched bolt (bottom) compared with an unstretched bolt (top). Copyright by American Honda Motor Co., Inc. and reprinted with permission.

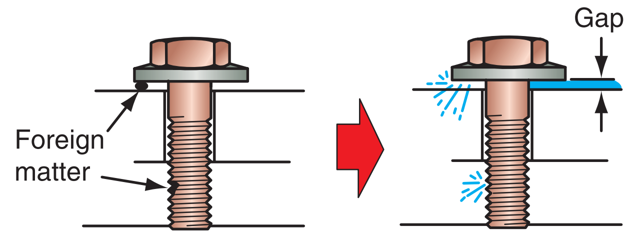

Figure 4-26 If debris is in or around a fastener, the latter will not function properly.

Figure 4-27 Cleaning a bolt using a wire wheel. Use proper safety apparel when using a wire wheel. Can you tell what safety apparel is missing in this picture?

on the threads or on the bolt- or nut-bearing surfaces will result in improper tension even if the required level of torque is applied (Figure 4-26). As the dirt of foreign matter breaks down because of vibration and the attached parts working against each other, the fastener will soon work its way loose.

Solvent cleaning can remove surface grime such as oil and grease. It's necessary sometimes to use a powered wire wheel (Figure 4-27) to remove rust and other materials from the head and threads of the fastener. Wear gloves and eye protection when using a powered wire wheel. Use of a thread die to chase (clean) the threads will insure that the thread is both clean and free of nicks that could cause excessive friction when installed.

Threaded holes in various components must be chased (cleaned) using a thread tap (Figure 4-28) to ensure that the internal threads are clean and

Figure 4-28 A technician chasing threads with a tap.

free of contamination. If damaged threads are found, the threads may be repaired by replacement. Thread replacement will be covered in detail later in this chapter.

STRESSES ON THREADED FASTENERS

Preload, as we had discussed earlier in this chapter, is the tension caused by tightening the fastener that holds the parts together. The forces acting on a threaded fastener are axial tension, torsion, and shear (see Figure 4-29). The clamping force is the reaction provided by the bolt on the part mated to it.

- **Axial tension.** The stretching force that is exerted on a bolt when it's tightened into a case or when a nut is tightened onto it. Axial tension is the most important force involved in the tightening of a fastener.
- **Torsion.** The twisting force that is exerted on the head of a bolt when it's tightened.
- **Shear.** The force that is exerted at an angle of 90° to the center line of a bolt.
- **Clamping force.** The force exerted by the bolt holding two parts together.

When a fastener is tightened, an **axial tension** is applied on it. This stress stretches the fastener and reduces its diameter slightly. As we further

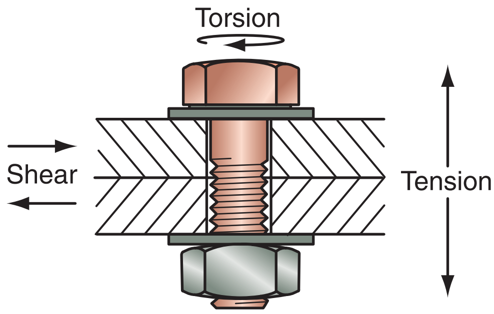

Figure 4-29 The forces acting on a threaded fastener. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

tighten the fastener, we reach what is referred to as a **yield point** (Figure 4-30). Continuing to tighten the fastener moves it into the **plastic range**, in which the fastener stretches permanently, that is, the fastener will not return to its original diameter when the axial tension is removed. If we continue to tighten the fastener beyond its yield point, the fastener reaches its ultimate tensile strength and shortly thereafter breaks.

Preload

For any fastener to work properly, it must be stretched sufficiently to produce a static preload (clamping force) that is greater than the expected external loads. This is what the torque applied to the fastener does. When in their **elastic range**, bolts and screws stretch like a spring and then return to their original length when tightened. It's critical that the fastener be tightened the right amount. Too little and they will loosen, too much and they may break or damage threads.

Fasteners tightened into their plastic range will remain permanently stretched and should be replaced. Fortunately, engineers have taken care of these design characteristics. All we need to do is prepare the fasteners correctly and tighten them to the torque specified in the service manual. Preparing fasteners includes inspecting, cleaning, and making sure they're dry.

There are some variables that can affect tightening torque. Tightening torque can decrease over time, from external forces or vibration.

Tightening forces are specified on the basis of fastener strength, strength of fastened parts, and intensity of external forces involved. Tightening must be carried out in accordance with service manual specifications, especially for critical fasteners. For example, tightening a connecting-rod-bearing cap with a torque higher than specified will reduce the oil clearance for the bearing to a value less than specified, which may lead to premature bearing seizure. A low torque,

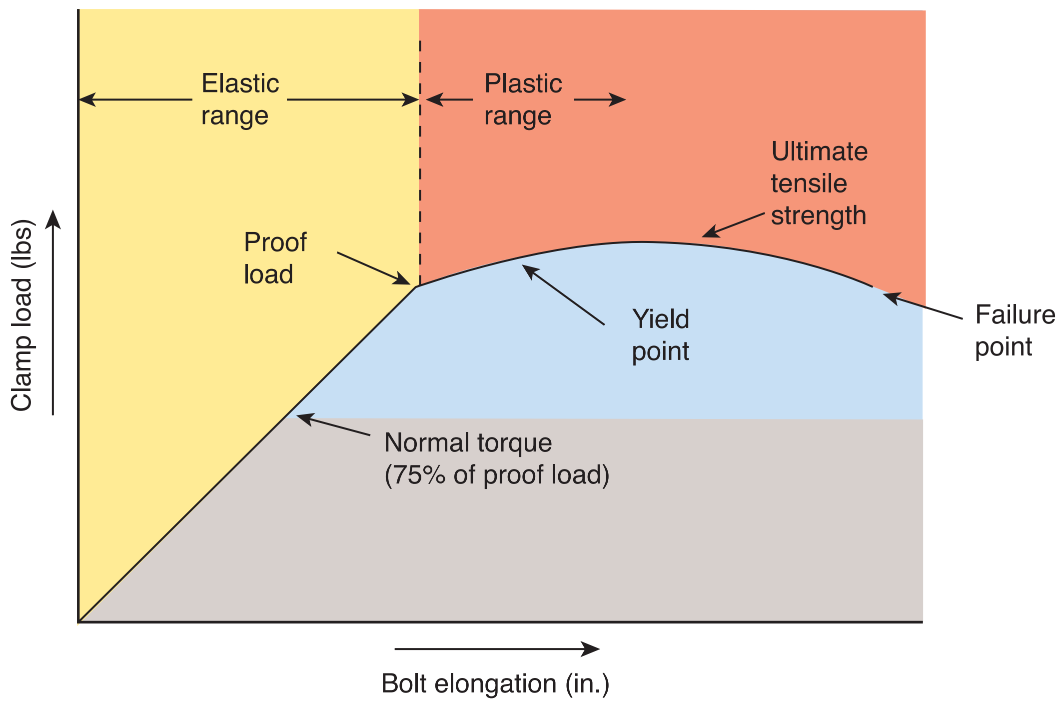

Figure 4-30 Different levels of torque that can be exerted on a fastener.

on the other hand, may loosen the nuts or bearing caps, which may then fall off during engine operation, leading to serious engine damage.

TIPS FOR WORKING WITH THREADED FASTENERS

Here are a few tips when working with threaded fasteners:

- Always clean bolts, screws, and threads in engine cases and blow them dry. Dirt or foreign matter under the head or on the threads will prevent a proper torque from being applied, leading to loosening.
- Don't lubricate fasteners unless specified in the service manual.
- Bolt or screw lengths can vary for engine covers and cases (Figure 4-31). These different lengths must be installed at correct locations. If you're not sure, place the bolts in their holes and compare the exposed lengths. Each should be exposed the same amount. A bolt that is too long will bottom out and break or strip threads. A bolt that is too short will pull the threads out of the case. The exposed length of bolts should be at least 1.5 times their diameter.

To prevent warping important components and ensure proper gasket sealing, torque to multiple-sized fasteners should be applied keeping in mind the following points:

- During disassembly, always loosen the small fasteners first.
- Tighten all fasteners to hand-tight.

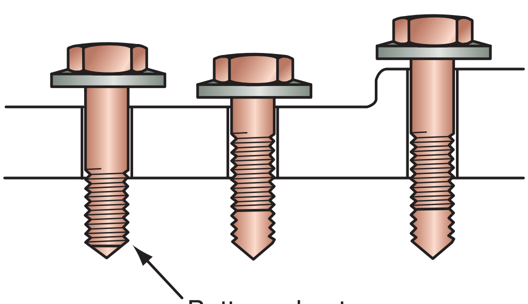

Figure 4-31 Use the right bolt lengths when reassembling any component. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

- Torque larger fasteners before smaller fasteners.
- Torque the bolts in sequence to half the specified torque and then repeat the sequence to the full specified torque to prevent component damage.
- If no sequence is given, torque in a crisscross pattern from inner to outer.

TIGHTENING AND TORQUE

As mentioned, the most important point in fastener tightening is the axial tension or tightening force. The problem is that this tightening force is difficult to measure. Using a predetermined tightening torque is, therefore, the most common method of controlling fastener tension. The axial tension is proportional to the torque applied in certain conditions, the most common of which being clean, dry threads.

Friction in the threads uses up 40% of the applied torque. The friction between the bolt head and mating surface uses 50% of the torque. That leaves 10% to tighten the bolt. Dry surfaces have the highest friction, whereas oiled threads have the lowest (Figure 4-32). When a lubricant

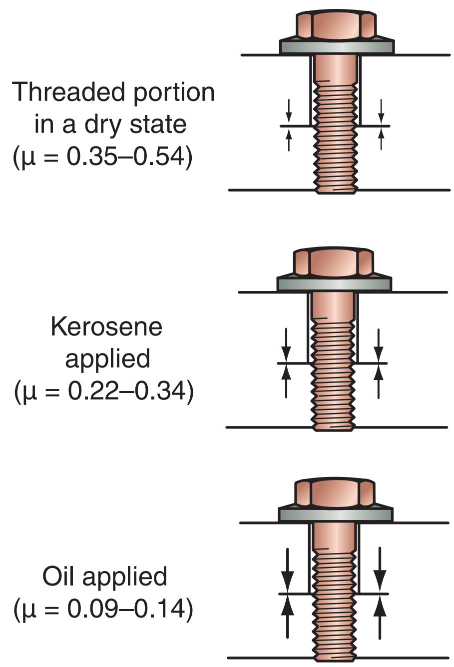

Figure 4-32 Dry surfaces have the highest levels of friction, as shown here. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

is applied to fasteners, friction is decreased. μ indicates the coefficient of friction: the lower this number, less the friction.

If the threads are lubricated, more of the torque applied contributes to the axial tension. This means the parts are held together with a greater force and the fastener is stressed more. Figure 4-33 gives examples of how much the friction is reduced when kerosene or oil is applied to the threads. With the same tightening torque, axial tension increases greatly with use of a lubricant. This graph can be compared to the images in Figure 4-32.

Some manufacturers specify that oil be applied to the threads and the underside of the head of certain fasteners. Such parts must be oiled before tightening. If they're assembled and tightened dry, the requisite preload (clamping force) will not be applied, which could cause the bolt to loosen or a joint to leak. Also of great importance: Don't over-oil: excessive oil could cause damage to a part.

All other threaded fasteners must be assembled and tightened dry, because lubrication of these bolts may cause them to break.

Torque

Torque values are determined according to fastener size and strength, and the strength of the parts that are fastened together. In earlier service manuals, a range of torque values was specified. In current service manuals, a single value is given for the torque to be applied. This is equivalent to the midpoint of the range in earlier manuals. Service manuals specify torque in newton-meters, kilogram-meters, and foot-pounds.

As seen in Figure 4-34, torque is simply a force applied to a lever of a specific length. One kilogram attached to the end of a 1-meter arm gives 1 kilogram meter (kg-m) of torque. A weight of 5 kg applied to an arm 1/5 of a meter gives the same torque.

$$\text{Torque} = \text{Force} \times \text{Length}$$

Torque Wrenches

As mentioned in Chapter 3, there are two common types of torque wrenches used by technicians to tighten fasteners to specifications. Both will be discussed in more detail here. We will discuss an additional type of torque wrench, the dial torque wrench, though it's not used as often.

Beam-Type Torque Wrench

The beam-type torque wrench (Figure 4-35) is the least expensive of the three types mentioned here and works by beam bending in response to the torque applied. It's simple, reliable, and

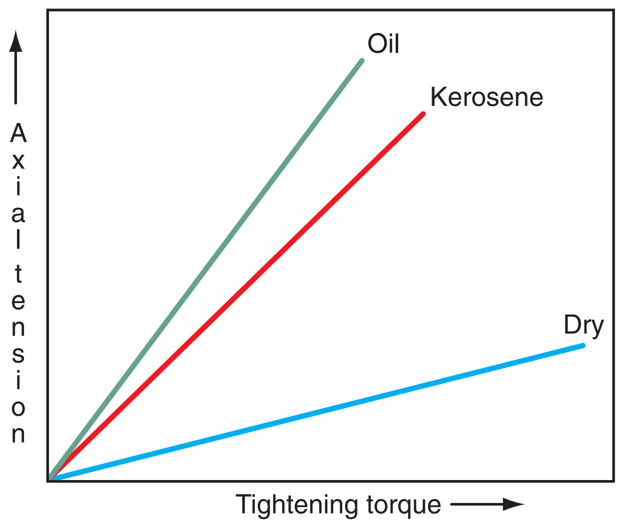

Figure 4-33 Different levels of friction when assembly is carried out dry (without lubrication), and when using kerosene and oil. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

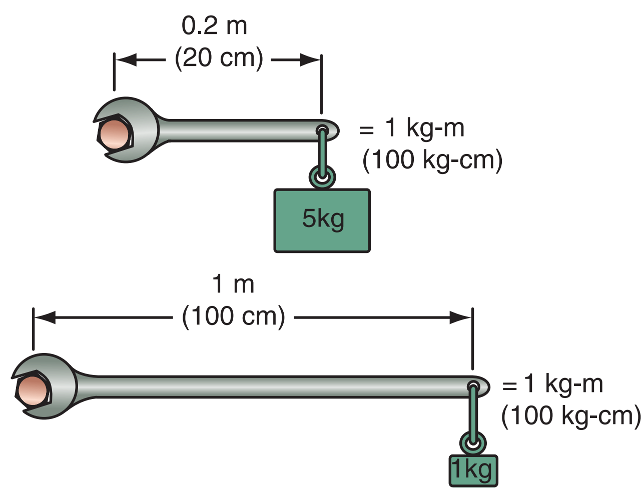

Figure 4-34 Torque applied varies with the point of application of torque. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

accurate. When tightening a bolt, apply force at the center of the handle. This allows the beam to bend in the manner designed to indicate the correct torque.

- Don't over-torque the wrench or the beam may bend permanently.
- Rough handling can bend the pointer arm. However, if bent, it can be bent back to the center without loosing accuracy.
- If the beam is bent, it can't be bent back.

Click-Type Torque Wrench

The click-type torque wrench (Figure 4-35) is popular with technicians because of its ease of use and easy-to-store profile. It works by preloading a "snap" mechanism with a spring that releases at the specified torque. When the mechanism releases, the ratchet head makes a "click" noise. The torque is set by rotating the micrometer-style handle to the appropriate torque setting. To use, pull on the handle until you feel the handle flex or hear the click.

- You'll find the click-type torque wrench easy to use in a confined space because of its ratchet head.
- Don't use this torque wrench to loosen tight fasteners as it may damage the calibration mechanism.
- When finished, always return the wrench to its lowest setting before putting it away. This will prevent the internal spring from taking a set.
- The actual click from a torque wrench is considered a "cycle" of that wrench. Most manufacturers recommend basic calibration after 8,000–12,000 cycles.

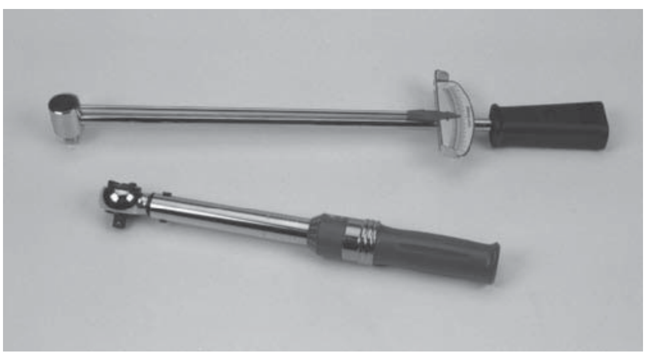

Figure 4-35 A beam-type torque wrench (top) and a click-type torque wrench (bottom).

Figure 4-36 Dial-type torque wrenches are not used often on power equipment engines.

Dial Torque Wrench

The dial torque wrench (Figure 4-36) isn't as popular as the previous two types mentioned but it's easy to operate. The bezel face can be rotated to "zero" to calibrate the wrench before use. The pointer moves up the scale as the fastener is tightened. Some technicians turn the bezel face to the torque setting and then pull the wrench back to zero to obtain the proper torque.

- Ensure "zero" before using the tool.
- The glass/plastic bezel cover can break or be scratched; use care when storing the tool.
- Calibration should be checked every 12–18 months.

Hints for Using Torque Wrenches

To ensure exact accuracy and reliability when using a torque wrench, keep in mind the following points:

- Even the most expensive torque wrenches lose accuracy. It's a good idea to have your torque wrench calibrated periodically.
- Always work on clean threads.
- For an accurate torque wrench reading, the final turn of the nut must be tightened with the torque wrench.
- Use your torque wrench for tightening only.
- Always loosen or remove bolts, nuts, or studs with a standard wrench (not the torque wrench).
- If using a dial-type torque wrench, ensure that the dial and pointer are set correctly before applying torque.

- Wear proper safety gear when using a torque wrench.
- Release the tension on click-type torque wrenches after working with them to keep them calibrated properly.

REPAIRING AND REPLACING BROKEN FASTENERS

Sooner of later, every technician would be required to remove a broken bolt or repair a damaged thread. It may take just a few minutes to repair or it may take hours. It may cost a few cents for a new bolt or screw or hundreds of dollars to repair or replace the component made unusable by a repair job gone bad.

A bolt that has broken off above the surface (Figure 4-37a) may be removable with vise grip pliers (Figure 4-37b). The following tips will assist you in removing a broken fastener using vise grip pliers:

- Tap the top of the broken fastener with a ball peen hammer a few times to loosen or break the grip between the threads.
- Applying a penetrating oil to loosen any rust or corrosion may help.
- Another technician trick is to heat the surface (with a heat gun or propane torch) to expand the metal and loosen the grip on the broken bolt.

A fastener broken flush with the surface may require the use of screw extractors. Some technicians may try using a sharp punch or chisel to tap the broken fastener counterclockwise to turn it out of the threaded material (Figure 4-38). This sometimes works but at times other methods are necessary. Also, using "left hand drills" to drill into the broken fastener may actually remove the bolt as you drill the larger hole. The drill motor must turn counterclockwise to work properly when using left-handed drill bits; therefore a reversible drill will be needed in these situations.

Screw Extractors

There are two common types of screw extractors. The easy out screw extractor has large, widely spaced, sharp edges and tapers to a rounded tip. The fluted extractor has multiple, sharp-edged groves along its length and does not have any taper.

Both types of extractors are usually packaged as kits to be used on different sizes of broken bolts, screws, or studs. To remove a broken fastener using an easy out:

- Use a center punch to mark the center of the fastener.
- Drill a pilot hole all the way through the bottom of the fastener using the smallest drill bit.

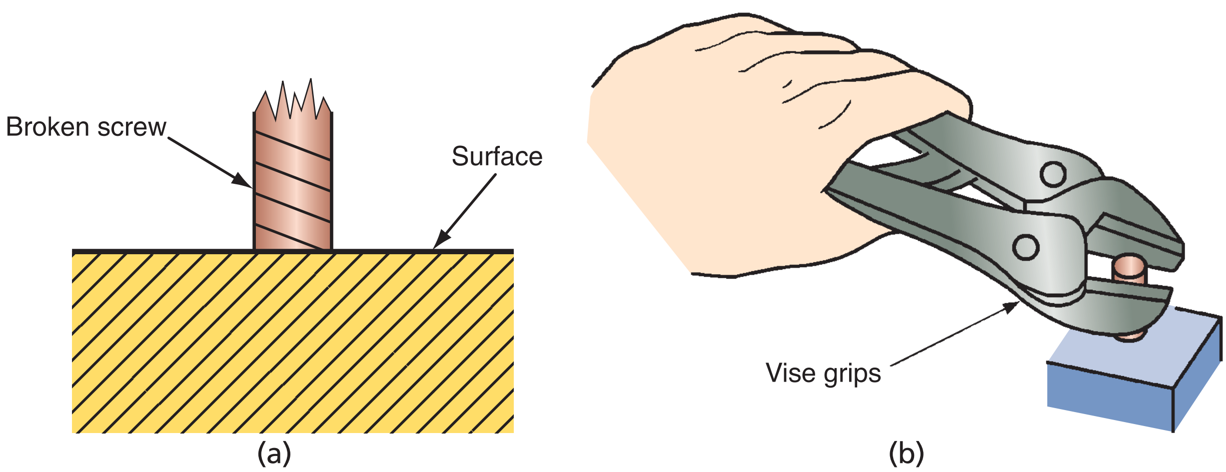

Figure 4-37 (a) In most cases, a bolt that has broken off above the surface can be removed more easily than one that has been broken off flush. (b) Using a vise grip wrench can be used to remove fasteners that have broken off above the surface.

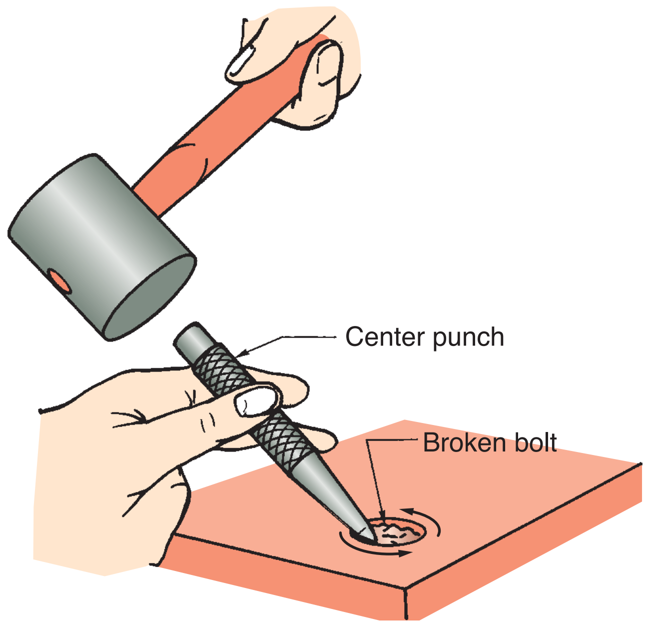

Figure 4-38 Try to remove a broken fastener off flush first by using a sharp punch or chisel and a hammer.

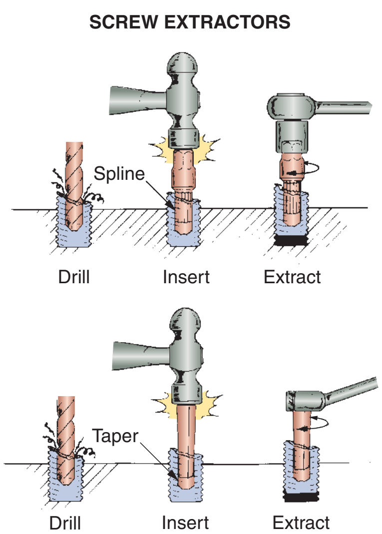

Figure 4-39 The two most common extractors.

Then, drill the hole out using a drill of recommended size for the tool being used.

- Insert the easy out by tapping it into place with a hammer, attach the handle, and turn counterclockwise to remove the damaged fastener (Figures 4-39 and 4-40).

The fluted extractor set includes several sizes of fluted extractors, the correct-sized drill bits, splined hex nuts, and drill guides. To remove a

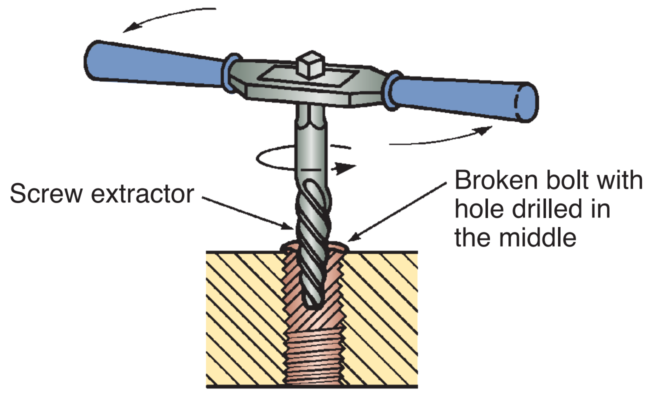

Figure 4-40 An easy out screw extractor in use.

broken fastener using a fluted extractor, use the same methods as mentioned for the easy out.

Extractors are hardened, which makes them difficult to remove if they break. A broken extractor can't be drilled with a common drill. Therefore, too much force must not be applied when removing a damaged fastener. If a drill, tap, or easy out does break off (somewhere it's not supposed to be), there are other methods of removal. A process known as EDM (electro discharge machining) can remove the broken piece(s). The process is quite expensive and requires the complete disassembly of item to be repaired. The process is like welding, only in reverse. The results are good but finding a shop in your area that can use this system of fastener removal may be a little tricky.

Drilling and Re-Tapping

Occasionally, after a broken fastener has been removed from a hole with damaged threads, a hole of slightly smaller diameter than the original is drilled. The hole is then carefully tapped back to the original diameter. This method sometimes works and may be well worth the effort.

Thread Inserts

When a screw thread is damaged or stripped, a thread insert may be necessary to restore the original thread size. A variety of thread inserts are available. They all involve drilling and tapping a slightly larger hole. The insert is then threaded and locked into place.

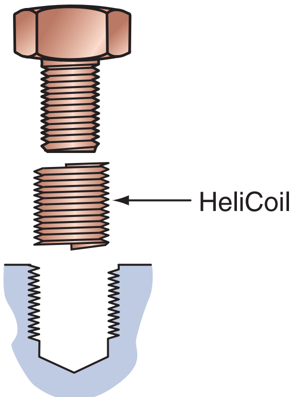

Figure 4-41 HeliCoils are used often when thread repair is required.

HeliCoil

The HeliCoil is an oversized spring coil made of stainless steel (Figure 4-41). HeliCoil kits are available for standard and metric thread sizes. When installed, the inside thread of the HeliCoil restores the original thread size and pitch and provides a repair that is just as strong and sometimes even stronger than the original thread.

To install a HeliCoil:

- Use the kit drill to drill an oversized hole.
- Tap the hole using the tap included with the kit.
- Install the insert using the special tool provided with the kit. The insert is installed slightly lower than the surface. A drive tang at the bottom of the HeliCoil locks to the tool during installation. The tang is notched for easy removal once the insert is installed.
- Break the driving tang off the bottom of the HeliCoil with a hammer and punch. Remove the tang before installing the bolt.

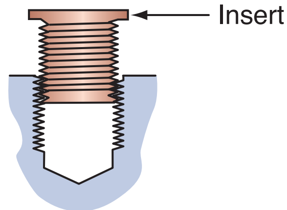

Figure 4-42 Solid-threaded inserts are widely used when repairing threads in a component.

Solid-Threaded Inserts

In applications that require high strength, such as repairing stripped head bolt/stud holes, solid-threaded inserts are used. The insert shown in Figure 4-42 has bottom external threads that are cold rolled. The installation tool locks the insert into place by forcing the bottom threads to expand the mating external threads into the threads cut into mating material (e.g., engines and transmission systems).

Summary

- Power equipment engines are held together by hundreds of threaded fasteners.
- There are two common systems used to classify the measurement systems used on power equipment engines: the conventional system and the metric system.
- Bolts and nuts come in various sizes, grades (strength), and thread types. The four most important bolt dimensions are bolt diameter, bolt head size, bolt length, and the thread pitch.
- Quality standards for fasteners are established by the ANSI and the ISO.
- A variety of washers serve to achieve the correct load on a bolt and to prevent loosening of threaded fasteners.
- Proper tightening of fasteners using a torque wrench is a critical skill required to reassemble components on a power equipment engine.
- Torque wrenches used to tighten threaded fasteners vary in accuracy, and for best results, they should be calibrated regularly.
- Broken bolts or studs can be difficult to remove or replace. Proper methods must be used to remove broken fasteners.
- Thread inserts are used to restore threads in engine or transmission cases and even to replace spark plug threads.

Chapter 4 Review Questions

Fill in the blanks in each of the following statements.

1. Power equipment engines use two common measurement systems, the _____ and the _____.
2. _____ is the technical term for the tension caused by tightening the fastener that holds the parts together.
3. The four most critical bolt dimensions are: bolt diameter, bolt head size, bolt length, and _____.
4. The three most common types of threads used on fasteners are _____, _____, and _____.
5. The _____ of a bolt is determined by the number of threads per inch when using the _____ of measurement.
6. A _____ has internal threads and usually a six-sided outer shape.
7. The two common tools used to torque fasteners are the _____ and _____ torque wrenches.
8. During disassembly, always loosen the _____ first.
9. When a screw thread is damaged or stripped, it may be necessary to use a _____ to restore the original thread size.
10. Don't lubricate fasteners unless specified to do so in the _____.

CHAPTER

5 Basic Engine Operation and Configurations

Learning Objectives

- Learn about reciprocating engines
- Understand the basic differences between a two-stroke engine and a four-stroke engine
- Understand how engines are rated
- Distinguish the primary components found in a two-stroke engine and a four-stroke engine
- Learn about the different cooling systems used in power equipment engines
- Understand the different engine configurations found in power equipment engines

Key Terms

Bore
Bottom-dead center (BDC)
Brake horsepower (bhp)
Combustion chamber
Combustion chamber volume (CCV)
Compression ratio
Connecting rod
Counter-balancer
Crankcase
Crankshaft
Cylinder
Cylinder block
Cylinder volume
Dynamometer
Electric start
Engine displacement
Forced draft
Four-stroke engine
Horsepower
Mechanical work
Piston
Piston stroke
Ports
Power
Reciprocating engine
Recoil starter
Revolutions per minute (rpm)
Stroke
Top-dead center (TDC)
Two-stroke engine
Valve
Water jacket

BASIC ENGINE OPERATION

In this chapter, we'll look at the different power equipment engine designs and configurations. We'll start with a simple overview of how engines work in general and then move to a basic overview of the different types of engines found in power equipment engines. Virtually all power equipment engines have either a four-stroke engine or a two-stroke engine. Each type of engine has advantages and disadvantages. We'll cover these in more detail in subsequent chapters.

For now, just keep in mind the primary difference between these two engine designs:

- The **four-stroke engine** has a power stroke every two turns (720° of rotation) of the crankshaft, which is every *four* piston *strokes*.
- The **two-stroke engine** has a power stroke every full turn (360° of rotation) of the crankshaft, which is every *two* piston *strokes*.

Reciprocating Engines

Power equipment engines use **reciprocating engines**. A reciprocating engine has a piston that moves alternately *up* and *down* inside a cylinder. All reciprocating engines—from tiny model airplane engines to large truck engines—have a number of common components.

Figure 5-1 shows a cylinder with a piston positioned inside it. A **cylinder** is a circular tube that's closed at one end. The closed end of the cylinder is sealed by a cylinder head. The **piston** is a circular plug that moves up and down inside the cylinder. When a piston is at its lowest position in the cylinder, it's said to be at **bottom-dead center** (**BDC**). When the piston is at its highest position in the cylinder, it's said to be at **top-dead center** (**TDC**).

When the piston is at TDC, a small space remains in the cylinder head. This small space above the top of the piston and below the cylinder head is called the **combustion chamber** (Figure 5-2). In the combustion chamber, a mixture of fuel and air is burned to produce power. A mixture of air and fuel is introduced into the combustion chamber through the intake side of the engine. When the air–fuel mixture burns in the combustion chamber, heat is produced, and the internal gases created by the burnt air–fuel mixture expand. This expansion is strong enough to force the piston downward the cylinder. Each movement of the piston either up or down the cylinder is called a **piston stroke**.

The bottom of the piston is connected to the crankshaft via a connecting rod (Figure 5-3). When the piston is forced downward in the cylinder, the piston's motion is transferred to the **connecting rod** and **crankshaft**. The connecting rod and crankshaft convert the up-and-down (reciprocating) motion of the piston into circular

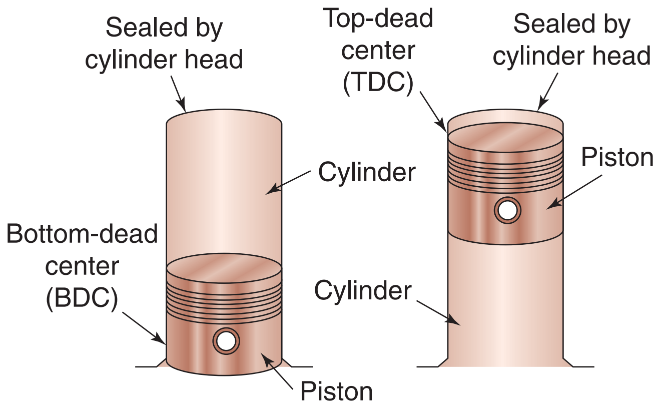

Figure 5-1 A simplified drawing of a cylinder and piston. Note the position of the cylinder at top-dead center (TDC) and bottom-dead center (BDC).

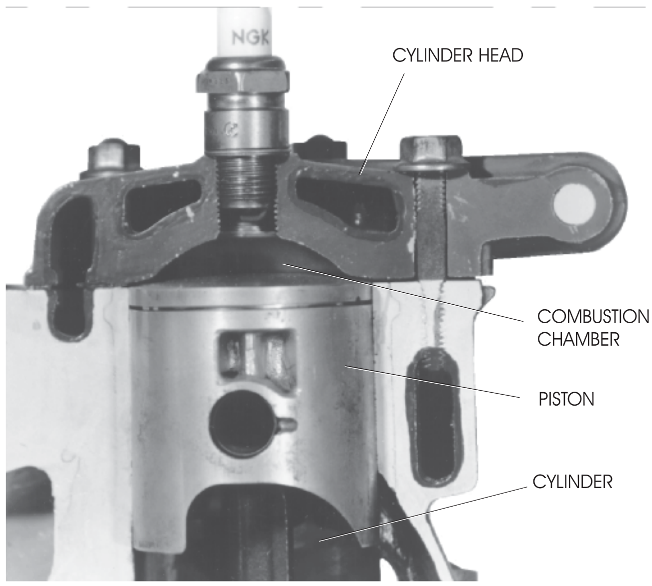

Figure 5-2 The piston, cylinder, and cylinder head. The small space between the top of the piston and cylinder head is called the combustion chamber.

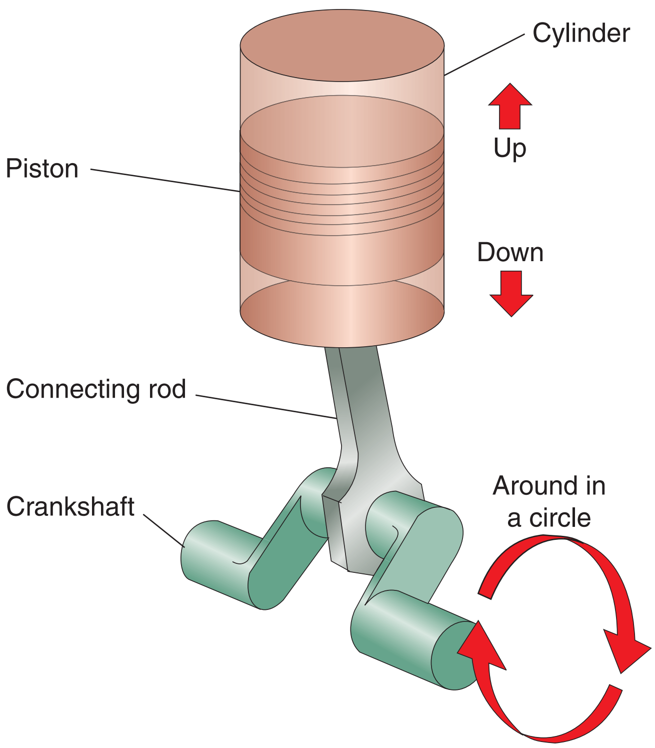

Figure 5-3 The connecting rod connects the piston to the crankshaft. The reciprocating (up-and-down) motion of the piston is changed to rotary (circular) motion at the crankshaft.

(rotary) motion. You can compare this conversion of reciprocating motion into rotary motion to the motion produced when you pedal a bicycle. When you pedal a bicycle, the up-and-down motion of your legs is converted into circular motion that drives the rear wheel.

Four-Stroke Basic Engine Operation

Today, four-stroke engines are found in almost all power equipment engines in the United States. The primary reason for this is that four-stroke engine design is more environmentally friendly than alternative engine designs. This will be discussed in more detail in Chapter 6.

The basic operation of a typical four-stroke engine is divided into four events: intake, compression, power, and exhaust (Figure 5-4). Here is a brief description of each event.

- **Intake.** The piston moves downward and increases the volume of the combustion chamber, which in turn lowers the pressure to a value below atmospheric pressure. This effectively creates a vacuum that draws the air–fuel mixture into the cylinder.
- **Compression.** The piston rises and compresses the air–fuel mixture into the combustion chamber.
- **Power.** The air–fuel mixture is ignited by the ignition system, which creates an expansion of the gases. The expansion pushes the piston back down in the cylinder. The downward motion of the piston is transferred to the connecting rod and crankshaft.
- **Exhaust.** The piston rises and pushes the exhaust gases out of the cylinder.

When a four-stroke engine is operating correctly, it continually runs through these events. A flywheel, which is a component that is weighted, is used to help keep the crankshaft rotating though these events.

Two-Stroke Basic Engine Operation

The two-stroke engine operates somewhat differently from the four-stroke engine. In a four-stroke engine, the four events (intake, compression, power, and exhaust) require four piston strokes. In a two-stroke engine, these events are accomplished in only two piston strokes.

The two-stroke engine has inlet and outlet holes, called ports, located at different heights on the sides of the cylinder (Figure 5-5). As the piston moves up and down in the cylinder, the ports are covered (closed) or uncovered (opened) at different points in time by the piston.

The air–fuel mixture in the two-stroke engine enters below the piston into the area around the crankshaft. The air–fuel mixture typically contains oil, to lubricate the crankshaft and related components of a two-stroke engine. The air–fuel mixture is delivered from the crankcase area to the combustion chamber through a port above the piston called a transfer port. As the air–fuel mixture enters the combustion chamber, exhaust gases are forced out an exhaust port. As the piston rises, all ports are eventually sealed off. The air–fuel mixture is compressed and ignited, producing a power stroke that forces

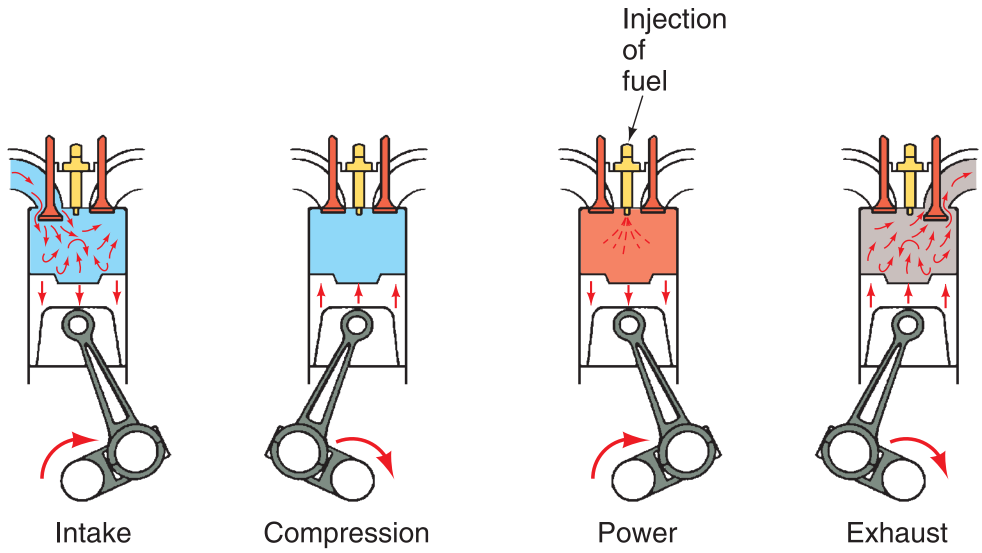

Figure 5-4 The four events of the four-stroke engine in their proper sequence: intake, compression, power, and exhaust.

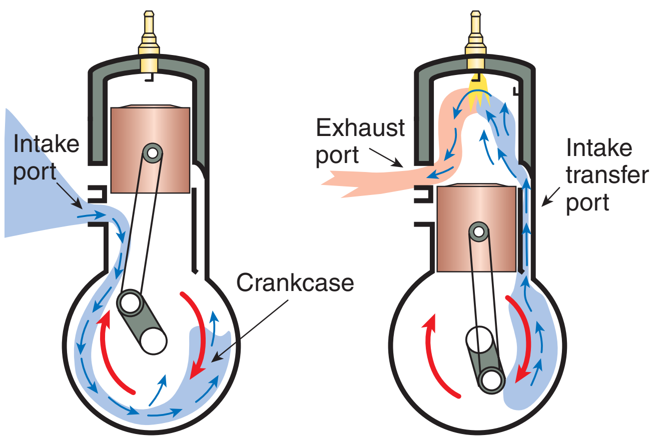

Figure 5-5 The two-stroke engine uses ports to allow the intake and exhaust gases flow through it. The piston opens and closes these ports as it goes by them.

the piston downward and transfers motion to the connecting rod and crankshaft.

ENGINE RATINGS

Now that we know the events of basic engine operation, let's take a look at how power equipment engine manufacturers rate and classify their engines. Power equipment engines are normally classified in one of the following ways:

- By the size of the engine
- By the amount of power the engine produces

Before we discuss how engine power is measured, let's define a few basic terms that we'll be using in this discussion.

Work

We're all familiar with the term *work*. People work in some way or another every day of their lives. However, when we refer to *mechanical work*, we actually measure the amount of work that's done. By definition, **mechanical work** is a force that's applied over a specific distance. We can calculate the amount of work that's being performed by a device (or a person) by multiplying the amount of force being applied by the distance over which it's applied. Therefore, the formula for work is as follows:

Work = Distance × Force ($W = D \times F$)

Using this formula, if the amount of force applied is measured in pounds (lb) and the distance measured in feet (ft), the amount of work performed is measured in units called foot-pounds (ft-lb).

Let's look at a simple example. Suppose you move a box from the floor to a shelf. The box weighs 10 lb, and the shelf is located 5 ft from the floor. When you lifted the box and placed it on the shelf, you performed a certain amount of work. You can calculate the amount of work by using the aforementioned formula. The box weighs 10 lb; so the amount of force you applied was 10 lb. You lifted the box 5 ft off the floor; so the distance is 5 ft. Substitute these values into the formula and solve.

Work = 5 ft × 10 lb = 50 ft-lb

Thus, the amount of work done in this example was 50 ft-lb.

Note, however, that this work formula doesn't mention time. The same amount of work is performed whether you took 10 seconds or 10 minutes to move the box from the floor to the shelf. Therefore, the time required to perform the task is directly related to the strength of the person doing the job. If we don't consider the amount of time it took to perform a task, we will be unable to determine the strength of the person who did the work.

The same idea applies to power equipment engines. We can use the formula to calculate how much work an engine can perform, but without a time factor introduced, we can't determine the true strength of the engine. To calculate the engine's strength, we have to figure out the time the engine takes to complete a job.

The rate at which work is accomplished is called **power**. In other words, power is work done per unit of time. The following formula is used to calculate power:

Power = Work/Time

In this formula, we'll divide the amount of work (ft-lb) by the amount of time in seconds (s). The amount of power in this case will be measured in units called foot-pounds per second (ft-lb/s).

Let's return to our example of the box and the shelf. We calculated that 50 ft-lb of work was required to move the 10-lb box from the floor onto the 5-ft-high shelf. Suppose that you completed this job in 2 s. We can use the power formula to calculate the power involved in doing the job.

Power = 50 ft-lb/2 s = 25 ft-lb/s

So, from our calculations, you can see that you required 25 ft-lb/s of power to complete your task.

Now that we've looked at the basic concepts of work and power, let's see how we apply this information to power equipment engine.

Horsepower

When internal combustion engines were invented, no one knew how to express the amount of work they could do. At that time, around 200 years back, horses provided most of the transportation and power. As a result, a gentleman by the name of James Watt (who we discussed in Chapter 1, remember?) made some observations and concluded that the average horse (of the time) could lift a 550-lb-weight over 1 ft in 1 s, thereby performing work at the rate of 550 ft-lb/s, or 33,000 ft-lb/minute (m). Watt then published those observations, stating that 33,000 ft-lb/m of work was equivalent to the power of one horse, or, 1 **horsepower (hp)**. Thereafter, the term *horsepower* came into existence.

- 1 hp = 550 ft-lb/s
- 1 hp = 33,000 ft-lb/m

Although horses are seldom used to perform work nowadays, we still use the standard unit of horsepower to describe the power output of power equipment engines. So, the next time you're looking at a power equipment engine on an implement in a showroom and it has "8 hp" marked on it, just imagine that power equipment engine being pulled by eight horses. That's pretty impressive!

Today, we rate almost all engines by their horsepower output. Stronger engines produce more horsepower. Now that you understand how to calculate horsepower, let's look at how we measure it.

There are different ways to calculate horsepower. The most common way is to measure the horsepower output of an engine as it runs on a device called a **dynamometer** (also called **dyno**). A dynamometer is an instrument designed to measure power.

During a typical dyno test (Figure 5-6), the technician places the power equipment engine on the dyno and runs the engine at full throttle. The dyno places a load (resistance) on the

Figure 5-6 A dynamometer (or a dyno) is used often in the motorcycle industry to measure horsepower and torque.

crankshaft. Usually, the load is either hydraulic or electronic.

As the load increases, its force tries to prevent the engine from turning. Therefore, the engine speed decreases as the load increases. Because the load applied is a known value, the dyno can determine the amount of torque produced by the engine. If we know the torque produced, we can calculate the horsepower of the engine.

Because this type of test involves the slowing or braking of the engine, the type of horsepower measured this way is commonly referred to as the **brake horsepower (bhp)**. The brake horsepower rating is the maximum power output of the engine. You'll usually see the specifications for an engine given in bhp.

In practical use, a power equipment engine is normally operated at a level well below its maximum power output. If the engine is run always at its maximum horsepower, it would have a very short life span.

You can compare an engine that's running at its maximum rated power to a person running at top speed. That person wouldn't be able to keep up that pace for long; neither would an engine running at its maximum horsepower.

Torque

Torque, as mentioned in Chapter 3, is a measure of twisting or rotational force. Remember that an engine's output is in the form of rotational motion. The power output from the crankshaft is used to turn another piece of equipment, such as a lawnmower blade, snowthrower auger, or the wheels of a go-cart. You can compare the torque produced by an engine to the twisting force a person exerts when opening a jar lid. Engine torque is usually measured in foot-pounds and can be measured on a dynamometer.

As you've probably figured out by now, the ideal engine would have a high horsepower and torque rating. Unfortunately, we don't see this combination too often in real life. In a typical power equipment engine, the horsepower and torque that are developed will vary with the speed of the engine (Figure 5-7). This speed is measured in **revolutions per minute (rpm)**, which is a measure of how many complete turns (360°) the crankshaft makes in 1 minute.

In a typical engine, horsepower generally increases as rpm increases. Remember that power is related to the rate (speed) at which work can be done. Therefore, the maximum horsepower develops near the maximum rpm limit of the engine. Torque, on the other hand, is produced somewhat differently. The maximum torque is normally produced at a lower rpm range and then declines as the rpm increases. This means that the maximum torque and the maximum rpm don't usually occur at the same time.

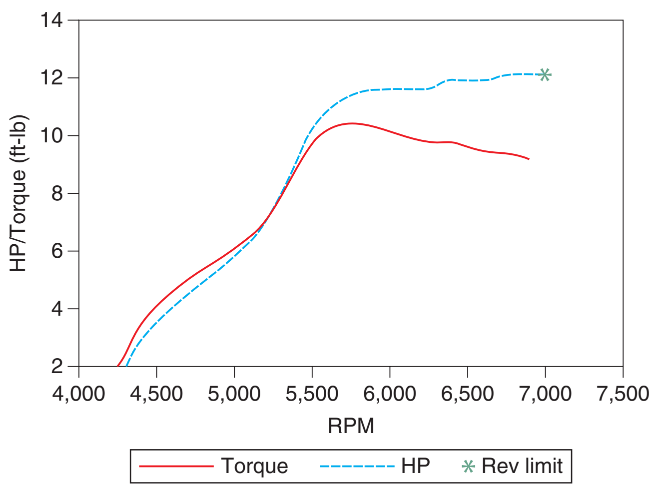

Figure 5-7 A typical dynamometer chart shows horsepower and torque over a wide range of engine revolutions per minute (rpm).

So, when manufacturers design power equipment engines, they must compromise. The design usually depends on the particular application.

More torque usually means better acceleration and more low-end power. Higher horsepower usually means higher top speed capabilities. The amount of horsepower and torque an engine develops depends on many design factors. The displacement, compression ratio, fuel mixture, engine design, ignition timing, and valve timing (in four-stroke engines) all affect horsepower and torque.

Engine Displacement

When you hear people refer to the size of an engine, they don't mean the overall size of the engine but rather the size of the area inside the engine where the air–fuel mixture is burned. The size of this area is known as the engine displacement.

By definition, **engine displacement** is the volume of space through which the piston moves as it moves from BDC to TDC. The distance that the piston travels up or down in a cylinder is called the **stroke** of the engine (Figure 5-8). The inside diameter of the cylinder is called the **bore**. Displacement in power equipment engines is generally measured in cubic centimeters (cc); but it may also be measured in cubic inches (ci). The displacement of an engine is usually stated in the service manual and often stamped on the engine itself.

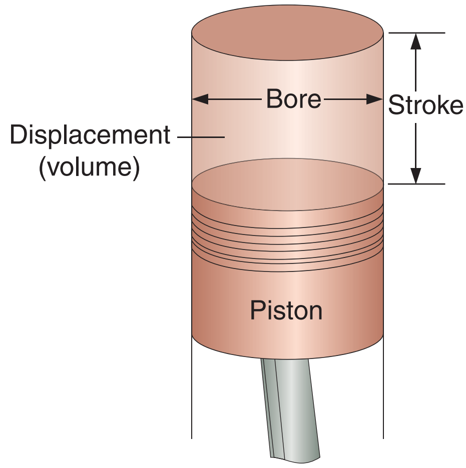

Figure 5-8 The bore and stroke of an engine. This information is used to determine engine displacement.

You can calculate the displacement of an engine if you know the diameter of the cylinder and the length of the stroke of the engine's crankshaft:

$$\text{Displacement} = B^2 \times 0.7854 \times S \times N$$

In this formula, B stands for the diameter (bore) of the cylinder. The number 0.7854 represents a constant, which is a number used in a formula that never changes. S stands for the stroke of the engine and N for the number of cylinders in the engine.

To see how this formula works, let's look at an example. Suppose an engine has one cylinder with a diameter of 73 millimeters (mm). The stroke of the engine is 58 mm. To calculate the displacement, we must first convert millimeters into centimeters (cm). Many power equipment engines are rated in cubic centimeters. Simply moving the decimal point one space to the left does this: 73 mm equals 7.3 cm (remember that 1 cm equals 10 mm). Substitute these values into the formula to determine the size of the engine.

Displacement = 7.3 cm (bore) × 7.3 cm (bore) × 0.7854 × 5.8 cm (stroke) × 1 (number of cylinders) = 242.753 cc

This example is for an 8-hp power equipment engine. Note that the power equipment engine manufacturer will round off the displacement number to indicate the size of the engine. In this case, the engine displacement would be 243 cc.

We can use the same formula to determine the displacement of an engine in cubic inches. For instance, if we have a single cylinder engine with a bore of 2.67 inches and a stroke of 1.96 inches, the displacement equation would look like this:

Displacement = 2.67 in (bore) × 2.67 in (bore) × 0.7854 × 1.96 in (stroke) × 1 (number of cylinders) = 10.974 cubic inches (ci)

This example is for a 6-hp power equipment engine. Note again that the power equipment engine manufacturer will round off the displacement number to describe the size of the engine, which in this case would be 11 ci.

An engine's displacement has an effect on the power that the engine develops. In most cases, the larger the displacement, the more power the engine will develop. However, this doesn't mean that a smaller engine can never develop more horsepower than a larger one. There are many factors besides displacement that affect an engine's power. However, in general, an engine with a larger displacement will develop more horsepower.

Compression Ratio

You have learned that the displacement of an engine is the volume of space through which a piston moves as it travels up and down in a cylinder. When a piston is at BDC, the **cylinder volume** (CV) is at its largest. When the piston is at TDC, the cylinder volume is at its smallest. When the cylinder is at its smallest volume position, it's said to be at its **combustion chamber volume** (**CCV**). The ratio of the largest cylinder volume to the smallest cylinder volume is called the **compression ratio** (Figure 5-9). A ratio is simply a comparison between two values. The compression ratio can be calculated by using the following formula:

Compression ratio = CV/CCV

The volumes at BDC and TDC can be determined by using a combination of mathematical calculations and special test instruments. The typical technician will never be required to measure these volumes, so we won't get into the details of how the volumes are determined. However, you should be aware that the compression ratio of an engine affects the amount of power that the engine develops.

Let's examine the compression ratio in a typical power equipment engine. For example, CV at BDC is 80 cc and CCV is 10 cc. The compression ratio of this engine is therefore 8 to 1. This ratio may be written as 8 to 1 or abbreviated as 8:1.

The compression ratio is important in a power equipment engine because it determines how effectively fuel is burned in the cylinder. As you learned earlier, fuel burns inside the cylinder to produce power.

An engine's compression ratio determines how much the fuel mixture will be compressed when the piston rises. The higher the compression ratio, the more the mixture is compressed. Our example engine had a compression ratio of 8 to 1. This means that when the air–fuel mixture first enters the cylinder, the mixture has a potential volume of 80 cc. When the piston is at TDC, the 80 cc of mixture is compressed into a 10-cc space. When this compression occurs, the pressure of the mixture increases dramatically. This large increase in pressure helps the mixture burn more completely and produce more power when it's ignited. The compression ratio is an important parameter in engine specifications. If an engine's compression ratio is too high, the excessive pressure can damage the engine. If the compression ratio is too low, the engine may not develop much power. Different engines have their own specified compression ratios.

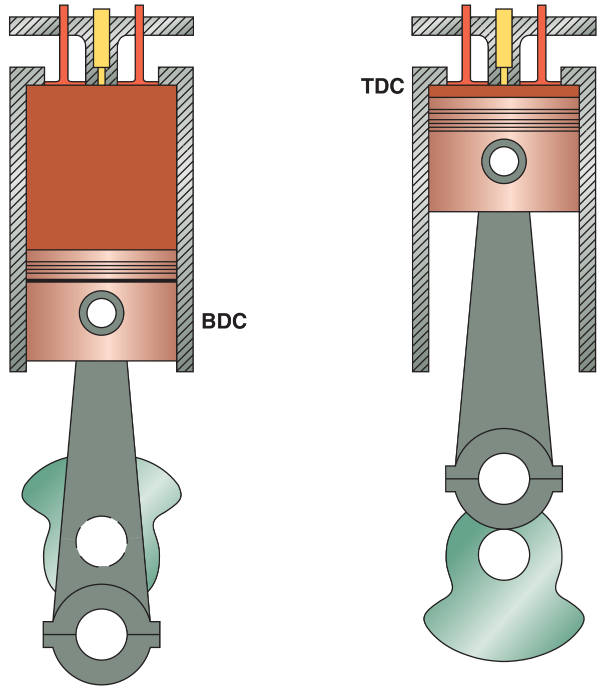

Figure 5-9 The TDC as well as BDC of a piston. Knowing the volume of the cylinder in these positions allows us to determine the compression ratio.

BASIC FOUR-STROKE ENGINE COMPONENTS

Now that we've established the required components of a simple internal combustion engine, let's discuss ways of making it work for us as a suitable power equipment engine power source.

To best explain the basic design of a typical four-stroke engine used in a power equipment engine, we will cover the main components found in a single cylinder four-stroke engine. Most power equipment engines will be found with single cylinder four-stroke engines. The single cylinder four-stroke design is the least complex of all four-stroke engine configurations and can come in a horizontal (Figure 5-10) or vertical (Figure 5-11) crankshaft configuration. This configuration is key to the type of implement that the engine is being attached to. For instance, a lawnmower will use a vertical-type engine, whereas a go-cart would use a horizontal-type design.

Figure 5-10 A single cylinder horizontal four-stroke engine.

Figure 5-11 A single cylinder vertical four-stroke engine mounted on a lawnmower.

Cylinder Block/Crankcase

The engine **cylinder block** (also referred to as a *crankcase* by some manufacturers) is used to hold all engine components together and provide the main engine mounting points (Figure 5-12). The cylinder block material may be iron or aluminum. Sometimes, the cylinder may comprise an aluminum block with an iron-sleeved cylinder. In many power equipment engines, the cylinder block also contains the intake and exhaust valves, which are used to allow air and fuel into the engine as well as expel the gases once combustion has occurred.

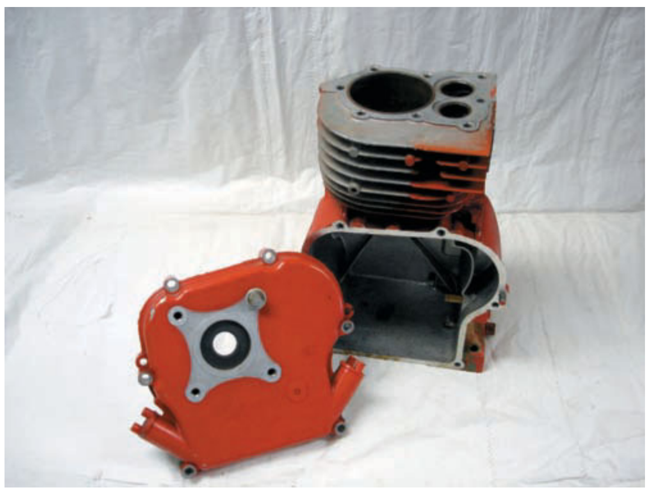

Figure 5-12 Four-stroke power equipment engines use a cylinder block that holds all engine components together and provides for the main engine mounting points. A cover is used to access the components inside the engine.

Crankshaft

Four-stroke crankshafts in almost all power equipment engines are made to a one-piece design (Figure 5-13). They will have connecting rods that attach to the piston. At least one bearing on each end supports the crankshaft and allows it to rotate freely. The crankshaft is located in the engine cylinder block.

Seals

Seals (Figure 5-14) are used to protect rotating shaft bearings. Seals are located typically at the ends of rotating shafts that go outside of the cylinder block. These seals prevent gases and oil from escaping from the cylinder block and also prevent outside substances from getting into the block.

Figure 5-13 A one-piece crankshaft without the connecting rod.

Figure 5-14 Seals used in engines protect the rotating shafts and seal in lubricants and prevent outside contaminants from getting into the engine.

Bearings

Bearings (Figure 5-15) are found primarily in the cylinder block of the four-stroke engine. Bearings are designed to reduce friction and allow shafts to rotate freely under various engine loads.

Gaskets

Gaskets (Figure 5-16) are used to seal the mating surfaces of various parts of the engine. Typically, the two surfaces are metallic. The gasket material may be rubber, cork, paper, or metal.

Piston

The piston is attached to the crankshaft via the connecting rod. The piston is held in place by

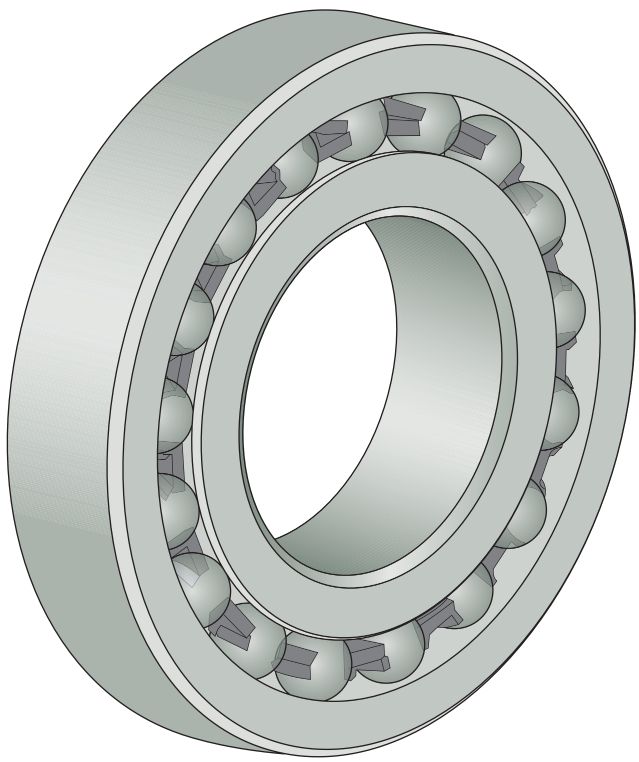

Figure 5-15 A typical ball bearing.

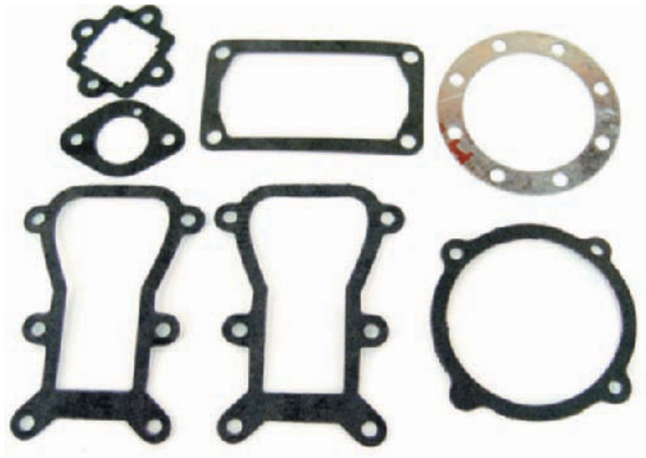

Figure 5-16 Gaskets are used to seal the mating surfaces of various parts of the engine.

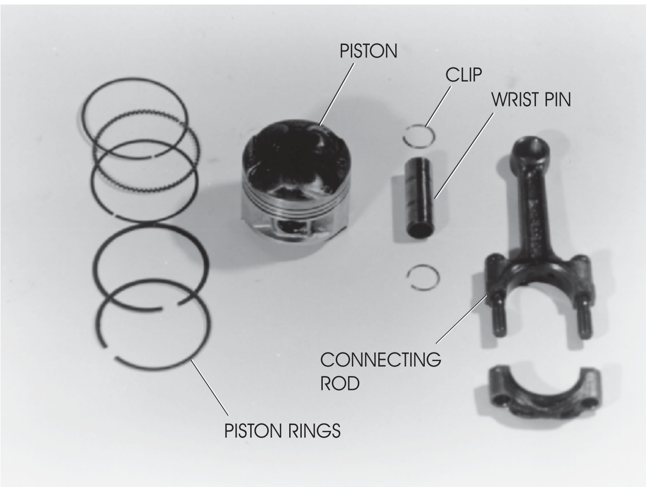

Figure 5-17 A four-stroke engine piston and its related components.

a wrist pin. Clips prevent the pin from moving. The wrist pin usually has a bushing between it and the connecting rod. Piston rings are located in the slots on the outside diameter of the piston to make a seal between the piston and cylinder wall (Figure 5-17). The piston travels up and down in the cylinder, which is usually positioned at a 90° angle from the crankshaft (Figure 5-18).

Figure 5-18 Piston rings are located in the slots on the outside diameter of the piston to make a seal between the piston and cylinder wall. The piston travels up and down in the cylinder, as shown in this cutaway.

Figure 5-19 Heads on engines that have the valve mechanism in the cylinder block have no moving parts. Note the fins that are used to assist in cooling the engine.

Cylinder Head

The cylinder head is attached to the cylinder block to seal the top of the cylinder from the outside of the engine and also forms the combustion chamber. Heads on engines that have the valve mechanism in the cylinder block have no moving parts (Figure 5-19). Engines that contain the valve mechanism located in the head are more complex and contain holes that are called ports (Figure 5-20). These ports are opened and closed with valves.

Figure 5-20 Engines that contain the valve mechanism in the head are more complex and contain holes that are called ports. These ports are opened and closed with valves.

The **valves** (Figure 5-21) in a four-stroke engine control the air–fuel mixture that's drawn into the cylinder and the exhaust gases that are expelled. These valves are actuated by a camshaft (Figure 5-22). Camshafts are normally located in the cylinder block. The camshaft is generally connected to the crankshaft with a timed gear drive and uses lifters and push rods to open and close the valves.

Figure 5-21 The valves in a four-stroke engine control the air–fuel mixture that's drawn into the cylinder and the exhaust gases that are expelled.

Counter-Balancer

Many manufacturers of single cylinder engines use a gear or chain-driven counter-balancer to offset the uneven forces that create vibration and help keep the engine running smoothly. A **counter-balancer** is a device that balances the power pulses created by the power strokes (Figure 5-23). Although using a counter-balancer requires additional parts, it requires very little maintenance.

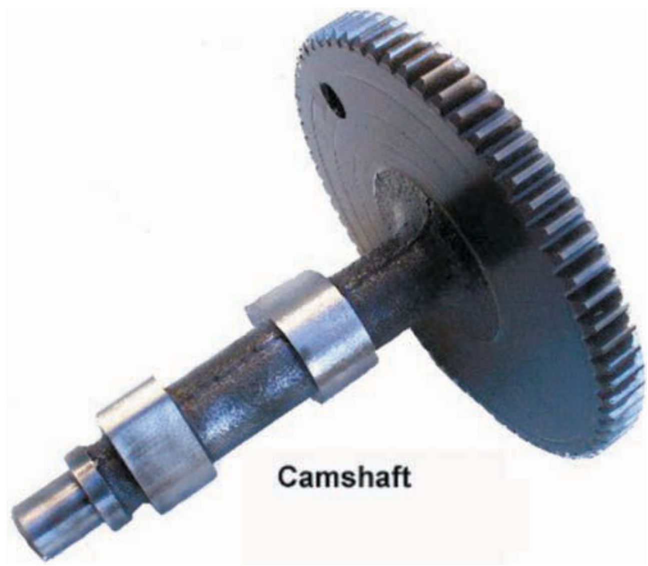

Figure 5-22 A typical camshaft used in a power equipment engine.

Starting Devices

The last part of the bottom end is the starting mechanism. The four-stroke engine uses one of two starting mechanisms.

- The **recoil starter** mechanism uses a pull cord that's attached to a pulley on the crankshaft. The operator pulls the cord to turn the

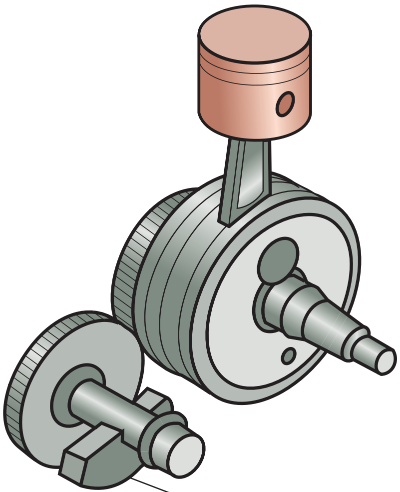

Figure 5-23 Counter-balancers are used to help some four-stroke engines run smoother by subsiding vibration.

crankshaft. The cord has a return spring to rewind it into the housing.

- The **electric start** mechanism is similar to an automobile's starter mechanism. It uses an electric motor with a reduction gear to turn the engine's crankshaft. The operator energizes the starter motor with a push-button or key-lock mechanism.

BASIC TWO-STROKE ENGINE COMPONENTS

Now we'll cover the two-stroke engine's major components and their layout. We'll discuss in detail how these components work in Chapter 6, but for now, let's concentrate on the basics. The two-stroke engine is the least complex engine as far as components are concerned (Figure 5-24).

A two-stroke engine has most of the same components as a four-stroke engine: a crankcase, crankshaft, seals, bearings, gaskets, and a starting mechanism. Only minor differences exist regarding the actual components.

Cylinder Block/Crankcase

Engine **crankcases** are used to hold all engine components together and supply the main engine mounting points. There are often two crankcases: center and side. The center crankcase holds all major components together. The side crankcase enables you to gain access to the various parts of the engine without having to fully disassemble it. Side crankcases are also known as side covers.

Figure 5-24 The single cylinder two-stroke engine is the least complex of all two-stroke designs. Shown here is a chain saw powered by a two-stroke engine.

Crankshaft

The two-stroke crankshaft is made up of two flywheel halves, a connecting rod, a connecting rod pin, and a connecting rod bearing (Figure 5-25). A bearing on each end supports the crankshaft and allows it to rotate.

Seals and Bearings

As in four-stroke engines, seals in two-stroke engines are used to protect rotating shaft bearings. The seals are typically located at the ends of the rotating shafts. These seals prevent the loss of gases and oil from the crankcases. Their sealing action also prevents outside substances and air from getting into the crankcases.

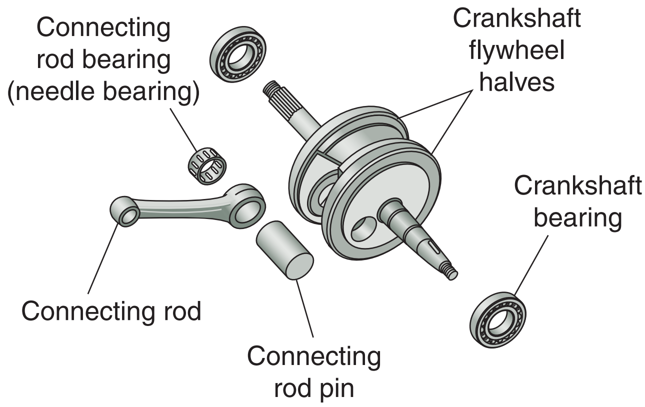

Figure 5-25 The parts of a single cylinder two-stroke engine.

Bearings are found primarily in the crankcase of the two-stroke engine and perform the same function as in the four-stroke engine: reduce friction and allow shafts to rotate freely under various engine loads.

Gaskets

Just as in four-stroke engines, gaskets in two-stroke engines are used to seal the mating surfaces of various parts of the engine. These surfaces are usually both metallic. The gasket material may be rubber, cork, paper, or metal. In some instances, the surface is machined so precisely that no gasket is needed; instead, a thin layer of liquid sealant is used.

Starting Devices

The most common starting device found in two-stroke engines used in power equipment is of the recoil-pull-start variety. The recoil starter consists of a rope, a handle, and a spring device that allows the starter to return after it has been pulled.

Piston

The piston is attached to the crankshaft via a connecting rod (Figure 5-26). The piston is held in place by a wrist pin. Clips prevent the wrist pin from moving laterally. There's usually a bearing where the piston pin attaches to the connecting rod. Each piston has one or more rings around its outside surface. These rings are called piston rings. The rings form a seal between the piston and the cylinder surfaces to improve the compression and exhaust functions. Small pins in the ring lands prevent the rings from moving into the ports of the cylinder.

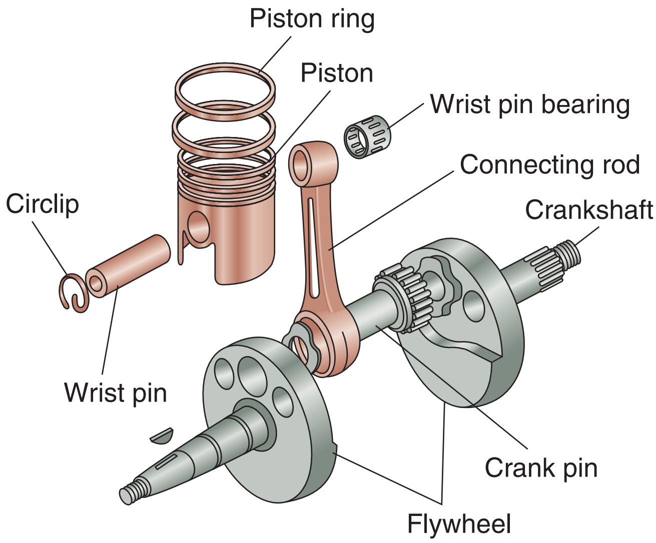

Figure 5-26 The piston and its related parts are attached to the crankshaft via the connecting rod.

Cylinder and Cylinder Head

A two-stroke engine's cylinder is the most complex component in the engine. The two-stroke engine cylinder has holes in it called ports. The **ports** allow fuel mixtures to enter the cylinder and exhaust gases to be removed from the cylinder (Figure 5-27). The cylinder head is attached to the cylinder and seals the top of the cylinder from the outside of the engine. Different types of two-stroke induction systems have their ports located in different areas.

ENGINE COOLING

A significant amount of heat is generated in any internal combustion engine during the combustion stage of the engine's operation. All engines must have a way to dissipate this heat because excessive heat will damage the components. Power equipment engines use one of two ways of maintaining ideal operating temperature—air-cooling and liquid-cooling temperature control.

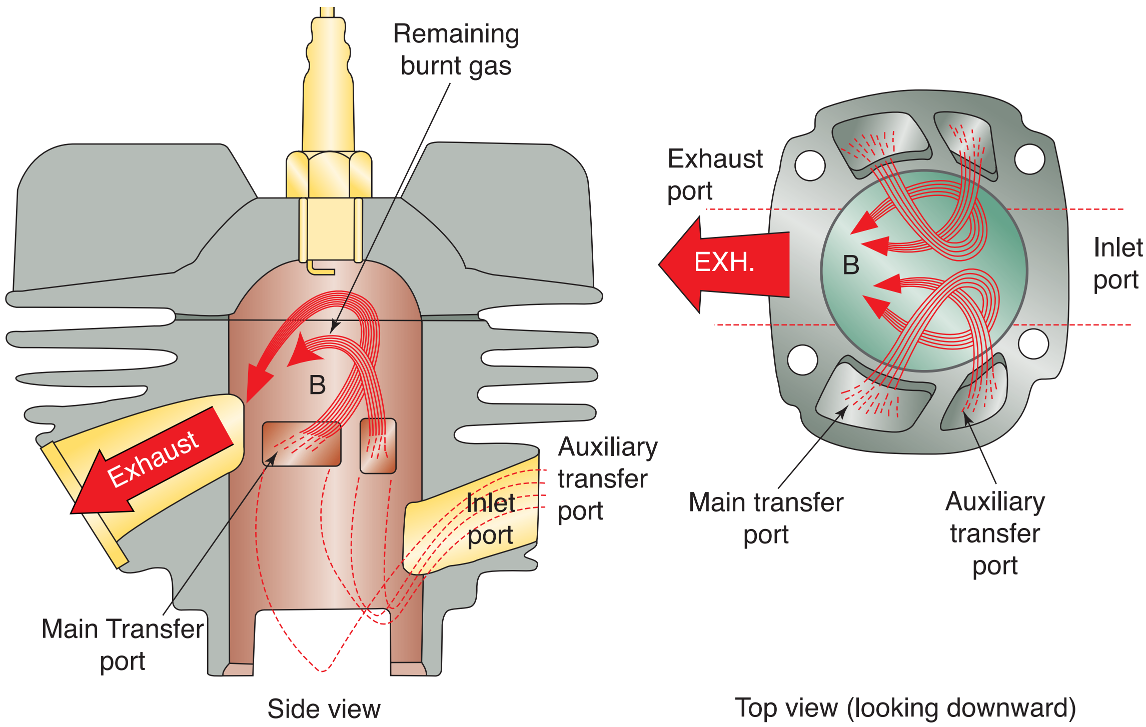

Figure 5-27 The ports in a two-stroke cylinder allow the flow of gases in and out of the engine, using the piston to open and close them.

Air-Cooled Engines

Air-cooled engines use cooling fins in the cylinder block and the cylinder head to remove excess heat from the engine. In power equipment engines, air cooling is achieved by using a forced draft design. The **forced draft** design uses air from an engine-driven fan that is attached to the crankshaft-mounted flywheel to move cool air through ducts. These ducts, called shrouds, surround the engine and keep it cool by forcing the air in toward the cylinder and head fins (Figure 5-28).

Figure 5-28 This air-cooled engine is completely covered in shrouds. Air-cooled power equipment engines use an engine-driven fan attached to the flywheel to move air and keep the engine running cool.

Liquid-Cooled Engines

The main difference between an air-cooled engine and a liquid-cooled engine is the use of liquid instead of air to maintain proper engine operating temperature. This liquid is usually made up of a 50/50 mixture of distilled water and anti-freeze (ethylene glycol). The cylinder and cylinder head have water jackets. A **water jacket** (Figure 5-29) comprises a series of passageways surrounding the cylinder and combustion chamber. As the liquid circulates through these passageways, the heat is transferred from the metal to the liquid, which helps to control the internal heat of the engine.

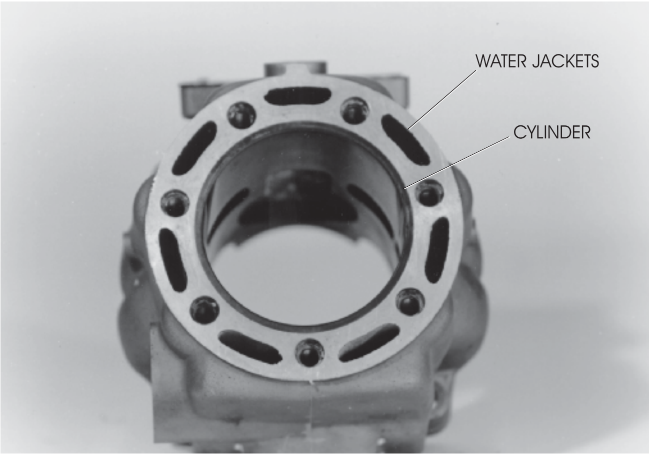

Figure 5-29 The liquid-cooled engine has water jackets surrounding the cylinder.

Other components such as the radiator, water pump, thermostat, hoses, and a reservoir tank assist with circulation and cooling of the liquid coolant. The prime advantage of liquid cooling is that the engine is maintained at a constant temperature. Another advantage with liquid-cooled engines is that the engines run quieter because the liquid coolant provides sound dampening to the internal engine noises.

ENGINE CONFIGURATIONS

Now that you have a preliminary understanding of basic engine components, let's take a look at the different engine configurations in a power equipment engine. The obvious difference between a single cylinder engine and a multi-cylinder engine is the number of cylinders and pistons. Multi-cylinder engines run more smoothly because there are more power strokes per 360° of crankshaft rotation. In most cases, more cylinders also means more displacement and more power. Multi-cylinder engines may be either air cooled or liquid cooled. Here are the main types of engine configurations.

Single Cylinder Engines

By far the most popular power equipment engine configuration, the single cylinder engine has a single piston and is primarily air cooled (Figure 5-30).

Horizontally Opposed Twin-Cylinder Engines

On horizontally opposed twin-cylinder power equipment engines, the cylinders oppose one another. The crankshaft in this engine configuration will always be of a 180° design. Because the cylinders oppose each other, the pistons move in and out at the same time and keep the engine in balance.

V-Twin Engines

The V-twin engine design (Figure 5-31) allows for the greatest amount of engine displacement in the smallest overall area.

Figure 5-30 The most common type of power equipment engine is of the single cylinder variety.

Figure 5-31 A V-twin engine.

Summary

- All power equipment engines use reciprocating engines as a source of power.
- There are two types of power equipment engines: two-stroke and four-stroke engines.
- Engines are rated by the amount of horsepower and torque that they produce.
- There are distinguishable components found in two-stroke and four-stroke engines.
- There are two basic types of engine cooling systems used in power equipment engines.
- There are different engine configurations found in power equipment engines.

Chapter 5 Review Questions

1. The single cylinder four-stroke engine has a power stroke every _____° of crankshaft revolution.
2. During which stage of engine operation does the burning mixture of air and fuel force the piston downward in a four-stroke engine?
   a. Compression
   b. Power
   c. Intake
   d. Exhaust
3. The four, basic four-stroke engine operation events, in their proper sequence, are
   a. compression, intake, power, exhaust.
   b. intake, compression, power, exhaust.
   c. power, compression, intake, exhaust.
   d. intake, power, compression, exhaust.
4. By definition, work is a force that is applied over a specific _____.
5. Work/Time = _____
6. What would the compression ratio be if a cylinder has a volume of 250 cc and a combustion chamber volume of 20 cc?
   a. 0.08:1
   b. 8:1
   c. 10:1
   d. 12.5:1
7. When the piston is at its highest point, it's said to be at
   a. TDC.
   b. BDC.
   c. ABC.
   d. BBC.
8. What is the name of the device used to measure engine torque and horsepower?
   a. Manometer
   b. Compressor
   c. Dynamometer
   d. Vernier caliper
9. A measurement of the twisting or rotational force that an engine can produce is called
   a. rotary distance.
   b. horsepower.
   c. torque.
   d. compression ratio.
10. The connecting rod and crankshaft convert up-and-down (reciprocating) motion into
    a. a small, contained explosion.
    b. rotary motion.
    c. a release of exhaust gases.
    d. movement in the cylinder head.

CHAPTER

6 Internal Combustion Engines

Learning Objectives

- Understand the general and scientific terms and laws associated with power equipment engines
- Describe the operation of a basic internal combustion engine
- Explain how fuel and air are used to make an engine operate
- Identify the component parts used in a four-stroke engine
- Describe the theory of operation for a four-stroke engine
- Identify the component parts used in a two-stroke engine
- Explain the theory behind the operation of a two-stroke engine
- Understand the different induction systems used in the two-stroke engine
- Describe how a two-stroke engine physically differs from a four-stroke engine
- Understand the advantages and disadvantages of the two-stroke engine and four-stroke engine used in the power equipment engine

Key Terms

Active combustion
Atomized liquid
Boyle's law
Camshaft
Catalyst
Chain reaction
Combustion
Compression event
Combustion lag
Compression stroke
Crosshatches
Energy
Engine cycle
Exhaust event
Exhaust stroke
Ignition
Induction
Intake event
Intake stroke
Internal combustion engine
Law of action and reaction
Law of inertia
Momentum
Piston ring
Ports
Post combustion
Power event
Power stroke
Transfer event
Valve float
Valve-closing devices
Vaporized liquid
Viscosity

INTRODUCTION

In Chapter 5, we learned about the various power equipment engine configurations. Now we'll focus on how power equipment engines operate. We'll begin by discussing physical laws that pertain to engines. Then we'll describe the theory of operation for a basic internal-combustion engine.

After you understand basic engine operation, we'll focus on the four-stroke engine. We'll discuss the basic components used in a four-stroke engine and then take an in-depth look at how a four-stroke engine operates. We'll then look at the two-stroke engine. We'll identify the components found in the two-stroke engine and learn how the two-stroke engine operates. We'll then describe the different types of induction systems. After completing our discussion of the two-stroke engine, we'll discuss the differences between two-stroke engines and four-stroke engines. Finally, we'll look at the advantages and disadvantages of each of these engine designs.

GENERAL AND SCIENTIFIC TERMS AND LAWS

Before we go into detail on how engines operate, it's important to understand terms and principles related to the combustion process and gasoline engines.

Matter

Matter can be described as any substance that occupies space and has weight. Matter can't be created or destroyed but can be changed from one form to another by a chemical or physical process. An example of matter changing from one form to another is a block of ice. The ice turns to water if not kept at a freezing temperature. Also, if enough heat is applied, the water can be changed to steam.

Matter can be in the form of a solid, liquid, or gas. The block of ice in the example is considered to be solid matter because it has three dimensions (length, width, and depth) that can be measured. When the ice melts, it changes from a solid form into a liquid form (water). A liquid has no definite shape and conforms to the shape of the container holding it. A liquid has the ability to exert pressure but can't be compressed. Another interesting fact about a liquid is that it won't burn! That's right, liquids don't burn. The following are two terms describing liquids that relate to engine operation.

- An **atomized liquid** consists of liquid drops suspended in air. An example of an atomized liquid is an early morning fog. Because an atomized liquid is still a liquid, it won't burn.
- A **vaporized liquid** is a liquid that's converted to a gaseous state through a heating process. A vaporized liquid has the ability to burn. Vaporized liquids are used to make an engine run.

Steam is a gas or gaseous matter. Keep in mind that we aren't talking about gasoline when we talk about gas. Gasoline is a liquid. A gas has no definite shape and, like a liquid, conforms to the shape of its container. A gas can transmit pressure but is lighter than a liquid when compared in equal volumes. Unlike a liquid, a gas is highly compressible.

An excellent example of a gas is the air we breathe. Air is made up of approximately 78% nitrogen, 21% oxygen, and 1% inert or inactive gases. The oxygen in the air keeps us alive and also helps an engine run at its best.

Air density can be described as the amount of oxygen per given volume of space, or in other words, the thickness of air. The air all around us is actually compressed. At sea level, air pressure is 14.7 pounds per square inch (psi). Air density decreases as altitude increases or when the temperature rises. When air density decreases, there are fewer oxygen molecules in the air. It would be more difficult for you to work at the same level of intensity at 10,000 feet above sea level than at 1,000 feet above sea level. Likewise, it's also more difficult to work at the same level of intensity on a very hot and humid day than on a cool and dry day. The same changes affect how an engine runs! As air density decreases, there are fewer oxygen molecules in the air for you and your engine to breathe!

Viscosity

A liquid will flow through a path such as a water hose. Its path of flow affects how fast a liquid flows. For example, a liquid won't flow uphill without some sort of pressure acting on it. The temperature of a liquid also affects its ability to flow. As the temperature of a liquid increases, the liquid tends to get thinner. This change is known as viscosity. **Viscosity** is a measure of a liquid's resistance to flow. You'll generally see the word *viscosity* in the context of oils used in engines. A liquid with high viscosity offers greater resistance to flow as compared with one with low viscosity.

Boyle's Law

As we stated earlier, a gas, like air, can be compressed. There's a physical law governing the interplay between pressure, volume, and temperature. This law, known as **Boyle's law**, states that the pressure and the volume of a given mass of gas remains constant if its temperature is not changed. Boyle's law tells us that when a gas is compressed, its temperature and pressure increase. The more a gas is compressed, the higher its temperature and pressure. Each time you decrease the volume of a gas one half, you double the pressure it exerts.

Pressure Differences

Pressure differences result in movement of a gas from a high-pressure area to a low-pressure area, in the process moving any matter that may be in the way along with it. A gas at high pressure always seeks low pressure. A common example of pressure differences can be seen every day in the weather around us. In engines, carburetion and the intake or induction phase take advantage of pressure differences for operation. We generally call pressure differences *vacuum* when talking about engines.

Momentum

Velocity is the speed of an object in a given direction. Mass is the weight of any form of matter. **Momentum** is the driving force that's the result of motion or movement. Momentum is determined by multiplying mass (weight) times velocity:

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

Laws of Motion

Two laws of motion concerned with understanding engine operation are the law of inertia and the law of action and reaction. The **law of inertia** states that anything at rest or in motion tends to remain at rest or in motion until acted upon by an outside force. The **law of action and reaction** states that for every action there's an equal and opposite reaction. These laws of motion were introduced by Sir Isaac Newton.

Energy

Energy is the ability to do work. If we have lots of energy, we can do lots of work. Energy itself can't be seen; however, the results of energy can be seen. An example is lifting a box and setting it on a table. Only the physical movement of the box can be seen. Energy exists in many forms and can be changed from one form to another. For example, a battery changes chemical energy to electrical energy. However, conversion of energy from one form to another is never 100% efficient. An example is your heating system at home. As your heating system burns fuel, most of the heat is used to warm your home; however, some of the heat is lost up the chimney. The same is true in a power equipment engine. Burning fuel in the engine provides the energy to move the power equipment engine, but some energy is lost in friction and heat produced by the engine.

There are two types of energy:

- **Potential energy.** Energy that is stored, as in a charged battery or a can of gasoline.
- **Active energy (or kinetic energy).** Energy that is in use or in motion, as when a battery is used to light a lamp or when gasoline is used to run an engine.

THE BASIC INTERNAL COMBUSTION PROCESS

In Chapter 5, we discussed the basic components and operation of an engine. Now we'll discuss these topics again but in greater detail.

Power equipment engines use a principle called combustion to operate. **Combustion** is the rapid combining of oxygen molecules with other elements. When elements are combined with oxygen, the ensuing chemical changes can result in the release of heat. Heat usually speeds up any chemical change and can act as a catalyst. A **catalyst** is generally a substance that speeds up a chemical reaction without undergoing any change itself. A cold condition usually slows down most chemical changes. This is why engines tend to run better when warmed up than when they're first started.

The engines found in all modern power equipment units are internal combustion engines. In an **internal combustion engine**, compressed fuel and air are burned inside the engine to produce power. The internal combustion engine produces mechanical energy by burning fuel. In a power equipment engine, fuel is sent to the engine through an induction system, where it's burned inside to produce the power that's used to help make the engine run. In contrast, an external combustion engine burns fuel outside of the engine. A steam engine with a boiler is an example of an external combustion engine. We won't discuss the external combustion engine design here because it's not relevant to power equipment engines.

Construction of the Internal Combustion Engine

Let's begin by reviewing some of the common parts in any type of internal combustion engine (Figure 6-1). The cylinder is a hollow metal tube. The top end of the cylinder is sealed by the cylinder head, which is bolted onto the top of the cylinder. The piston, which is the main moving part in an engine, is a can-shaped metal component that can move up and down inside the cylinder.

The area between the piston and the cylinder head is called the combustion chamber.

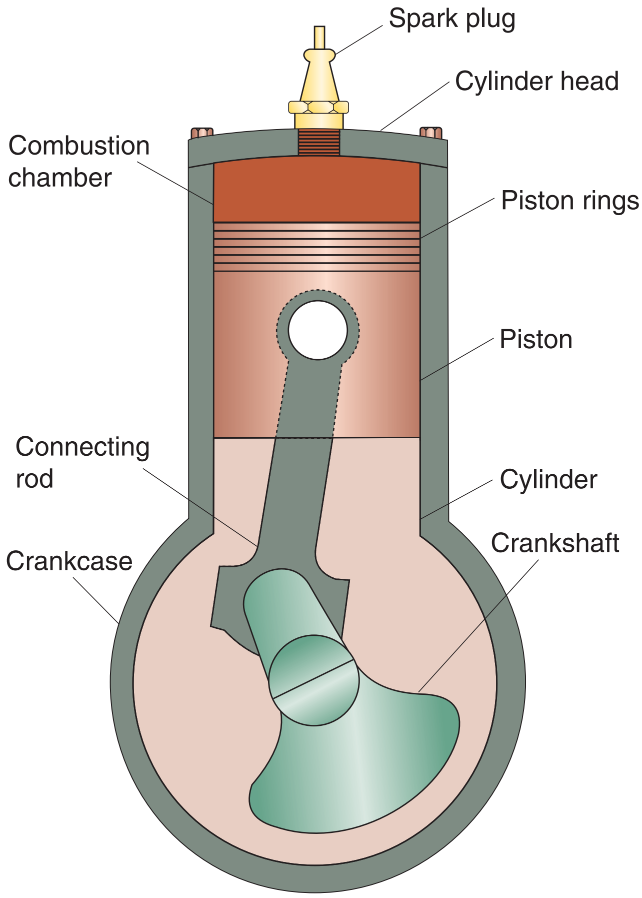

Figure 6-1 A simplified cutaway view of an engine. During operation, the piston moves up and down inside the cylinder. This movement is transferred to the crankshaft through the connecting rod.

In this chamber, a mixture of air and gasoline is compressed and burned to produce power. A spark plug is screwed into a threaded hole in the cylinder head. The end of the spark plug protrudes from the cylinder head and into the combustion chamber. The spark plug is used to ignite the compressed air–fuel mixture in the cylinder and cause it to burn. The sparking action of the spark plug is controlled by the engine's ignition system, which we'll discuss in detail in Chapter 15.

When the air–fuel mixture burns correctly in the combustion chamber, the gases inside expand rapidly. The expansion of the gases due to the rapid burning is enough to force the piston downward the cylinder. The bottom end of the piston is attached to a connecting rod and crankshaft assembly. When the piston is forced downward the cylinder, the downward motion is transferred to the rod and crankshaft. The rod and crankshaft then convert the up-and-down (or reciprocating) motion of the piston into circular or rotary motion.

Now, let's take a few minutes to review a few terms that were presented earlier. When a piston is at its highest position in the cylinder, it's said to be at top-dead center (TDC) (Figure 6-2). When the piston is at its lowest position in the cylinder, it's said to be at bottom-dead center (BDC). The distance that the piston moves from the top of the cylinder to the bottom of the cylinder is called the piston stroke.

The outside surface of a piston has several horizontal grooves cut into it. Each groove holds a metal ring called a piston ring. A **piston ring** is a metal ring that's split at one point and is designed to be springy. The piston rings slip over the outside of the piston and fit into the piston ring grooves. Once they're in place, the rings stick out like ridges on the surface of the piston. When a piston is inside a cylinder, the piston rings press outward against the walls of the cylinder. This helps form a tight seal between the piston and the cylinder, which is necessary for proper engine operation.

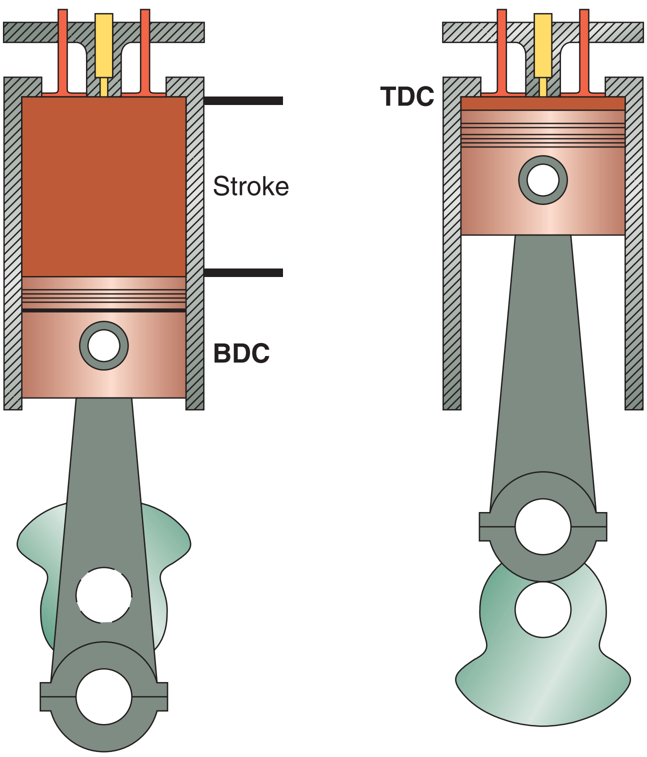

Figure 6-2 An engine with the piston located at top-dead center (right) and bottom-dead center (left).

The Three Phases of Internal Combustion

There are two methods of initiating normal combustion in an engine. The first method is **ignition**, which happens when an atomized fuel makes contact with a spark. The second method comprises reducing the space occupied by oxygen and a combustible material, which produces heat. Power equipment engines use a combination of these two methods. The air–fuel mixture is compressed into a very small space. An ignition spark begins the combustion process. As the air–fuel mixture burns, the hot expanding gases push the piston down. The combustion process changes potential energy in the form of the air–gas mixture (chemical energy) to active (kinetic) energy in the form of heat. There are three phases of combustion that occur during the power stroke of the internal combustion engine: combustion lag, active combustion, and post combustion.

Combustion Lag

The first phase of the internal combustion engine process starts as the piston moves upward and compresses the air–fuel mixture. The spark plug ignites a small portion of this mixture before the piston reaches TDC. A ball of fire spreads outward and begins to consume the remaining compressed air–fuel mixture. However, this ball of fire that initiates combustion doesn't immediately spread outward. A **chain reaction** soon occurs, as a result of which the gases expand rapidly. Before the chain reaction spreads to the outside area of the combustion chamber, a short period of relatively slow burning takes place. This slow burning is known as **combustion lag**.

Active Combustion

The second phase of the internal combustion engine process begins when the initial combustion lag is overcome and the chain reaction begins to spread quickly outward. A rapid temperature and pressure buildup occurs as the charge is consumed. The chain reaction of burning molecules accelerates and the chemical conversion causes heat to be released very quickly. This increase in temperature causes the pressure in the cylinder to increase. This phase is known as **active combustion**.

Post Combustion

As the piston moves down and the volume inside the cylinder increases, the pressure drops and the power is then absorbed by the piston. The cylinder now eliminates spent gases to prepare for the next cycle of fresh air–fuel mixture. All engines begin to release exhaust gases out of the cylinder well before the piston reaches BDC. This phase is known as **post combustion**.

Results of Combustion

The heat and power generated within the combustion chamber produce work, which is realized through the crankshaft and eventually through the drive system of the power equipment unit. Although most four-stroke engines run at lower temperatures, cylinder head temperatures can be as high as 300–375°Fahrenheit (°F). Combustion chamber gas temperatures within the engine are known to be as high as 4,000°F. This relates to cylinder pressures reaching 800–1000 psi. The heat produced expands the gases in the combustion chamber and pushes the piston toward BDC.

The chemical changes that occur during combustion convert the fuel–air mixture into the following chemicals:

- **Carbon monoxide (CO).** Results from partially burned fuel or fuel that's not completely burned during the combustion process. Remember that carbon monoxide is a colorless, odorless, poisonous, and deadly gas.
- **Hydrocarbons (HC).** Results from unburned or raw fuel.
- **Carbon dioxide (CO_2).** The result of complete combustion.
- **Oxides of nitrogen (NO_x).** Forms of oxidized nitrogen resulting from extremely high combustion temperatures.
- **Water (H_2O).** Results from complete combustion. Believe it or not, for every gallon of fuel burned, approximately 1 gallon of water is produced in a vaporized form.

In the United States, the Environmental Protection Agency (EPA) has developed emission standards for new non–road engines. Since 1995, power equipment engines have been required to comply with EPA emission standards. The two key emissions produced by power equipments and monitored by the EPA are hydrocarbons and oxides of nitrogen.

INTERNAL COMBUSTION ENGINE OPERATION

So far, we've looked at the basic internal combustion process in a typical engine. Now, let's take a look at how combustion is used to enable the engine to operate. In order to work, all internal combustion engines must perform four basic actions. They must:

- Take in air and fuel
- Squeeze or compress the air–fuel mixture
- Ignite and burn the mixture
- Get rid of the burned gases

These engine actions are the four events of engine operation. You may recall that the proper names for these events are intake, compression, power, and exhaust. When an engine is operating, it continually runs through these four events, over and over again.

- **Intake.** Air that has been mixed with fuel is drawn into the cylinder because of the downward movement of the piston, which increases cylinder volume and lowers the pressure in the cylinder, in effect creating a vacuum.
- **Compression.** The piston rises and compresses the air–fuel mixture trapped inside the combustion chamber.
- **Power.** The air–fuel mixture is ignited. The rapid and confined burning of the fuel pushes the piston back down the cylinder. The downward motion of the piston is

transferred through the connecting rod to the crankshaft.

- **Exhaust.** The exhaust gases are released from the cylinder. The four events then begin all over again.

One **engine cycle** is a complete run through of all four events of operation: intake, compression, power, and exhaust. Keep in mind that the four events of operation we've described occur very quickly, and they repeat continually for as long as the engine is running. All power equipment engines operate in these same four basic events, and all the events must occur in order for the engine to run properly. To understand how an engine works, one of the most important things you can do is memorize the four events of engine operation. Once you understand these four events, everything else we discuss about engine operation will fall into place.

BASIC FOUR-STROKE ENGINE COMPONENTS

Now that we've reviewed the basics of engine operation, let's look at the four-stroke power equipment engine components in more detail. We'll cover all the basic parts of a four-stroke engine and explain their purpose. Many components found in four-stroke engines are in two-stroke engines also. Refer to the illustrations for reference as we discuss each component. Be aware that not all engines look exactly alike. However, the illustrations provided are typical of four-stroke engines you'll see.

Four-Stroke Cylinder Heads

Cylinder heads are constructed out of aluminum alloy or cast iron (Figure 6-3). There are two basic types of cylinder heads found in power equipment engines. One, known as an L-head-type, is more or less a cover for the cylinder, which caps the top of the engine. The other type of four-stroke cylinder head, called the overhead valve (OHV) cylinder head, holds the intake and exhaust valve train components. All cylinder heads seal the top end of the

Figure 6-3 There are two basic types of cylinder heads in power equipment engines. The cylinder head on the left contains the intake and exhaust valve train components. The cylinder head on the right is more or less a cover for the cylinder, which caps the top of the engine.

cylinder for compression of the air–fuel mixture under the spark plug (which is threaded into the cylinder head) to increase combustion efficiency. Holes in the OHV cylinder head are called ports and provide for the air–fuel mixture to come into the combustion chamber and also remove the spent gases after the combustion process. Cylinder heads also aid in the transfer of heat from the engine by the use of fins in air-cooled engines or by using water jackets in liquid-cooled engines.

Most power equipment engines use one valve each for the intake and exhaust (2-valve systems) but may have more valves for each cylinder. The intake valve area, in most cases, is larger than the exhaust valve area in the four-stroke engine. This is because it's more difficult to get the intake gases into the engine than it is to remove the gases that are being pushed out of the exhaust valve.

There are two basic types of valve mechanisms found in power equipment engines: L-head and OHV (Figure 6-4). The L-head-type uses a valve design that has the valves located in the cylinder block next to the piston. Commonly called a flathead or side-valve, the L-head type of engine was popular in many older power equipment engines and is still used in some engines. The OHV-type uses a valve design that locates the valves in the cylinder head above the

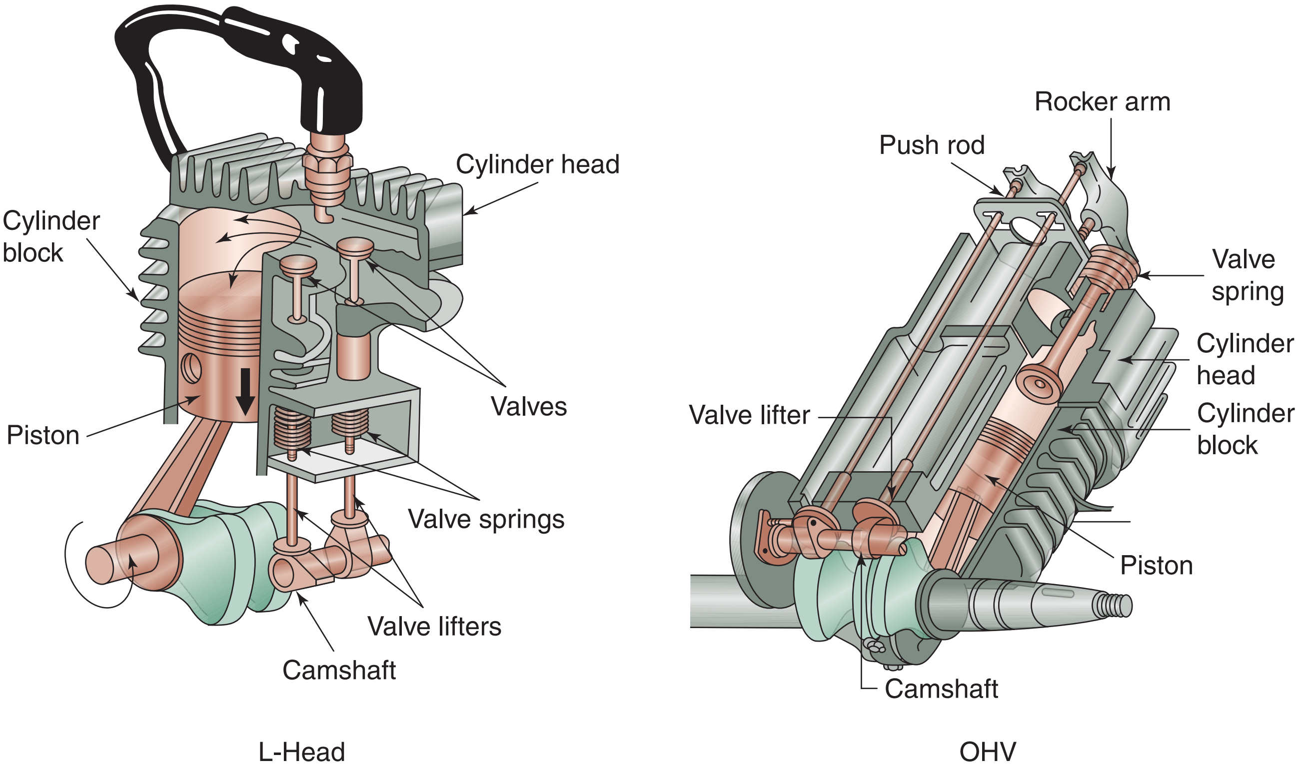

Figure 6-4 An L-head-type engine (left) and overhead valve (OHV) engine (right). Note that the valves are contained in the block on the L-head-type, whereas they're attached to the head on the OHV head.

piston. Use of the OHV is becoming popular because this style of engine is much more efficient at getting the gases get in and out of the combustion chamber. The result of this design is increased power and less emissions.

Poppet Valves

Four-stroke engines use mechanical valves called poppet valves to control the gases coming into and going out of the engine. Poppet valves, which are tulip shaped, open and close every other crankshaft revolution. The poppet valve may be made from stainless steel, carbon steel, or titanium. The intake valve allows the air–fuel mixture into the cylinder. The following list describes various parts of a poppet valve (Figure 6-5):

- The keeper groove is where keepers lock the valve and spring retainer in place.
- The valve fillet is the sloped area of the valve that connects the valve stem to the valve head.
- The valve face mates with the cylinder head valve seat to seal gases in the combustion chamber and aid in heat transfer. The valve face is often coated with stellite to reduce wear and prolong the life of the valve.
- The margin supports the valve face and shields the face from high combustion temperatures.
- The valve head is the bottom portion of the valve and forms a part of the combustion chamber.

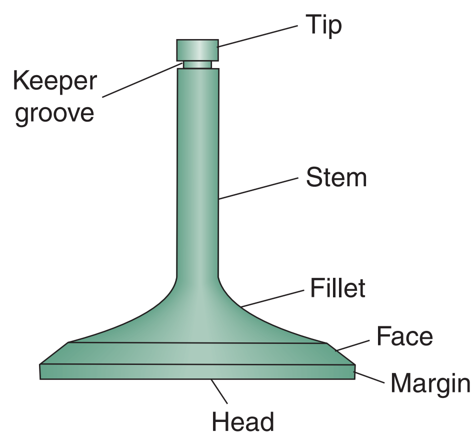

Figure 6-5 Parts of a typical poppet valve.

- The valve tip is the part of the valve that rides against the valve-opening device. Most valve tips are stellite plated for wear. Stellite is an extremely hard metal alloy that resists wear and won't soften at high temperatures.
- The valve stem is the thrust surface for the valve guide and is considered to be a major wear area. If the stem is worn, excessive amounts of oil can pass between the stem and guide into the combustion chamber. If oil leaks into the combustion chamber, smoke appears in the exhaust.

Common wear areas of the valve are the tip, face, stem, and keeper groove.

Valve Seats

Cylinder head valve seats (Figure 6-6) are stationary in the cylinder head or cylinder block depending on the engine design and are the sealing surface for the valve face. When servicing valve seats, there are generally three angles cut into the valve seat to allow for optimum air and fuel flow into the cylinder through the valve opening.

Valve Guides

Valve guides (Figure 6-6) are installed in the four-stroke cylinder head or in the cylinder block depending on the engine type. Valve guides provide a bushing surface for the valve stem.

Valve Stem Seals

Valve stem seals are installed on the valve guides and are used to prevent excessive oil from entering between the inside of the valve guide and valve stem. Depending on the engine design, valve seals may be installed on the intake, exhaust, or both valve guides.

Valve-Closing Devices

Valve-closing devices keep the valve closed when required. The most common method to close a valve is with the use of coil springs (Figure 6-7) attached between the valve and the cylinder head or block depending on the type of engine. The springs are held in place with valve spring retainers and valve keepers that fit into the valve keeper grooves. Although many modern four-stroke power equipment engines use only one valve spring, some use two coil springs per valve to reduce the chance of valve float. **Valve float** is a condition in which the valve doesn't stay in constant contact with the valve train. Valve float can occur when the valve springs are weak or during excessively high engine speeds.

Valve springs are held in place by retainers (Figure 6-8). There are three types of retainers found in power equipment engines: pin-type retainers are found in older engines, whereas

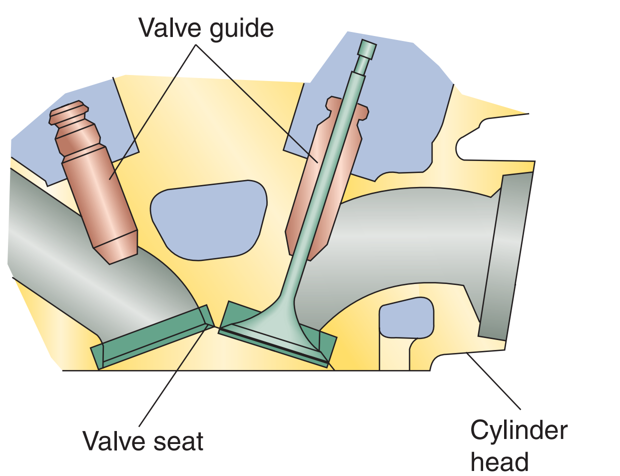

Figure 6-6 Valve seats and guides are located in the cylinder head on the OHV engine. On the L-head-type, seats and guides are located in the block but they perform the same function.

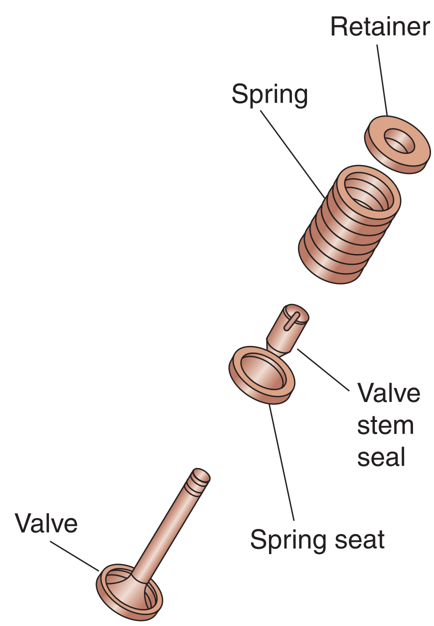

Figure 6-7 A valve spring and the components used commonly to close the valve.

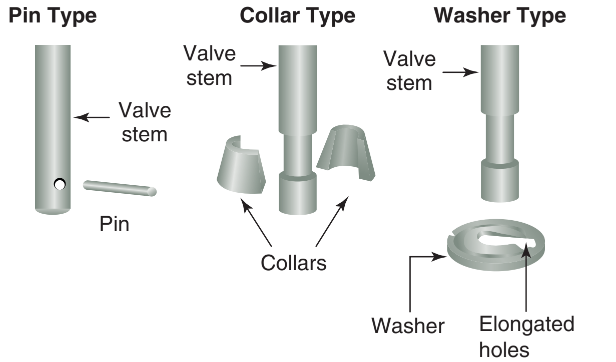

Figure 6-8 Three types of retaining methods used in power equipment engines. The collar-type and washer-type retainers are the most popular.

collar-type and washer-type retainers are more commonly found in today's engines.

Valve-Opening Devices

There are two common types of valve-opening devices used in the four-stroke power equipment engine depending on the type of engine being used: rocker arms and valve lifters. They can be reviewed using Figure 6-4.

The rocker arm is a lever that can gain a mechanical advantage and change the direction of force applied to it. There are various rocker arm designs used in the four-stroke engine but they all perform the same function. Rocker arms are found in OHV engines.

The valve lifter, also commonly called tappet, is used to directly open the valve from under the valve. This type of valve-opening device is seen in L-head engines.

Valve Clearance

Valve clearance or lash is necessary to allow for heat expansion, oil clearance, and for proper sealing of the valve. Too little clearance causes improper sealing of the valve and excessive heat. Too much clearance causes excessive noise.

There are different ways (Figure 6-9) used to adjust valves in power equipment engines.

- The screw and lock nut uses a screw that can be turned in or out to change the clearance. After the adjustment has been made, a lock nut holds the screw in place. The screw and lock nut may be located on the rocker arm, on a push rod, or on a valve lifter.
- Some valves are adjusted by removing them and grinding the tip. You must be careful not to grind off too much of the valve; so use caution when adjusting the valve using this method.

Four-Stroke Camshafts

The purpose of the **camshaft** (also known as the **cam**) is to change rotary motion to reciprocating motion. The camshaft is also a mechanical valve timer that controls:

- When to open
- How fast to open
- How far to open

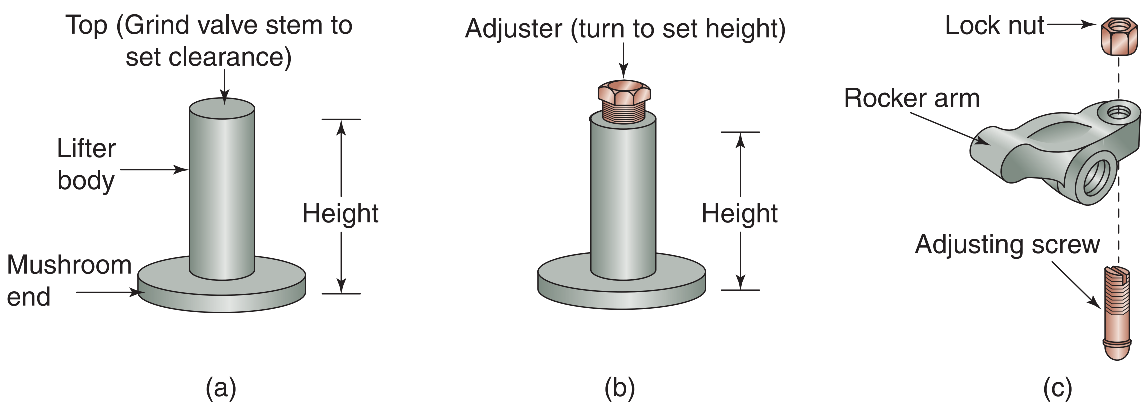

Figure 6-9 A valve clearance with a screw and lock nut for adjustment (c) and two types of valve lifters (a and b). The lifter on the center is adjusted with its own adjuster, whereas the lifter on the left requires grinding of the valve. Valve clearance is important to allow for heat expansion, oil clearance, and proper sealing of the valve.

- How long to stay open
- When to close
- How fast to close
- How long to stay closed

Parts of a Camshaft

The various parts of a camshaft are important to its ability to function properly in the four-stroke power equipment engine (Figure 6-10).

- The base circle is the area of the camshaft that forms a constant radius from the centerline of the journal to the heel. The heel is the part of the camshaft that allows the valve to seat onto the cylinder head and seal off the combustion chamber.
- Clearance ramps take up the valve clearance and open and close the valve. These ramps act similarly to a shock absorber and are used to gently (relatively speaking!) open and close the valve.
- The flanks of the camshaft determine and control the acceleration of the opening and closing of the valve.
- The nose is the area of the camshaft where the valve is opened the greatest distance from the cylinder head area; it controls lift dwell. Lift dwell is the amount of time in crankshaft degrees that the valve stays open at maximum lift.
- Camshaft lift is a measure of the difference between the base circle and the nose. Depending on the type of engine, this may or may not translate into the actual valve lift, which is the distance that the valve actually moves away from the cylinder head.

The duration of a camshaft is a measure of how long the valve is held open. Duration is measured in crankshaft degrees.

Most camshafts have what's known as valve overlap built into them. Valve overlap occurs between the exhaust and intake strokes. It's the time for which both valves are open simultaneously and is measured in crankshaft degrees. High-performance engines generally have more valve overlap to allow for more air–fuel mixture to be packed into the cylinder combustion chamber. As high velocity exhaust gases leave the cylinder, a low pressure area is created. Opening the intake valve allows fuel and air to be drawn into the cylinder quicker. Although this allows for higher peak power, an engine with a camshaft exceeding 30° of valve overlap will lack efficiency in the low- and mid-range power areas of the engine.

Camshaft Drive

The camshaft rotates at one-half the speed of the crankshaft to properly time the intake and exhaust valves with the piston as it moves up and down the cylinder. The primary method used to drive the camshaft is by a gear attached to the camshaft, which is driven by the crankshaft (Figure 6-11). The gear on the camshaft has twice as many gear teeth as found on the

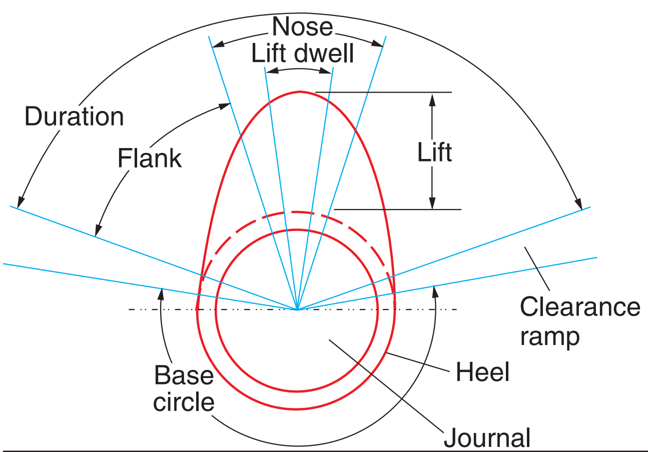

Figure 6-10 The parts of a camshaft.

Figure 6-11 A typical camshaft.

crankshaft drive gear, to allow for the one-half speed factor mentioned. The gears of the crankshaft and camshaft operate in an oil bath in the crankcase.

Four-Stroke Cylinders

The purpose of the four-stroke engine cylinder is to guide the piston as it travels up and down. The cylinder is attached directly to the crankcase in most cases in the typical power equipment engine and helps to transfer engine heat. These cylinders may be either air cooled or liquid cooled. Liquid-cooled cylinders have water jackets surrounding the cylinder area (Figure 6-12).

There are different types of materials used in the construction of a cylinder. Each material has its advantages and disadvantages.

- **Cast-iron cylinders.** These can be fit with oversized pistons by boring to a larger size. When a cylinder is bored, material is removed from the cylinder to enlarge the hole. A larger oversized piston (and appropriate piston rings) is then used in place of the previous piston. The cast-iron cylinder is inexpensive to manufacture but has poor heat transfer characteristics when compared with other materials used to construct cylinders. Not found often in today's modern power equipment engines, cast-iron cylinders are very heavy.
- **Aluminum cylinders with cast-iron or steel sleeves.** These have much better heat transfer abilities than cast-iron cylinders and are much lighter. These cylinders can also be bored to a larger diameter. In some cases, the sleeve can also be replaced if needed, but in most cases, the cost to replace the cylinders is less than that to replace the sleeve. This type of cylinder is most popular in today's engines and allows for longevity of the engine.
- **Aluminum cylinders.** Cylinders made of aluminum have the least weight and when properly maintained, last a long time. The disadvantage of aluminum cylinders is that although they can be bored when needed, it's prohibitively costly to do so. They're generally replaced when damaged. These cylinders are the least expensive to produce.
- **Plated aluminum cylinders.** These use a thin layer of chrome or Nikasil to increase the durability of the cylinder. This combines the lightweight benefit of aluminum with added durability of a hardened cylinder surface.

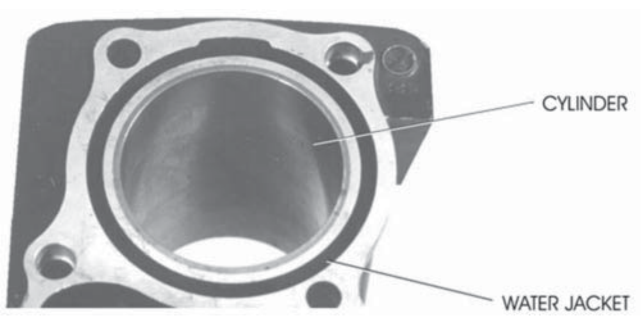

Figure 6-12 A typical liquid-cooled cylinder. A liquid-cooled cylinder uses water jackets as opposed to the cylinder fins used in an air-cooled cylinder.

Some cylinders may have tiny scratches cut into them called **crosshatches**. Crosshatching is accomplished by honing the cylinder wall with a tool called a cylinder hone. The purpose of honing is to help seat the piston rings and retain a thin layer of oil on the cylinder walls to keep them properly lubricated.

Cylinders must be round from top to bottom to work properly. They shouldn't have any taper or out-of-roundness. We'll discuss how to measure four-stroke cylinders later, in Chapter 12.

Four-Stroke Pistons

The purpose of the piston is to transfer power produced in the combustion chamber to the connecting rod. The piston is manufactured in a way that makes it directional. This makes it necessary to install the piston in the specific manner indicated in the service manual.

Pistons are tapered from top to bottom. The top of the piston is smaller than the bottom to allow for different heat expansion rates of the piston. To allow for further heat expansion, pistons are cam ground so they're oval in shape when cold. When the piston reaches operating temperature, it becomes round to match the cylinder.

There are two common piston-manufacturing methods: cast aluminum and forged. Cast-aluminum pistons are the more common.

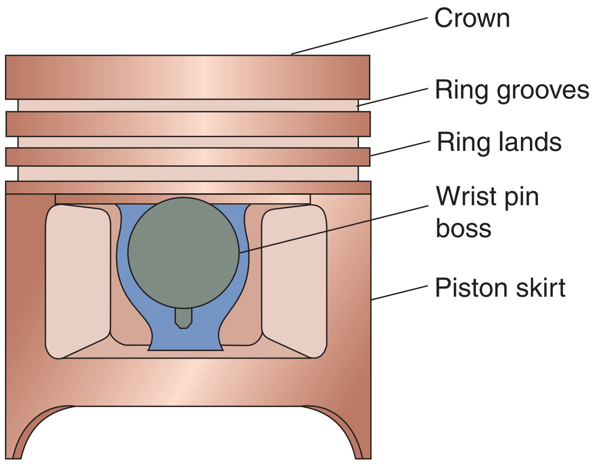

Figure 6-13 The parts of a typical four-stroke piston.

Forged pistons use aluminum alloy forced into a die under extreme pressures. This manufacturing method produces a stronger piston, but makes the piston more expensive.

A piston has several parts (Figure 6-13). The crown is the top of the piston and acts as the bottom of the combustion chamber. The crown is the hottest part of the piston, because of the high combustion chamber temperatures. The crown area expands more than the rest of the piston because it's hotter and has more mass. The piston crown may have a positive dome, flattop, or negative dome. There also may be machined clearance notches in the crown to allow for valve relief.

The ring grooves allow for installation of piston rings. The bottom ring groove of the four-stroke piston has holes or slots for oil return that help remove oil from the cylinder wall. This also helps to lubricate the wrist pin. The piston ring lands support the piston rings.

The wrist pin boss is where the piston attaches to the small end of the connecting rod. A hardened tool-steel wrist pin attaches the piston to the rod. The wrist pin is generally held in place with retaining clips to prevent it from contacting the cylinder wall.

The piston skirt is the load-bearing surface of the piston. The piston skirt contacts the cylinder wall and is the primary wiping surface for the cylinder wall. The largest diameter of the piston is usually at or close to the bottom of the skirt and 90° from the wrist pin. This is where the piston is generally measured.

Four-Stroke Piston Rings

The purpose of piston rings is to aid in heat transfer from the piston to the cylinder wall, seal in the combustion gases, and prevent excessive oil consumption. Generally, there are three types of piston rings used on the four-stroke piston (Figure 6-14):

- The **compression ring**. This ring is closest to the piston crown and is used to seal most of the combustion chamber gases. The compression ring is usually made of cast iron and may be chrome plated or Teflon or moly coated.
- The **scraper ring**. This is the middle ring and aids in sealing the combustion chamber gases. The scraper ring scrapes excessive oil from the cylinder wall. Like the compression ring, the scraper ring is made of cast iron but in most cases has no coating. Many modern engines no longer use the scraper ring. This is to reduce friction and increase the engine's horsepower rating.
- The **oil control ring**. This is the ring closest to the piston skirt. The oil control ring removes the oil from the cylinder walls left behind by the piston skirt.

Piston rings have an end gap to allow for heat expansion. The ring end gap is measured by using a feeler gauge after fitting the ring

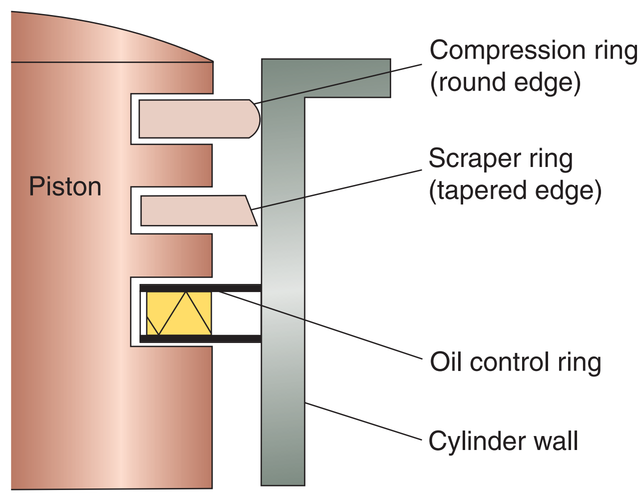

Figure 6-14 Three common types of piston rings found in four-stroke engine pistons.

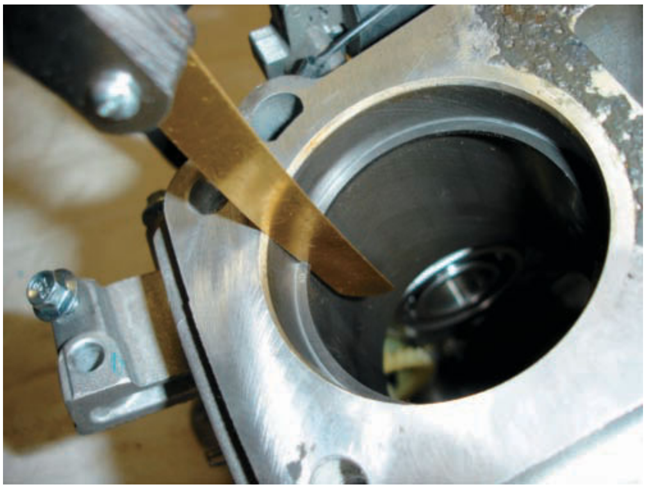

Figure 6-15 The piston ring end gap is measured using a feeler gauge. Ring end gap is required to allow for heat expansion.

squarely in the cylinder (Figure 6-15). Ring end gap should be measured at the locations recommended by the engine manufacturer.

Four-Stroke Crankshafts

As we discussed earlier, the purpose of a crankshaft is to change the reciprocating motion of the piston into a rotary motion. The primary parts of a crankshaft include journals and counterweights (Figure 6-16). The main journals support the mass of the crankshaft and are located at the center of the rotating axis and supported by bearings, bushings, or a combination of both. A connecting-rod journal supports the connecting rod and is offset from the main journals. Counterweights add momentum to the crankshaft. The counterweights assist in keeping the crankshaft rotating and the engine running smoothly by counterbalancing the reciprocating masses from the piston and connecting rod. Some engines use remote counterbalancers, which are located on separate shafts and are chain or gear driven. Counter-balancers must be timed properly with the crankshaft.

Figure 6-16 A one-piece crankshaft used in four-stroke engines.

Four-Stroke Connecting Rods

The connecting rod is a lever that transfers power from the piston to the crankshaft. Connecting rods in power equipment engines are usually made of aluminum but can also be made of steel. Both types generally use an I-beam construction to increase strength.

The typical connecting rod is of a multipiece (Figure 6-17) design and consists of the connecting rod, connecting-rod end cap, and

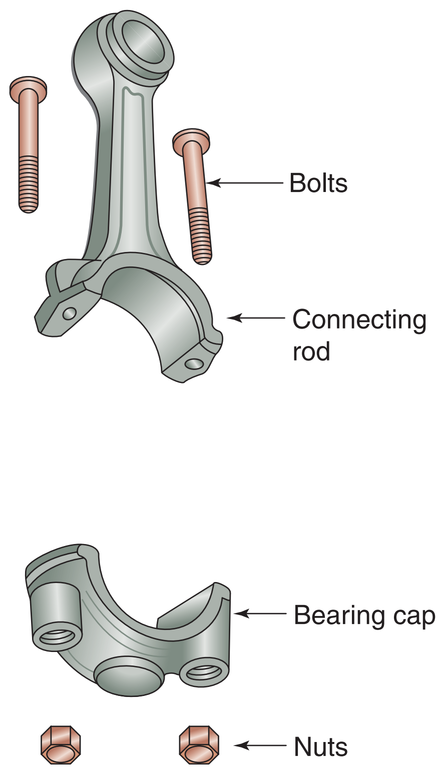

Figure 6-17 The typical connecting rod on a power equipment engine is a multipiece design, as illustrated here. The rod may or may not have nuts on the end (instead it may have threads).

connecting-rod bolts. The multipiece connecting rod is precisely machined on each end to allow for a smooth bearing surface.

Four-Stroke Crankcase

The purpose of the crankcase is to house and support the major engine components, which include the crankshaft, cylinder, and camshaft. The four-stroke crankcase must be vented to the atmosphere to prevent excessive pressure from building up inside the engine. The most common type of crankcase found in power equipment engines is the one-piece design. A one-piece crankcase consists of a case that's a single-piece construction with a separate access cover to remove main components (Figure 6-18). Also known as a "block," this type of crankcase is the most common crankcase found in power equipment engines.

THEORY OF OPERATION OF THE FOUR-STROKE ENGINE

Although the four-stroke engine is somewhat complex in design because of the parts necessary for it to function, it's relatively simple in terms of operation. The engine runs by repeatedly completing a cycle of operation. Each cycle of operation consists of two crankshaft revolutions in which four piston strokes occur. Each of the four piston strokes performs a distinct operation. The four operations (or events)—intake, compression, power, and exhaust—must occur in the proper order for the engine to run correctly.

Valve Operation

As mentioned earlier, the four-stroke engine uses mechanical valves: the intake valve and the exhaust valve (Figure 6-19). These valves move up and down to open and close during engine operation. The intake valve opens to allow the air–fuel mixture to flow into the combustion chamber. The exhaust valve opens to allow exhaust gases to flow out of the combustion chamber after the air–fuel mixture is burned.

The intake and exhaust valves are mechanically lifted to make them open and close. A valve-lifting device that rests on the lobes of the camshaft opens the valves. As the camshaft turns, the lobes open the valves in a timed sequence to match up properly with the up-and-down motion of the piston. The valve springs hold the valves closed when they aren't being forced open by the camshaft and lifting device.

Fuel Induction

To burn properly in an engine, fuel must be mixed with air. This is done via a carburetor or a fuel injection system, generally known as a fuel induction system. Fuel moves from the fuel tank

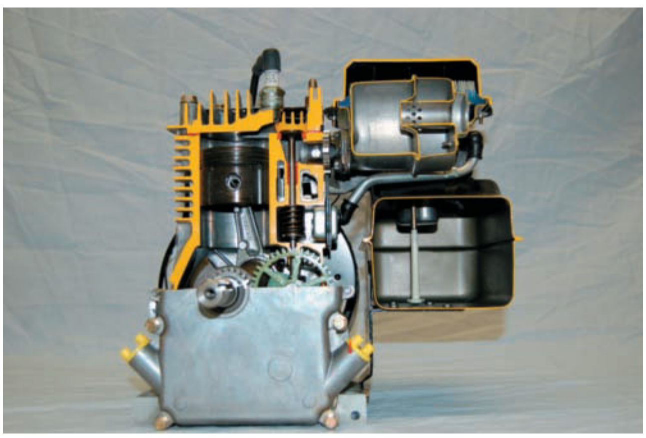

Figure 6-18 A cutaway of a one-piece engine crankcase (also known as a block). All the components of the engine are contained in or on the block.

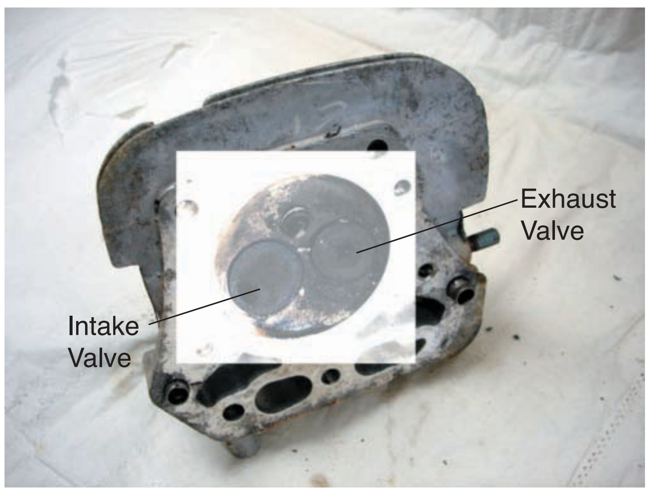

Figure 6-19 The intake valve (on left) is almost always larger than the exhaust valve.

into the induction system, where it's atomized and mixed with air. The air–fuel mixture is then transferred out of the induction system and into the cylinder through the intake valve, where it's vaporized. We'll discuss the specific functions and details of induction systems in Chapter 8.

The Strokes of a Four-Stroke Engine

Now, let's take a closer look at the individual operations, known as strokes, that occur in the four-stroke engine (Figure 6-20).

The Intake Stroke

During the **intake stroke**, the air–fuel mixture enters the cylinder. The intake sequence starts when the intake valve begins to open. As the piston moves downward in the cylinder away from the cylinder head, the volume of the cylinder above the piston expands. This increase in volume creates a low-pressure area, which develops a less-than-atmospheric pressure inside the cylinder. With the intake valve open, a path is completed through the intake manifold and carburetor. In an effort to balance the pressure difference between the atmospheric pressure of the outside air and the less-than-atmospheric pressure inside the cylinder, the outside air moves through the carburetor toward the cylinder. (Remember, gas in a high-pressure area will always seek a low-pressure area.) The intake valve closes and seals the combustion chamber when the piston is near the bottom of its stroke near the crankshaft.

The Compression Stroke

When the piston approaches BDC, both valves are closed. The air–fuel mixture is now trapped inside the sealed combustion chamber. At this point, the piston begins to rise, which compresses the air–fuel mixture very tightly in the combustion chamber. This is known as the **compression stroke**.

The Power Stroke

Just before the piston reaches TDC during the compression stroke, the engine's ignition system fires the spark plug; that is, the ignition system produces an electric current that causes a spark to jump across the two electrodes of the spark plug. When the spark is applied to the compressed air–fuel mixture, ignition causes a rapid contained burn and the compressed air–fuel mixture quickly expands.

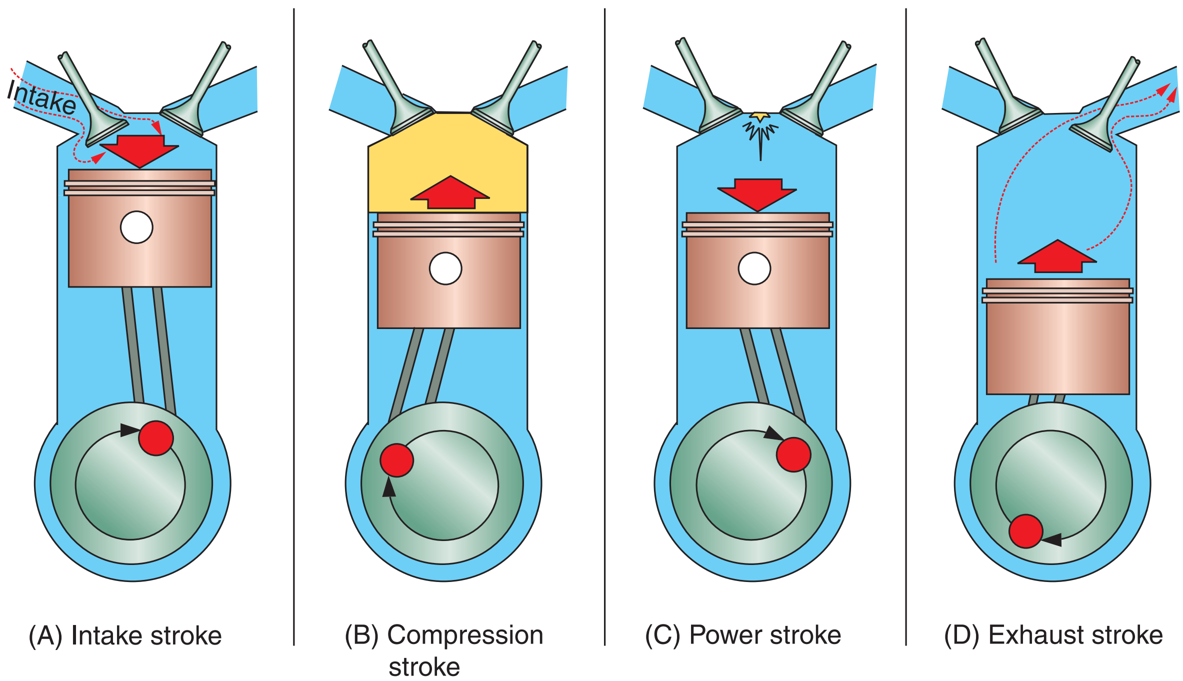

Figure 6-20 The four piston strokes of a four-stroke engine in the sequence needed to complete one cycle of operation. An engine runs by repeatedly completing this cycle.

When gases burn, they expand rapidly. The force of this contained burn pushes the piston down in the cylinder. The connecting rod, which connects the piston and the crankshaft, causes the downward motion of the piston to force the crankshaft to rotate. This is known as the **power stroke**.

The Exhaust Stroke

As the piston moves downward during the power stroke, the exhaust valve opens. By the time the piston reaches BDC, the exhaust valve is completely open. As the piston moves up again, it pushes the burned gases out through the exhaust valve. This is known as the **exhaust stroke**.

Once the exhaust event is completed, the four events of operation begin again. The movement of the camshaft closes the exhaust valve and opens the intake valve, and the piston moves down to begin a new intake event.

The four events of operation continue as long as the engine is operating. Keep in mind that these cycles are repeated at a very high speed. An average power equipment engine crankshaft rotates anywhere from 500 to 10,000 revolutions every minute. This means that these engine cycles are repeated thousands of times over and over again.

TWO-STROKE ENGINES

We'll now describe the components found in the two-stroke engine. We'll discuss the operation of the two-stroke engine as well as the different types of induction systems (the way that the air–fuel mixture passes through the engine) found in a two-stroke engine.

You've already learned that an engine is classified according to the number of strokes its piston takes to complete one full engine cycle. You've also learned that, for any engine to operate, it must run through four events of operation: intake, compression, power, and exhaust. The four-stroke engine accomplishes these four events in four piston strokes—one stroke for each event. Now we'll learn how the two-stroke engine operates.

As you're aware, in a two-stroke engine, the piston takes only two strokes to complete one full operational cycle. When the piston in a two-stroke engine moves in an upward direction, it completes the intake and compression events. When the piston moves downward, it completes the power and the exhaust events.

Two-stroke engines are much simpler in design than four-stroke engines. The basic two-stroke engine has only three moving parts: the piston, the connecting rod, and the crankshaft. Note that in the two-stroke engine, there's no camshaft to operate valves for the flow of the air–fuel mixture or exhaust gases.

TWO-STROKE ENGINE COMPONENTS

Before you learn how two-stroke engines operate, we'll discuss the component parts used in two-stroke engines. You'll notice that many of the parts used in the two-stroke engine are similar—if not identical—to those used in the four-stroke engine.

As we've mentioned before, not all engines look exactly the same. The engines illustrated here are typical of many of the two-stroke engines you'll see.

Two-Stroke Engine Cylinder Heads

There are no ports (and therefore no valves) in the two-stroke cylinder head. The purpose of the two-stroke cylinder head is to create a combustion chamber by sealing the area between the cylinder and the cylinder head (Figure 6-21). The second purpose is to hold the spark plug. The squish area of the combustion chamber forces the air–fuel mixture into a tight pocket under the spark plug to increase the combustion efficiency. This squish area, or the squish band, is more critical in the two-stroke engine as compared with the four-stroke engine.

The modern two-stroke cylinder head is constructed of aluminum alloy. Like four-stroke cylinder heads, two-stroke cylinder heads also aid in the transfer of heat from the engine by the use of fins in air-cooled engines or water jackets in liquid-cooled engines.

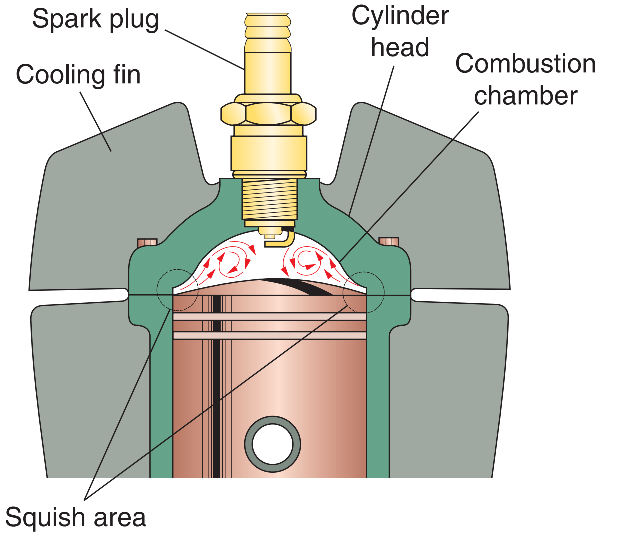

Figure 6-21 The two-stroke cylinder head attaches to the cylinder just as on a four-stroke engine. Note the squish area, which forces the air–fuel mixture into a tight pocket under the spark plug to increase the combustion efficiency. This squish area is more critical in the two-stroke engine as compared with the four-stroke engine.

Two-Stroke Cylinders

The main difference between the two-stroke cylinder and the four-stroke cylinder is that the two-stroke cylinder has holes located in the cylinder wall called ports (Figure 6-22). These ports serve the same purpose as the ports in the cylinder head (or block depending on the engine type) of the four-stroke engine.

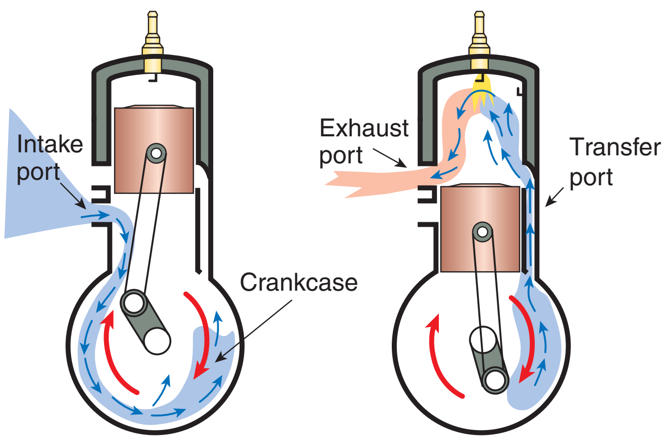

Figure 6-22 Ports are located on the cylinder wall of the two-stroke engine.

Ports allow the air–fuel mixture to enter the cylinder and exhaust gases to leave the cylinder and are opened and closed by the piston.

The ports in a two-stroke cylinder may be bridged. Bridged ports are used on very wide ports to prevent the piston ring from catching on the edge of the port. Both the upper and lower edges of the ports are chamfered. When ports are chamfered, the sharp edge of the port is removed to help keep the piston ring from catching as it moves up and down in the cylinder. The ports that may be found in the two-stroke cylinder are:

- The exhaust port, which is used to allow the exhaust gases to escape.
- The transfer ports, which are used to transfer the intake gases from the crankcases to the combustion chamber.
- The intake port, which is used to allow the gases to enter the crankcase.

Like the four-stroke cylinder, the two-stroke engine cylinder guides the piston as it travels up and down. The cylinder also aids in transferring engine heat and may be either air cooled or liquid cooled. Also, just as with the four-stroke engine cylinder, there are different types of materials used in the construction of a two-stroke cylinder. Each material has its own advantages and disadvantages. You may wish to review the section on four-stroke cylinders in this chapter for a refresher on the different materials and their advantages and disadvantages.

It should be noted that many small two-stroke engines have the cylinder and head attached together.

Two-Stroke Pistons

Just as with the four-stroke piston, the purpose of the two-stroke piston is to transfer the power produced in the combustion chamber to the connecting rod. The two-stroke piston has pins to prevent the piston rings from rotating around the piston and being caught in the cylinder ports (Figure 6-23).

The two-stroke piston is similar in design from the four-stroke piston (see Figure 6-24).

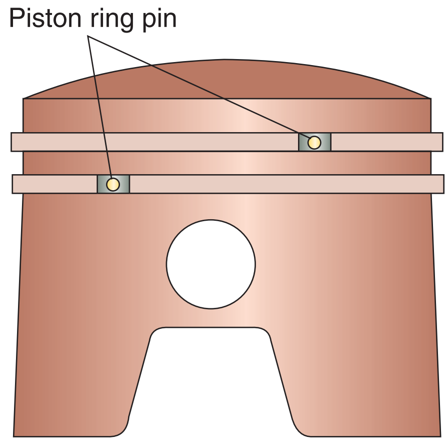

Figure 6-23 Pins installed in the two-stroke piston prevent the piston rings from rotating.

The crown, which acts as the bottom of the combustion chamber, is the top of the piston. The crown is the hottest part of the piston, because of high combustion chamber temperatures. The crown area, as in the four-stroke engine, expands more than the rest of the piston because it's hotter and has more mass. The piston crown on the two-stroke engine generally has a positive dome, but may have a flat top or even a negative dome or dish. The piston crown on a two-stroke engine also controls the duration of the exhaust and transfer ports. Duration is the time that the ports are open and is measured in crankshaft degrees.

Ring grooves have pins installed in them to prevent the piston rings from rotating. The two-stroke piston generally has no more than two piston ring grooves. Piston ring lands support the piston rings.

The wrist pin boss is where the piston attaches to the small end of the connecting rod. A hardened tool-steel wrist pin attaches the piston to the rod. The wrist pin is generally held in place with retaining clips to prevent the wrist pin from contacting the cylinder wall.

The piston skirt is the load-bearing surface of the piston. The piston skirt contacts the cylinder wall and is the primary wiping surface for the cylinder wall. The largest diameter of the piston is usually at or close to the bottom of the skirt, 90° from the wrist pin. This is where the piston is generally measured.

Two-Stroke Piston Rings

The purpose of the two-stroke piston ring is to aid in heat transfer from the piston to the cylinder wall and to seal in the combustion gases. There are three different types of piston rings used on the two-stroke piston (Figure 6-25).

The standard piston ring is rectangular in shape and is the most popular ring found on the two-stroke engine. Standard rings are usually made of cast iron and are chrome plated.

The keystone piston ring is a wedged-shaped ring that seals better than the standard piston ring. However, the keystone ring is more

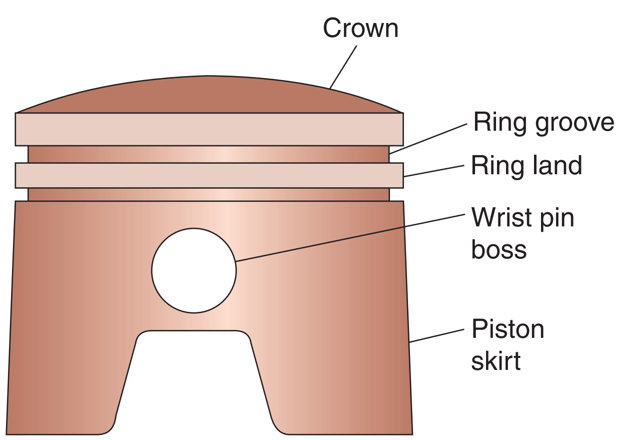

Figure 6-24 The parts of a typical two-stroke piston.

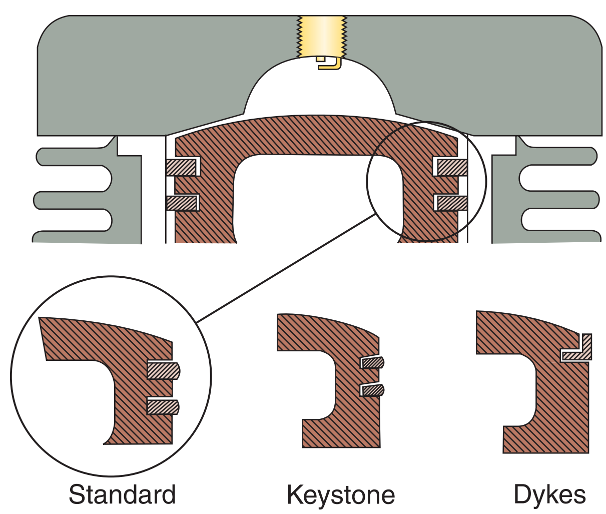

Figure 6-25 The three common types of two-stroke piston rings.

expensive to manufacture and requires a special wedge-shaped piston groove.

The Dykes piston ring is an L-shaped ring that's used only as a top ring on the piston. This type of piston ring expands outward when the combustion gases force the piston downward. Although the Dykes ring is the most expensive piston ring to produce, it's also the best-sealing ring found on a two-stroke piston.

All piston rings must have an end gap to allow for heat expansion. As we had discussed with the four-stroke piston ring, the piston ring end gap is measured using a feeler gauge (blade) after fitting the ring squarely in the cylinder. In the two-stroke engine, the ring end gap fits around the piston pin that prevents the ring from rotating around the piston.

Two-Stroke Crankshafts

The two-stroke engine generally uses a multipiece crankshaft (Figure 6-26). The crankshaft halves are cast or forged. The connecting rod journal is a pin (crankpin) that's press fit into the crankshaft halves. A one-piece connecting rod uses a roller bearing at the connecting-rod journal. The multipiece crankshaft generally uses ball bearings on the main journals. Most multipiece crankshafts found on a two-stroke engine can be rebuilt.

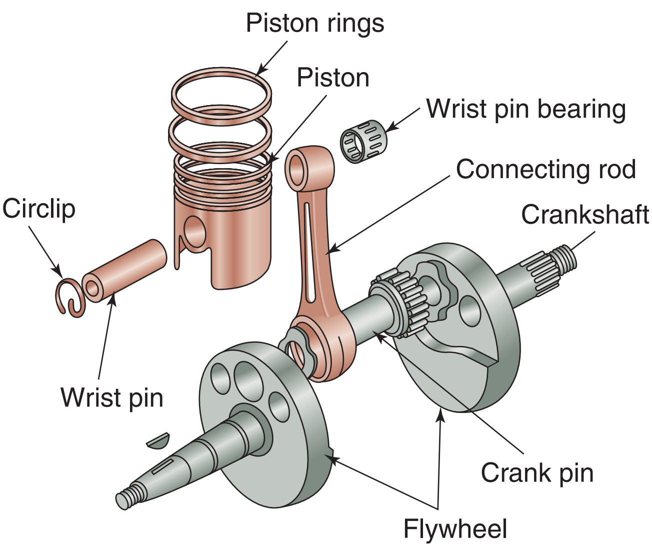

Figure 6-26 The parts of a two-stroke engine crankshaft.

Two-Stroke Engine Connecting Rods

The connecting rod (Figure 6-26) is a lever that transfers power from the piston to the crankshaft. Connecting rods are usually made of stamped steel, forged steel, or aluminum. Some use an I-beam construction for added strength. The connecting rods found on two-stroke engines are a one-piece design. This design uses a roller bearing at the big end and a needle bearing at the small end of the rod. The one-piece connecting rod generally has holes or slots on both the small and large ends for added lubrication.

Two-Stroke Engine Crankcases

The purpose of the two-stroke crankcase is the same as that of the four-stroke crankcase—to house and support the major engine components. These components include the crankshaft and cylinder. Unlike the four-stroke engine, which requires ventilation, the two-stroke crankcase must be sealed from the atmosphere to create pressure and vacuum pulses. The two-stroke engine crankcase is usually multipiece and can be horizontally or vertically split. In many two-stroke engines, the cylinder is separate from the crankcase instead of being part of the block, as in four-stroke engines. Crankcase seals are used in this design to allow pressure to be held inside the crankcase when the piston moves up and down.

THEORY OF OPERATION OF THE TWO-STROKE ENGINE

Although a two-stroke engine has many of the same components as a four-stroke engine, its method of operation is different. You'll remember that in a four-stroke engine, one power stroke occurs every two revolutions of the crankshaft. In a two-stroke engine, one power stroke occurs for each crankshaft revolution. Two-stroke engines are much simpler in design than four-stroke engines. The basic two-stroke engine has only three moving parts: the piston, the connecting rod, and the crankshaft. The two-stroke engine, though simpler in construction, is more complex in its operation.

The moving parts in all engines must be lubricated with oil to prevent wear. Although we'll discuss the lubrication systems used in two-stroke engines in Chapter 7, it should be noted that the two-stroke engine mixes the oil used for lubrication of the engine components with the fuel supply.

The Four Events of Two-Stroke Engine Operation

Remember, the two-stroke engine must go through the same four events of engine operation as any internal combustion engine—intake, compression, power, and exhaust. However, where the four-stroke engine uses one piston stroke to accomplish each event, the two-stroke engine uses just one piston stroke to accomplish two events (Figure 6-27). Each time the piston moves upward, it completes the intake and compression events. Each time the piston moves downward, it completes the power and exhaust events. Because two events of engine operation occur for each piston stroke, the operation of the two-stroke engine is more complex when compared to that of the four-stroke engine.

Two-Stroke Engine Areas

The two-stroke engine is split into two different areas (Figure 6-28):

- The primary area is the area below the piston crown, including the crankcase. The crankcase in a two-stroke engine must be sealed to allow for the compression of the intake gases while they're in the primary area.
- The secondary area is the area above the piston crown, including the combustion chamber, where the air–fuel mixture is compressed to prepare for ignition.

Two-Stroke Engine Ports

Two-stroke engines don't use the same mechanical valves in the combustion chamber as four-stroke engines do. Instead, the two-stroke engine has holes in the cylinder walls called **ports** (Figure 6-29). These ports control the flow of the air–fuel mixture and exhaust gases. As the piston moves up and down in the cylinder, it covers and uncovers these ports, allowing the air–fuel mixture to enter while also allowing the removal of the exhaust gases.

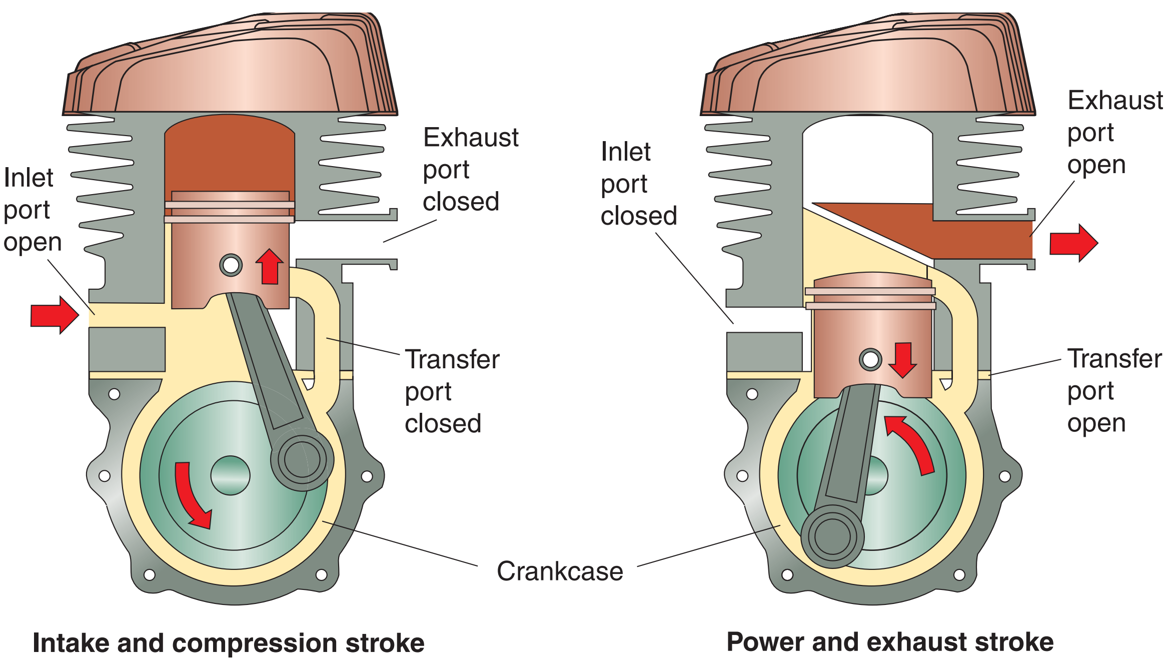

Figure 6-27 In a two-stroke engine, as the piston moves upward, it completes the intake and compression stages of operation. As the piston moves downward, it completes the power and exhaust stages of operation.

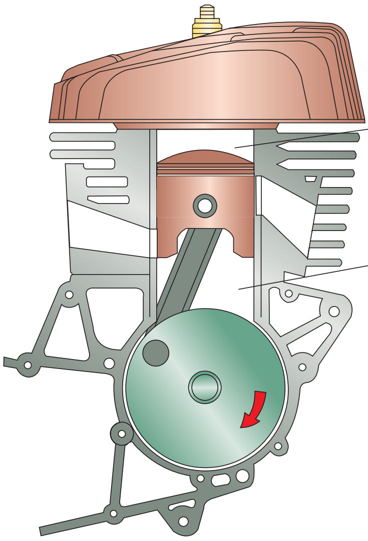

Figure 6-28 The area below the piston is called the primary area (crankcase). The area above the piston is called the secondary area (cylinder).

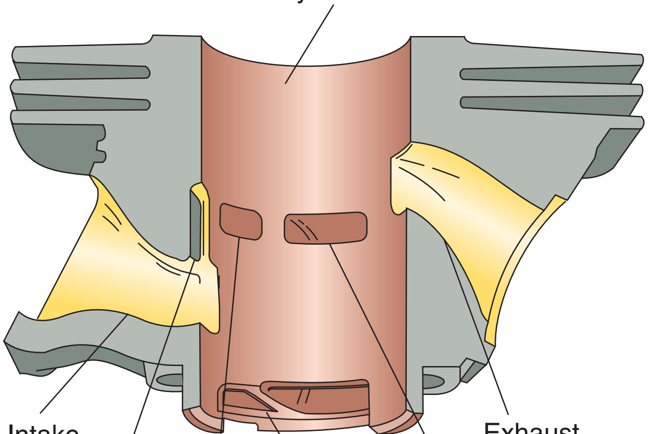

Figure 6-29 This cutaway view of a two-stroke cylinder shows its ports.

Two-stroke engines have different types of ports to allow for the flow of intake and exhaust gases.

The intake port is used to control the flow of fresh air and fuel into the primary area (crankcase area). Depending on the induction system used, the intake port either is the lowest port in the cylinder or is in the crankcase.

The boost port isn't used on all two-stroke cylinders. It's found primarily on two-stroke engines using reed valves. When boost ports are used, there may be one or more that are located at the rear of the cylinder, opposite the exhaust port. The purpose of a boost port is to allow an extra amount of the air–fuel mixture to flow into the combustion chamber directly from the intake port area. This directly bypasses the crankcase and transfer ports to help fill the secondary area with additional fresh air and fuel to produce more power.

The transfer ports are used to control the transfer of the air–fuel mixture from the primary (crankcase) area to the secondary (cylinder) area. The transfer inlet is located at the bottom of the cylinder where it meets the crankcase assembly. The transfer outlet is located in the middle of the cylinder, attached to the crankcase through a transfer tube, which is cast into the cylinder. The transfer ports are controlled by the position of the piston crown. The number of transfer ports varies from engine to engine. When more than two transfer ports are used, the extra ports are called auxiliary ports.

The exhaust port controls the flow of the exhaust gases from the cylinder. The exhaust port is the highest port in the cylinder. The opening and closing of the exhaust port is controlled by the position of the piston crown.

Two-Stroke Engine Events

There are five actual events that occur in each engine cycle of a two-stroke engine (Figure 6-30). To complete all five events, it takes only two strokes of the piston, which is one revolution of the crankshaft.

The **intake event** begins when the piston moves toward TDC. The primary (crankcase) area, located below the piston, increases in size, which causes pressure to decrease. Because of the pressure difference, fresh air and fuel are pushed into the primary area through the intake port. The intake event has the longest port duration of all of the two-stroke events.

The **compression event** (also known as secondary compression) occurs as the secondary (cylinder) area decreases above the piston. The air–fuel mixture that was previously brought

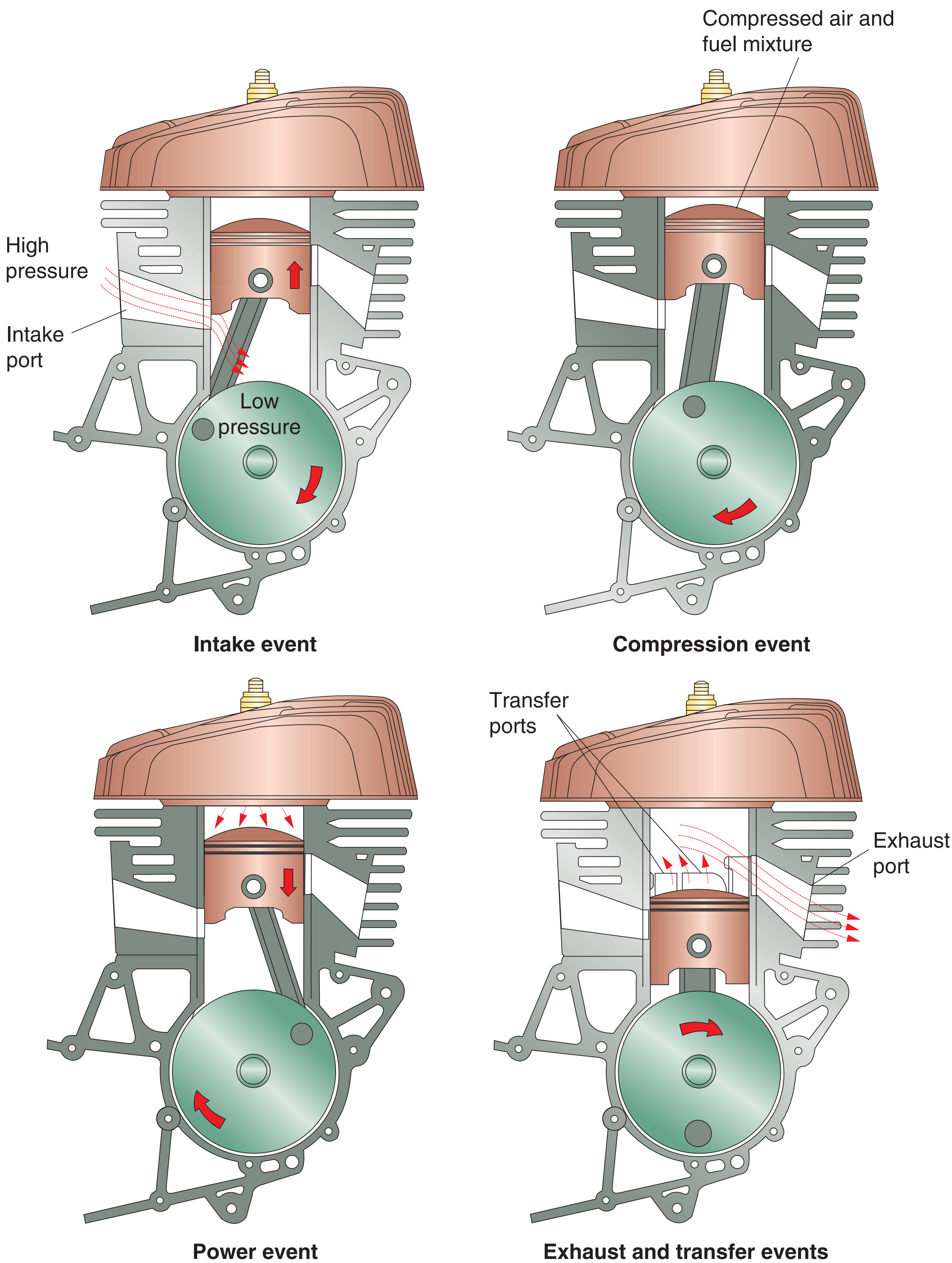

Figure 6-30 The five events that occur in one crankshaft revolution in a two-stroke engine.

into the cylinder is compressed while the piston is still moving toward TDC. At a precise time, the ignition fires and creates a spark at the spark plug.

The **power event** begins after the piston reaches TDC, when the expanding combustion gases caused by the ignition force the piston downward. The power event ends when the exhaust port is uncovered (opened) by the piston.

The **exhaust event** begins when the piston crown uncovers the exhaust port while moving down toward BDC. Because of the high pressure in the cylinder, the exhaust gases are pushed into the exhaust system.

The **transfer event** also occurs as the piston is moving toward BDC. As the piston travels downward, the primary area decreases, which increases the primary-area pressure. This is known as primary compression in a two-stroke engine. While this occurs in the primary area, the secondary-area pressure decreases. Because of the pressure differences between the primary and secondary areas, the fresh air–gas mixture located in the primary area is pushed through the transfer ports into the secondary area. The transfer event occurs during the exhaust event, which helps scavenge (similar to four-stroke valve overlap) residual exhaust gases by pushing the remaining exhaust gases out through the exhaust port. The transfer event has the shortest port duration. The transfer event uses what's known as loop scavenging, in which the transfer ports are angled away from the exhaust ports. The angle of the transfer ports directs the fresh air–fuel mixture up and away from the exhaust port to prevent the mixture from directly flowing out of the port.

TWO-STROKE ENGINE INDUCTION SYSTEMS

As we've discussed, the intake air–fuel mixture flows through ports inside the engine. Two-stroke engines use different methods of controlling the intake flow by what's known as induction. **Induction** is the method used to pass the air–fuel mixture through the intake port of the engine. Two-stroke power equipment engines use three types of induction systems.

Piston Port Induction

The piston port engine is the oldest and simplest type of two-stroke engine. This engine contains all three engine ports (intake, transfer, and exhaust) in the cylinder walls. As the piston moves up and down, it covers or uncovers the ports.

The piston skirt opens and closes the intake port. As with all two-stroke engines, the piston port engine has a sealed crankcase. As the piston moves upward, low pressure is created in the crankcase. The intake port is uncovered and the air–fuel mixture is drawn into the crankcase. As the piston continues to move up the cylinder, the exhaust and transfer ports are covered and the air–fuel mixture that's already in the combustion chamber is compressed.

When the piston approaches TDC, the spark plug fires and ignites the air–fuel mixture in the combustion chamber. Once the piston reaches TDC, it's forced downward by the expanding gases and the exhaust gases flow out the exhaust port. As the piston moves downward, the air–fuel mixture in the crankcase is compressed. The transfer port is still closed at this time. As the piston continues downward, the piston uncovers the transfer port. When the transfer port is uncovered, the air–fuel mixture moves from the crankcase area, through the transfer port, and into cylinder. As the air–fuel mixture enters the combustion chamber area, it helps to remove the remaining exhaust gases. When the piston starts to rise, the intake and compression events begin again.

The piston port engine has the narrowest power band of all two-stroke engines. It may be tuned to run at low speed or high speed, but not both. If the piston port engine is tuned to run at high speed but is operated at low speed, the carburetor tends to allow fuel to come back out of the carburetor. This is called spit back.

Reed Valve Induction

To aid in keeping the crankcase sealed and prevent a loss of pressure as the piston moves downward, many modern two-stroke power equipment engines use small one-way valves called reed valves (Figure 6-31). A reed valve opens during the intake-and-compression event and then closes tightly during the power-and-exhaust event, to seal the crankcase area and prevent any of the fuel mixture from escaping back into the carburetor. This prevents spit back.

A reed valve is placed generally between the carburetor and the intake port of the engine. As the piston moves upward during the intake-and-compression event of operation, the air–fuel

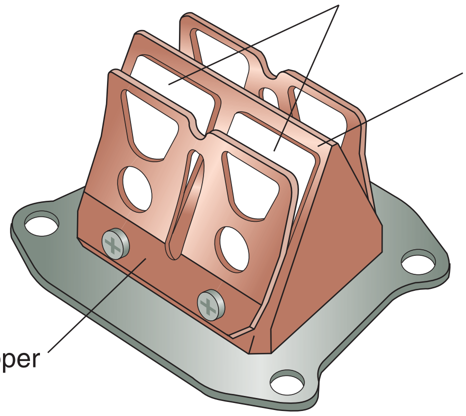

Figure 6-31 A typical reed valve assembly.

mixture is pulled through the reed valve into the crankcase. When the piston reaches TDC, the reed valve closes, to prevent the air–fuel mixture from flowing back through the carburetor. In this way, the air–fuel mixture is compressed more completely in the crankcase, which allows the mixture to be pushed more forcefully into the combustion chamber as the piston reaches BDC. Reed valves are made from one of two materials: stainless steel or fiber resin material (fiberglass or carbon fiber).

In some engines that use reed valves, the piston may have either a cutaway or holes on the intake side of the piston skirt to allow the flow of the intake mixture at all possible times (Figure 6-32).

Common Reed Valve Induction Systems

There are three types of reed valve induction systems commonly used in two-stroke power equipment engines.

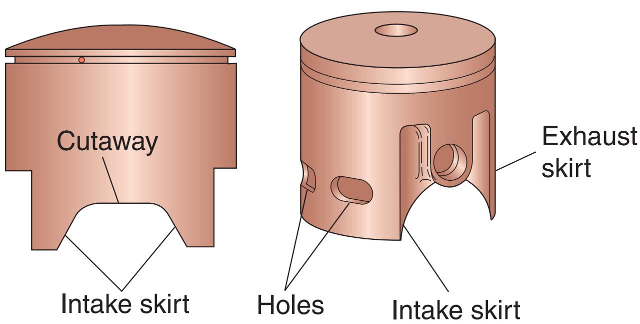

Figure 6-32 Two types of reed valve pistons. The piston on the left uses a cutaway on the intake side of the piston skirt. The piston on the right has holes on the intake side of the piston skirt.

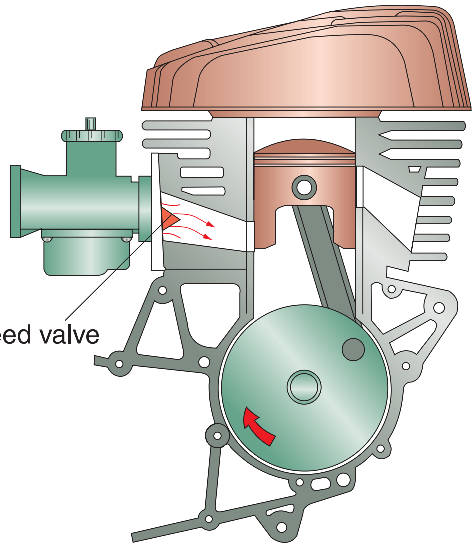

Figure 6-33 The location of the reed valve in a cylinder reed valve induction system in an air-cooled two-stroke engine.

In some older and larger two-stroke engines, the cylinder reed valve induction design (Figure 6-33) has the intake port in the same location as the piston port engine (located in the cylinder). With a cylinder reed valve engine, the intake port never closes. The purpose of the cylinder reed valve engine is to broaden the power band of the standard piston port engine. By using reed valves on a piston port engine, we can tune the engine to run at high speed while the valve prevents spit back through the carburetor at lower speeds.

The crankcase reed valve induction system (Figure 6-34) has the intake port located directly on the crankcase. This design can develop a

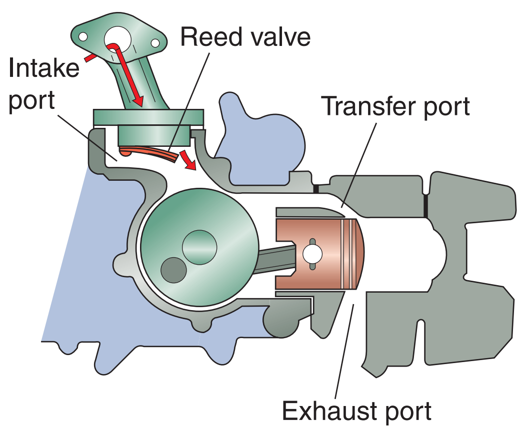

Figure 6-34 The location of the reed valve in a crankcase reed valve induction system.

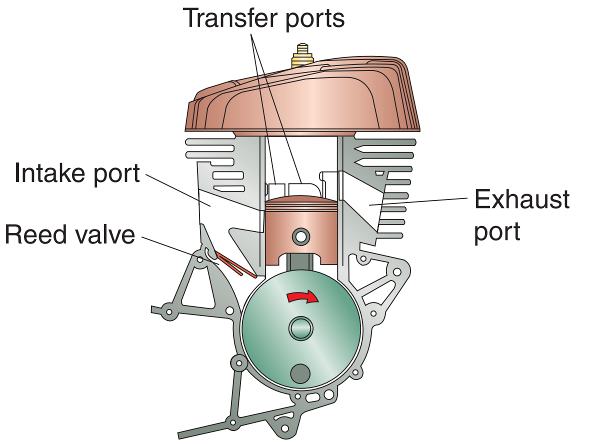

Figure 6-35 The location of the reed valve in a piston port/crankcase reed induction system.

wide power band because it allows a shorter and more direct path to the crankcase and permits approximately 33% more transfer port area. This lets more air and fuel enter the combustion chamber.

The piston port/crankcase reed induction system (Figure 6-35) takes the benefits of both the piston port type of induction to control the lower-speed range of the engine and the crankcase reed induction system for high-speed operation.

Rotary Valve Induction

The rotary valve induction system has the intake port located on the crankcase of the engine (Figure 6-36). A rotary disk that covers and uncovers the intake port controls the opening and closing of the port. The disk is attached directly to the crankshaft. When the cutaway opening on the disk aligns with the intake port, fuel flows into the crankcase. In a rotary valve assembly, the rotary plate rotates between two fixed plates or between a fixed plate and the crankcase. The two fixed plates, or fixed plate and crankcase, also contain openings. Fuel enters the crankcase only when all three holes line up during the rotation of the rotary plate. At all other times, the rotary valve blocks the passage from the carburetor to the crankcase.

The rotary valve engine design is seldom used in today's power equipment engines because of its size. Rotary valve engines have carburetors attached to the crankcase near the crankshaft and each cylinder has its own disk, which requires that the engine be wider than engines of other designs. This engine generally has the

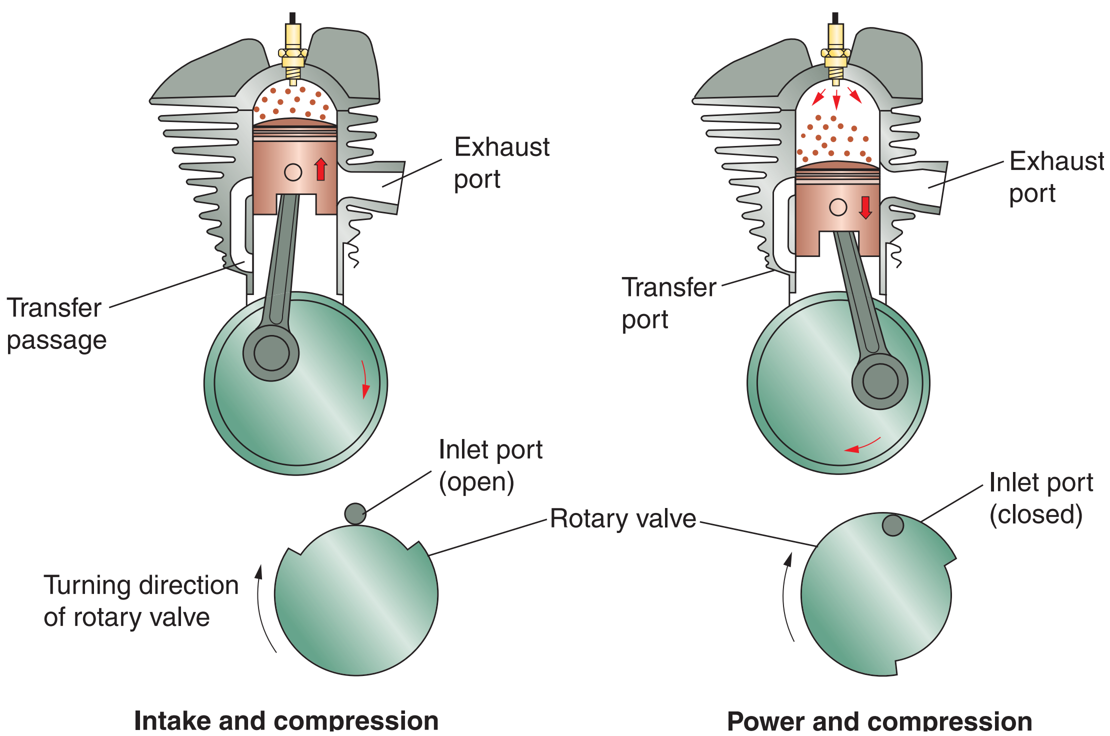

Figure 6-36 A rotary-valve induction system in a two-stroke engine.

widest power band because it has the shortest and most direct intake path into the primary area of the crankcase.

TWO-STROKE EXHAUST SYSTEMS

The two-stroke exhaust system is a tuned chamber that operates from sonic (sound) waves created by the engine. The shape of the chamber has a direct effect on the performance of the two-stroke engine's operational characteristics. The shape of the expansion chamber also aids in the scavenging of residual exhaust gases and allows for an adjustment of the power band characteristics of the engine.

COMPARING TWO-STROKE AND FOUR-STROKE ENGINES

There are many advantages and disadvantages of two-stroke and four-stroke engines. Because each engine is specifically designed to produce good power over a broad range of engine speeds, you would think that manufacturers would tend to make only one type of engine or the other. Power equipment engine manufacturers are constantly working to build better, longer-lasting, and more powerful engines.

So, which engine is better—the two-stroke engine or the four-stroke engine? Let's look at the two-stroke engine and compare it with the four-stroke engine.

Advantages of the Two-Stroke Engine

The most noticeable advantage of the two-stroke engine over the four-stroke engine is that the two-stroke engine has fewer internal moving parts. This allows the two-stroke engine to be smaller and lighter than the four-stroke engine. In almost all cases, the two-stroke engine will be lighter than the four-stroke engine when comparing equal displacement engines.

Another advantage of the two-stroke engine is that it generally produces more horsepower compared with a four-stroke engine of equal size. This is because the two-stroke engine has twice as many power strokes in the same given period of time as the four-stroke engine, resulting in better mechanical efficiency.

With these advantages, why aren't all power equipment engine made of two-stroke engines? To answer that question, let's look at the disadvantages of the two-stroke engine.

Disadvantages of the Two-Stroke Engine

The primary disadvantage of the two-stroke engine is that it emits a large amount of hydrocarbons (unburned fuels) in the exhaust, making it a high air-polluting engine. This occurs during the transfer and exhaust events of operation. While the intake gases are being transferred from the primary area to the secondary area of the engine, some of the raw, unburned fuel mixture escapes directly out the exhaust system and into the atmosphere. Even with a properly tuned exhaust system, some raw fuel escapes from the exhaust port at certain engine speeds.

Other disadvantages of the two-stroke engine are directly related to one of its primary advantages. Because the two-stroke engine creates a power stroke every time the crankshaft makes one revolution, it burns more fuel than the four-stroke engine in the same time period. This generally results in poorer fuel economy. The two-stroke engine also runs at hotter temperatures compared with four-stroke engines for this same reason. Because the two-stroke engine runs hotter, it's internal parts wear out sooner than those of the four-stroke engine. This tends to make the two-stroke engine less reliable. It therefore requires more frequent service than the four-stroke power equipment engines.

Finally, as we had mentioned earlier, the basic two-stroke engine has a narrow power band when compared with the four-stroke engine's generally wide power delivery over a range of speeds. For these reasons, most power equipment engine manufacturers primarily build four-stroke engines.

Comparison Tables

Table 6-1 summarizes our discussion of the advantages and disadvantages of the two-stroke engine compared with the four-stroke engine.

Table 6-2 compares the advantages and disadvantages of the four-stroke engine compared with the two-stroke engine.

Table 6-1 Advantages and disadvantages of the two-stroke engine

Advantages	Disadvantages
Fewer internal parts	High HC emissions (air pollution)
Lighter	Poor fuel economy
Generates more power	Higher engine temperatures
Higher mechanical efficiency	Generally less reliable Frequent servicing required Narrow power band

Table 6-2 Advantages and disadvantages of the four-stroke engine

Advantages	Disadvantages
Lower HC emissions (less air pollution)	More internal moving parts
Better fuel economy	Heavier
Lower engine temperatures	Generates less power
Generally more reliable Less vibration (smoother running) Wider power band	Lower mechanical efficiency

Summary

- There are certain physical laws associated with power equipment engines.
- All internal combustion engines run using the same basic operational methods.
- A mixture of fuel and air is used to make an engine operate.
- There are four piston strokes that must be in sequence to complete one full cycle in a four-stroke engine.
- Many components used in a two-stroke engine are similar to the components found in a four-stroke engine.
- Although simple in construction, the operation of the two-stroke engine is somewhat complex.
- There are different types of induction systems used in the two-stroke engine.
- A two-stroke engine has various differences compared with a four-stroke engine.
- There are advantages and disadvantages with both a two-stroke engine and four-stroke engine used in the modern power equipment.

Chapter 6 Review Questions

1. If you travel from sea level to 10,000 feet above sea level, what happens to the density of the air?
2. If a gas is compressed, what happens to its temperature?
3. What type of liquid has the ability to burn?
4. What are the four events of engine operation?
5. What type of combustion engine is found in all modern-day power equipment engines?

6. The camshaft in a four-stroke engine rotates at _____ the speed of the crankshaft.
7. The one-piece connecting rod is used on multipiece crankshafts. (True/False)
8. In a four-stroke engine, if the piston is rising toward TDC and valves are closed, the engine is on the _____ stroke.
9. Hot gases are released from the four-stroke engine during the _____ stroke.
10. The cylinder used in a two-stroke engine contains _____ to allow for the flow of gases through the engine.
11. The three basic moving parts in a two-stroke engine are the _____, the _____, and the _____.
12. The _____ opens and closes the ports in a two-stroke engine.
13. Two-stroke engines generally generate more hydrocarbon emissions than four-stroke engines. (True/False)
14. Two-stroke engines are heavier than four-stroke engines. (True/False)

CHAPTER

7 Lubrication and Cooling Systems

Learning Objectives

- Define the four key purposes of lubrication
- Describe the types of lubricating oils and how they're classified
- Explain why bearings, bushings, and seals are needed in an engine
- Identify the different types of bearings used in power equipment engines
- State the purpose of two-stroke and four-stroke engine lubrication systems
- Identify the different types of lubrication systems used in two-stroke and four-stroke power equipment engines
- Describe how cooling systems work and why they're used
- Identify the components of power equipment cooling systems
- Identify the various specialty lubricants used in lubrication system maintenance

Key Terms

Bearings
Bleeding
Bushings
Coolant
Engine seizure
Friction
Grease
Hydrometer
Multi-viscosity oil
Oil additives
Oil injection system
Radiator
Seal
Thermostat
Viscosity index

INTRODUCTION

Both two-stroke and four-stroke engines used in power engine equipment have many moving internal parts that are machined to extremely tight tolerances. To the naked eye, these parts have a smooth, fine finish, which is required to optimize wear inside the engine. However, if you were to look at these parts under a microscope, you would see that these seemingly smooth parts are actually quite rough! To reduce the friction that occurs if two or more of these surfaces make contact, it's necessary to maintain a thin layer of lubrication between them (Figure 7-1).

A thin layer of lubricant between all internal engine parts effectively separates the parts from each other and provides a slight cushion for them to rest against. A lack of lubrication between these parts causes an immediate buildup of excessive heat and in extreme cases, causes the parts to actually melt together. When two or more parts inside an engine are hot enough to melt together in this manner, we say an **engine seizure** has occurred.

In addition to its role as a lubricant, oil inside an engine performs many other functions. The oil film that coats each internal part keeps air and moisture from the parts, thereby preventing the buildup of corrosion. Also, when used in the four-stroke engine, oil is constantly recirculated, carrying away contamination and trapping it in an oil filter. Oil is also used to aid in the creation of seals in two-stroke and four-stroke engine

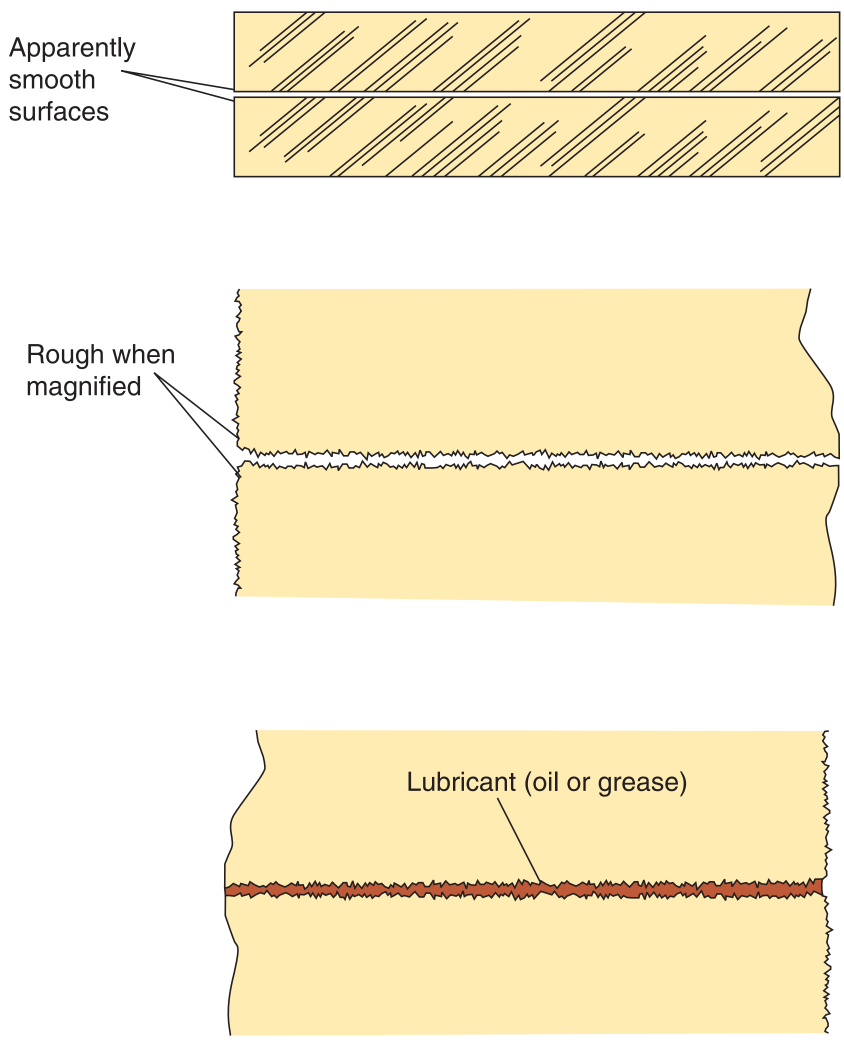

Figure 7-1 Engine parts that seem very smooth may actually be quite rough when viewed under magnification. Lubricants provide a cushion to prevent the rough edges of component parts from making contact with each other.

parts that require additional sealing. Finally, oil helps to disperse the heat generated in high-temperature areas such as the piston, cylinder, transmission, and combustion chamber.

Although power equipment engines built today are quite efficient, they still waste a considerable amount of energy. Ideally, a 100% efficient engine would convert all the heat energy it produces into mechanical energy. Unfortunately, there's a considerable amount of heat energy produced in engines that's not converted to mechanical energy, thus creating engine heat. It's the job of the lubricants and the engine lubrication and cooling systems to remove the unwanted heat, thus preventing engine damage.

Now, let's learn about lubricants, lubrication systems, and cooling systems used in the engines found in power equipment.

The importance of an engine's lubrication system and the lubricants used in power equipment engines can't be overemphasized. If proper lubricants are missing or the engine's lubrication system is operating improperly, the moving parts inside the engine will get hot enough to actually melt together, as mentioned earlier. These internal engine components can score or even lock together in a matter of minutes. The buildup of heat, caused by friction, is one of the worst enemies of the engine.

This chapter will give you an understanding of the types of lubricants and lubrication systems used in power equipment engines. It covers both two-stroke and four-stroke engine designs. You'll learn how bearings, bushings, and seals help control and reduce friction. In addition, we'll discuss lubrication requirements for components of the engine found in power equipment. You'll also learn about the specific cooling systems used in power equipment engines.

LUBRICANTS AND LUBRICATION

An engine has two main enemies: friction and heat. The main purpose of lubrication is to reduce friction. What is friction? **Friction** is the resistance to motion created when two surfaces move against each other, or when a moving surface moves against a stationary one. To understand what we are talking about here, take a moment and rub your hands together quickly, pushing against them as hard as you can. Feel the heat? That's friction! Now, do the same thing with one hand against any stationary object, like an arm on a chair. Then repeat the action with some lotion on your hands and you can feel the difference lubrication makes! Friction can occur in many places in a power equipment engine. Some of these places are the:

- Cylinder wall, where the piston and piston rings rub wrist pin and mating surfaces of the piston and connecting rod
- Crankshaft pin, bearing, and connecting rod
- Teeth of any gear inside the engine
- Camshaft lobes, valve guides, and valve stems (in four-stroke engines)

If these surfaces are not protected by some form of lubrication, they will quickly heat up and wear.

The great amount of heat created inside the engine by friction places a strain on vital engine components. To prevent these parts from overheating, modern power equipment engines require high quality lubricants. Lubricants and engine lubrication systems used in modern power equipment engines have been greatly improved over the years, thanks to the research done by power equipment engine and lubricant manufacturers. The useful life of an engine without proper lubrication might be measured in minutes; the service life of a properly lubricated engine can be thousands of hours!

Lubrication serves four key purposes. When used properly, a lubricant will

- Cool
- Clean
- Seal
- Lubricate to reduce friction

Cooling

When oil in the engine flows through oil passageways or splashes within the engine, it helps cool the internal engine components by absorbing heat from the metal parts. The circulating hot oil is then returned to the engine's crankcase, where it's cooled.

Cleaning

While the oil is moving around and through the internal engine components, it's also cleaning the engine's parts. Combustion and normal wear and tear of engine parts produce tiny metallic particles and other contaminants. Today's engine oils contain special additives that help hold these contaminants in suspension until they can be removed. The lubrication system removes contaminants as it passes oil through the engine's oil-filtering system. The oil filter system can't remove all the contaminants in the oil; those remaining are removed by draining the engine oil. This is why oil turns darker in color after hours of use.

Sealing

Another function of engine oils is to help the piston rings seal in engine compression and combustion pressures. A thin oil film between the piston rings and cylinder wall is essential for the rings to seal properly. Oil between the piston ring groove and piston rings also aids in preventing combustion pressure leakage. Oil on engine parts also protects the components from corrosion and moisture.

Lubricating

It should now be clear that power equipment engines consist of many internal components and parts that contact each other as they move. As a result of this contact, a certain amount of friction and heat is always present. The main purpose of oil in a lubrication system is to help reduce friction by keeping a thin layer of oil between all the engine parts. This thin film of oil helps to prevent excessive metal-to-metal contact and unwanted friction.

Remember, friction is the resistance to movement between two surfaces. A lubricant helps to reduce friction and the heat that friction produces. Lubricants thus reduce engine component wear.

Types of Engine Oils

In today's power equipment engines, selecting suitable lubricating oil is very important. Power equipment engine and oil manufacturers have worked hard to develop oils that meet and even exceed the high demands of power equipment engines. There are three basic types of oils used in today's engines.

Petroleum-Based Oils

The first type of oil is standard mineral-based oil, more widely known as petroleum-based oil. Petroleum-based oil starts out as crude oil, located in large underground pools all over the world. After this oil is removed from the ground, it's heated in a process known as fractional distillation. This process separates the needed lubricating oil from other elements within the crude oil. The oil is then blended with other additives to adjust its viscosity to desired levels. Viscosity is determined by the rate of oil flow under certain controlled conditions. High-viscosity oils flow slower at room temperature than low-viscosity oils.

Standard petroleum-based oils perform poorly without additives. **Oil additives** are selected and used in the manufacturing of oils to improve the oil's operating qualities. Additives don't change the basic characteristics of oil; they just add new properties to it. Several additives are used in oil today; each is selected for a specific purpose. Table 7-1 lists the types of commonly used additives and the characteristics they impart to oil. One example of an engine oil additive is sulfur, which is used to improve the oil's extreme-pressure properties. Another example is zinc, which is added to oil to increase its shear strength. Some desirable characteristics that result from the proper use of oil additives are higher film strength, resistance to foaming of the oil, resistance to oxidation of the oil, and the ability to keep oil contaminants in suspension. One important and interesting fact about standard mineral-based oils is that

Table 7-1 Improving an oil's operating qualities

Additive	Characteristics imparted to oil
Oxidation inhibitor	Increased life, less sludge
Corrosion inhibitor	Protection against chemical attack
Viscosity index improver	Improved viscosity–temperature characteristics
Pour point depressant	Low temperature fluidity
Oiliness agent	Increased load-carrying ability
Extreme-pressure additive	Lubrication under extreme pressures
Antifoam agent	Resistance to foam
Detergent/dispersant	Ability to suspend contamination

the base oils themselves don't wear out, only the additives do!

Synthetic-Based Oils

Another type of oil is synthetic-based oil. Synthetic oils were developed during World War II, when petroleum products were not widely available. Today's synthetic oils operate more efficiently and over a larger range of temperatures, compared with standard mineral-based oils. When synthetic oils are manufactured, a variety of synthetic additives are added to help increase the oil's effectiveness. Advantages of using synthetic-based oils include the ability to handle higher engine temperatures before breaking down and less viscosity change with change in temperature. The main disadvantage to using synthetic-based oils is that it may not be compatible with some petroleum-based oils. Synthetic-based oils are also more expensive than petroleum-based oils.

Petroleum–Synthetic Blended Oils

Blended oils are popular today. They combine a petroleum base stock with synthetic additives, instead of petroleum additives. This combination greatly increases the quality of the oil. For this reason, blended oils are widely used in today's power equipment engines.

Oil Classification

The internal combustion engine has become more sophisticated and technologically advanced over the years, thus increasing the operating requirements of engine oil. As a result, two general automotive agencies were established to test, standardize, and classify lubricating oils (Figure 7-2): the American Petroleum Institute (API) and the Society of Automotive Engineers (SAE). These agencies classify oil on the basis of:

- Manufacturer requirements regarding additives
- Intended use of the oil
- Viscosity ratings

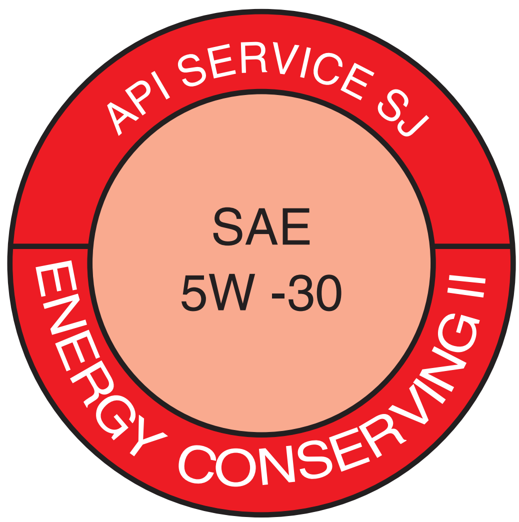

Figure 7-2 All lubricating oils have labels showing a classification determined by the American Petroleum Institute (API) and viscosity ratings by the Society of Automotive Engineers (SAE).

Letter Classification Codes

Oil classifications use a double-letter code to indicate their intended use and manufacturer requirements. Oils used in power equipment gasoline engines have a code that begins with the letter S. The "S" stands for "spark" ignition engines. The lowest-grade oil for use in the gasoline engine has a classification of SA. Rarely used today, this type of oil is a petroleum-based oil containing no additives. This oil classification isn't recommended for use in any power equipment engine. Today's highest classification of oil is rated SM. Oils rated SE, SF, SG, SH, SJ, or SL are also recommended for use in power equipment engines. Most manufacturers today recommend oil rated "SG or higher" for their engines.

Table 7-2 shows the classifications used by the API. The API also classifies diesel engine oil. The letter code for diesel oil is C. The letter "C" stands for "compression" ignition engines. Although you wouldn't use oil designed for a diesel engine in a power equipment engine, there are times when the same oil can be used for either engine. When this is the case, it's indicated on the API label. It's important to understand which oil to use in a particular power equipment engine. Engine service and owner's manuals contain the manufacturer's recommendation regarding oil usage.

Engine Oil Weight Classifications

Let's now discuss oil weight and how the SAE measures it. The weight of oil is a reference to its thickness, from extremely thin oils of 0-weight, up to 90- or 140-weight oils. It's important to understand that a lower-number weight, such as 10-weight oil, is thinner than higher-numbered oil, such as 40-weight oil. The oil-weight numbering system tells us that, all conditions being equal, a 10-weight oil flows faster than a 40-weight oil when poured through holes of the same size at the same temperature.

To determine the viscosity of oil, it's poured through an orifice at a predetermined temperature. Two temperatures are used to test oil viscosity. For winter usage, oils are tested at 0° Fahrenheit (°F) and are marked with a "W" after the number to indicate "winter." All other oils are tested at a temperature of 210°F or higher.

Table 7-2 API oil classifications

Rating	Service Duties
SA	Mild conditions, no additives (base oil only)
SB	Medium conditions, uses antifoaming and detergent additives
SC	Meets 1964 through 1967 automotive manufacturer requirements
SD	Meets 1968 through 1971 automotive manufacturer requirements
SE	Meets 1972 through 1979 automotive manufacturer requirements
SF	Meets 1980 through 1989 automotive manufacturer requirements
SG	Meets 1990 through 1993 automotive manufacturer requirements
SH	Meets 1994 through 1996 automotive manufacturer requirements
SJ	Meets 1996 through 2000 automotive manufacturer requirements
SL	Meets 2001 through 2003 automotive manufacturer requirements
SM	Meets 2004 through current automotive manufacturer requirements

Keep in mind that the weight numbers indicate the oil's viscosity rating only. A higher-numbered oil, such as a 50-weight oil, doesn't indicate better lubrication capacity than, say, a 10-weight oil. The weight of oil has nothing to do with its quality; it's a designation used for comparison purposes only.

So, what does this really mean? Different temperatures have a direct effect on oil viscosity. Oil tends to become thicker at lower temperatures; therefore, a lower weight number or a thinner oil should be used in cold weather conditions. Extremely hot temperatures require a higher-weight-numbered oil, or heavier, thicker oil.

Multi-Viscosity Oils

The majority of engine oils used in modern power equipment engines have designation numbers such as 10W40 or 20W50. This type of oil is called a **multi-viscosity oil**. These designations indicate oil viscosity that's suitable for use under many different climatic and driving conditions. For example, 10W40-rated oil gives proper lubrication in both cold and warm conditions. The 10-weight rating indicates that the oil will flow when the temperature is low (recall that the W stands for winter test). Protection is also provided as the temperature increases, as indicated by the 40-weight rating.

Multi-viscosity oils contain additives that allow the oil to work as a higher-weight oil at higher temperatures to improve the viscosity index. The **viscosity index** is the number used to indicate the consistency of the oil with changes of temperature. Oil labeled 10W30 is a 10-weight oil at 0°F, but has the viscosity of a 30-weight oil at 210°F. It's important to note that oils such as these are specially designed; thus, combining a straight 10-weight oil and 40-weight oil doesn't have the same effect as the factory-prepared 10W40 multi-viscosity oil.

The type or grade of lubricant best suited for any given power equipment engine component depends on many factors. Considerations include the type of power equipment engine running conditions, types of intended use, and weather conditions, such as dry, wet, or extremely hot. Power equipment engine manufacturers recommend a certain type or grade oil or lubricant for each specific component. It's best to follow the manufacturer's recommendations. If these recommendations aren't readily available, check with the manufacturer or ask your local power equipment engine dealership. They can usually give advice that will help determine product suitability for the job at hand.

Specialty Lubricants

Now that you have a basic understanding of engine oils, let's briefly discuss other types of lubricants used in power equipment engines. The type of specialty lubricant used depends on the component to be lubricated.

Grease

Grease is a lubricant that's suspended in gel. It's often used in non–engine-related components, such as wheel bearings and axles. Grease is designed for long-term lubrication.

Dry Lubricants

Dry lubricants are used to lubricate without attracting contaminants. These lubricants use an evaporating solvent as a carrier. Dry lubricants are often used on cables and areas that are in the open atmosphere.

Other Lubricants

You'll use many other types of specialty lubricants, such as silicone spray, penetrating oils, and multipurpose lubricants, on various parts of power equipment engines. These products are widely available and are used for everything from helping to loosen rusted nuts and bolts to lubricating squeaky parts.

FRICTION-REDUCING DEVICES

The purpose of friction-reducing devices in an engine is, as the name indicates, to reduce friction. These devices, called **bearings**, are also used to reduce free-play between engine shafts, allow for proper spacing, and support different types of loads. Bearings can use either a rolling motion or a sliding motion to reduce friction. Examples of bearings that use a rolling motion are:

- Ball bearings
- Roller bearings
- Tapered roller bearings
- Needle bearings

Examples of bearings that use a sliding motion are:

- Plain bearings
- Bushings

Keep in mind that the purpose of any bearing is to help reduce the buildup of friction between moving parts that are carrying a load.

Ball Bearings

Ball bearings are the most popular bearing used in power equipment engines because they provide the greatest amount of friction reduction and have the ability to handle both axial (side to side) and radial (rotating) loads.

Ball bearings consist of spherical balls contained in a cage and are held in place by inner and outer races (Figure 7-3). The cage ensures the balls don't touch one another. Ball bearings require very little lubrication. They're used to support crankshafts in both the two-stroke and four-stroke engine cases, allowing the shafts to rotate freely.

Roller Bearings

Roller bearings are similar in design to ball bearings, except they use cylindrical-shaped rollers instead of spherical balls. The roller bearing is capable of withstanding higher radial loads than the ball bearing because of its greater available surface contact area.

Tapered Roller Bearings

Figure 7-3 also shows a variation of the roller bearing, known as a tapered roller bearing. The diameter of each roller of a tapered roller bearing is larger at one end than at the other. Tapered roller bearings are normally used in pairs with opposing angles, such as in steering mechanisms.

Needle Bearings

Needle bearings are yet another variation of the roller bearing. The lengths of needles or rollers of a needle bearing are usually several times more than their diameters. Needle bearings normally have an attached cage, which keep the needles from making contact with one another. Needle bearings often have only an outer race. In this case, the needles make direct contact with the shaft surface they're supporting. Needle bearings can be found on some camshafts, and in almost all two-stroke engine connecting rods.

A key advantage of both the ball bearing and the roller bearing is that they can operate well with minimal lubrication. However, if there's complete absence of lubrication, either bearing will be destroyed because of the extreme heat that occurs during friction.

Plain Bearings

Precision insert bearings, more widely known as plain bearings, are typically made in the shape of a cylindrical sleeve and are designed to withstand extremely heavy loads (Figure 7-4). They're used exclusively in the four-stroke engine. These bearings normally come in two separate pieces, but may also be of a one-piece design.

Plain bearings have a large surface area, which provides them the ability to handle high radial loads. However, they don't reduce friction as efficiently as a ball bearing. Plain bearings can be found in two-piece connecting rod big ends, or they may be found as two-piece bearings supporting a crankshaft in the engine's crankcases. Many small engines use finely machined surfaces instead of plain bearings.

Plain bearings require constant high oil pressure to produce a lubricating film known as hydrodynamic lubrication. This oil film, located between the rotating shaft and the bearing, is required at all times during engine operation to prevent unwanted metal-to-metal contact.

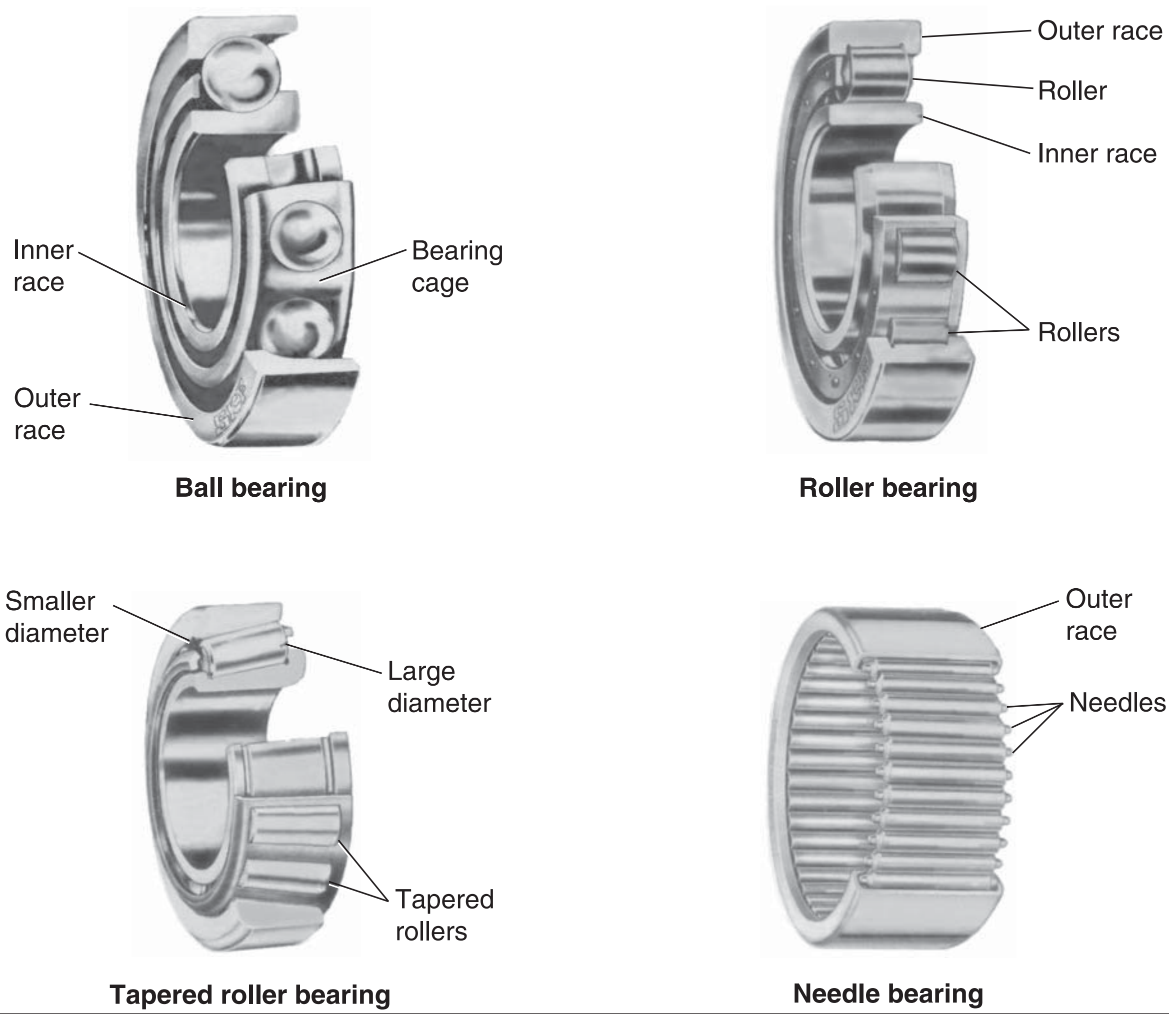

Figure 7-3 Different bearings commonly found in power equipment engines and their components.

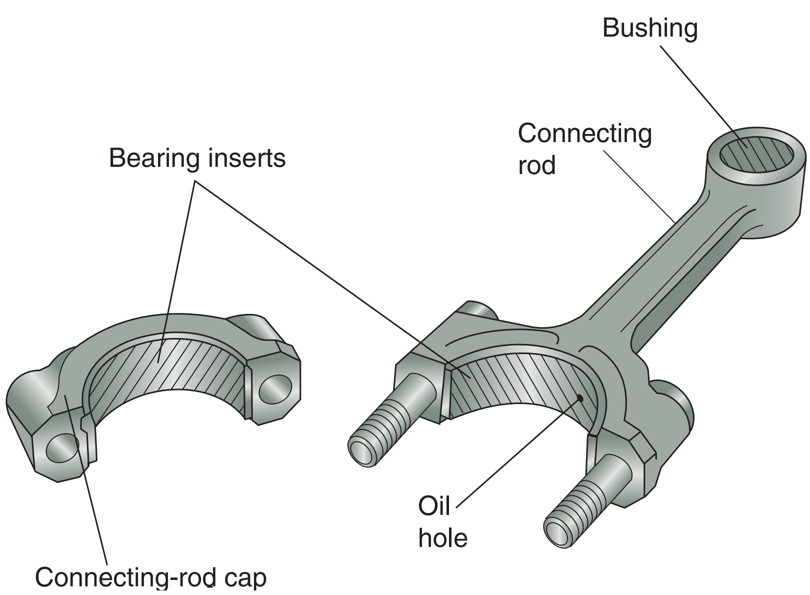

Figure 7-4 Plain bearing inserts and bushings can support large radial loads. In many cases in small power equipment engines, the bearing surface is machined instead of using an insert bearing.

The plain bearing receives the majority of its wear during the start phase of engine operation, due to the lack of lubrication at the time of engine start-up.

Bushings

Like plain bearings, the purpose of **bushings** is to support large radial loads and, occasionally, axial loads. Bushings are cylindrical in design with a lining made of a soft alloy such as brass, aluminum, plastic, or silicone bronze (Figure 7-4). Most bushings are press-fit into place and are generally replaceable. A press fit is a force fit that's accomplished using a press. In contrast, a push fit is a force fit that's accomplished manually.

Seals

Although not used to reduce friction, **seals** are used on transmission shafts and other rotating shafts within a power equipment engine to

- Prevent oil loss from the engine and bearings
- Keep contaminants from entering the engine and bearings
- Seal out atmospheric air, when necessary

There are many types of seals (Figure 7-5). Seals are usually held in place by press or push fit. In most cases, the seal lip applies tension against the shaft by the use of a spring, which creates a predetermined amount of sealing pressure. The engine oil keeps the seal lubricated for durability.

TWO-STROKE ENGINE LUBRICATION

As mentioned in Chapter 6, the lubrication of a two-stroke engine is different from that of a four-stroke engine. In the two-stroke engine, lubrication is accomplished by mixing fuel with a recommended two-stroke oil and then introducing the mixture to the internal moving parts of the engine. When the oil-and-fuel mixture enters the engine, the oil lubricates the piston and other moving parts. The mixture also enters the combustion chamber, where it's ignited by a timed ignition spark. Because the oil doesn't burn as well as the fuel, some of it exits out the exhaust system.

Oils used to lubricate two-stroke engines are specially prepared and recommended by the manufacturer. They help reduce piston-to-cylinder wall scuffing and reduce excessive carbon buildup in the cylinder combustion chamber, exhaust ports, and exhaust systems. It's essential to combine the special two-stroke oil and fuel before the mixture enters the engine, to ensure that all internal engine components receive the correct amount of lubrication. The oil uses the fuel as a carrier to get into the engine and then separates

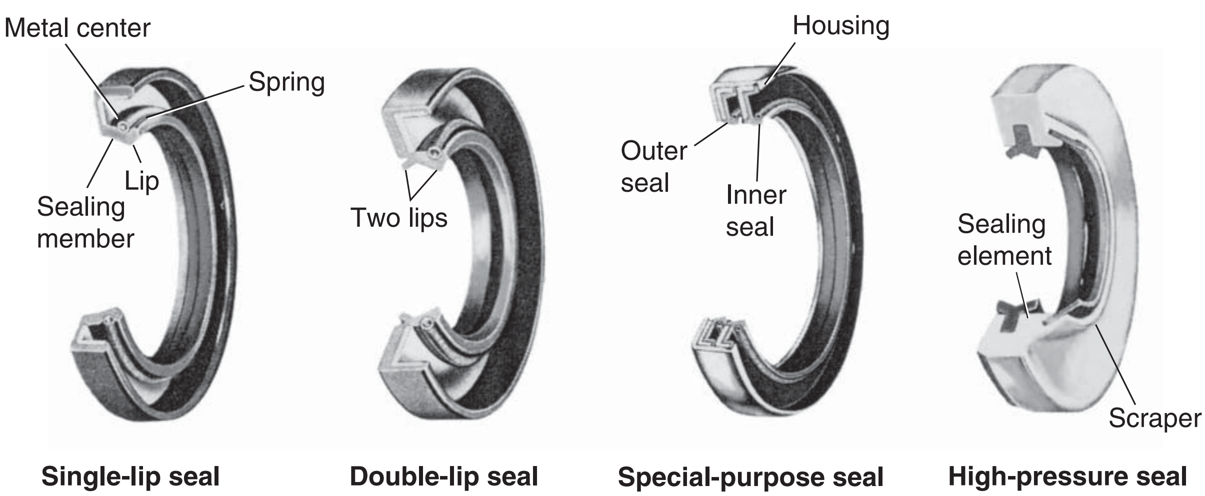

Figure 7-5 Seals are made in different ways to keep oil and lubricants inside the component as well as to keep contamination out of the engine.

itself from the fuel. Although it does eventually burn to an extent, the oil isn't designed to burn with the fuel in the combustion chamber, but to lubricate the moving parts of the engine.

There are two methods used for two-stroke engine lubrication.

Premixed Fuel and Oil

The premixed method of lubrication in a two-stroke engine is by far the most common method found in power-equipment-based engines and requires the use of a specified ratio of gasoline and oil mixed together in a specified container. It's usually recommended that this procedure be completed in a separate fuel container to ensure proper mixing. Figure 7-6 shows that the fuel and oil have already been combined before entering the engine. It's important to always shake the mixture well before using it, to ensure that the oil and gas are completely mixed.

Use the following steps to determine how much oil to mix with the fuel to obtain the proper fuel-to-oil ratio.

Step 1 Divide 128 (the number of ounces in a gallon of gasoline) by the manufacturer's recommended fuel-to-oil ratio.

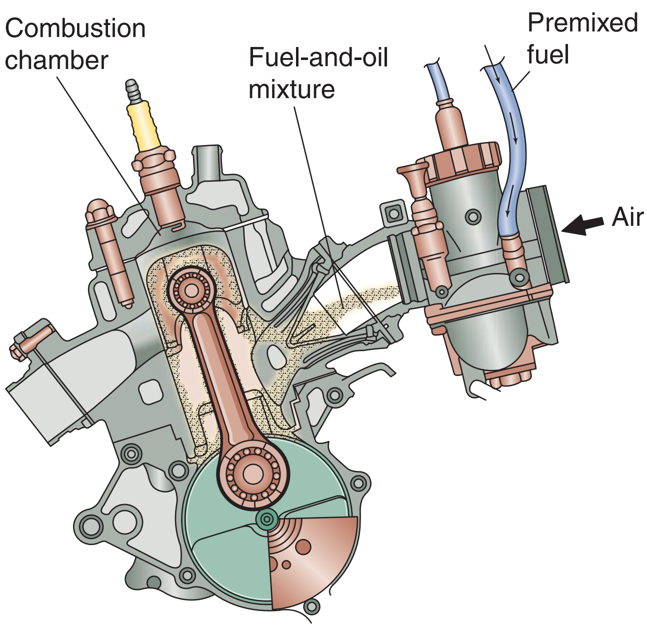

Figure 7-6 Using the premixed method of lubrication in a two-stroke engine, the user combines the fuel and oil manually, before the mixture enters the engine.

Step 2 Multiply the result of Step 1 by the number of gallons of gasoline to be used. The result is the number of *ounces* of oil you need to add to the gas.

As an example, let's determine how much oil must be added to 5 gallons of fuel when the manufacturer recommends a 40:1 fuel-to-oil ratio.

Step 1: Divide 128 by 40. The result is 3.2, which is the number of ounces of oil that must be added to each gallon of fuel.

Step 2: Multiply 3.2 by 5. The result is 16. Therefore, 16 ounces of oil must be added to 5 gallons of fuel.

The recommended ratio of fuel to oil may vary from 16:1 (16 parts of fuel to every 1 part of oil) to 50:1 (50 parts of fuel to 1 part of oil). Variations are based upon the manufacturer's recommendations and the brand of oil used. Many brands of oil are available, each with different lubrication qualities. Be sure to investigate each product carefully and choose one based on the manufacturer's recommendations. More important, choose one that best protects the two-stroke engine's moving parts.

One disadvantage of premixing the fuel and oil is that there's no way to adjust the amount of oil entering the engine with the fuel as the engine operates. At slow engine speeds, the engine doesn't work as hard; thus the proportion of oil may be greater than required to lubricate the engine components. The result may be excessive oil in the engine. As the engine speed is increased, excess oil exits through the combustion chamber, causing exhaust smoke as the mixture burns. Excessive oil can also cause the spark plug to foul, or misfire. At higher engine speeds, on the other hand, the proportion of oil may not be adequate to supply sufficient lubrication needed to reduce friction. These are reasons why it's so important to use the manufacturers recommended oils and oil ratios.

Oil Injection

Although not often found in power equipment engines (but commonly found in other two-stroke machines such as snowmobiles), oil injection systems deserve some discussion here.

The method of injecting oil into the engine, instead of premixing it with the fuel, requires the use of a pump. An oil pump measures and feeds the oil from a separate storage tank to all the two-stroke engine's components that require lubrication. With an **oil injection system** (Figure 7-7), the mixing of oil and gas occurs automatically. Increasing or decreasing the speed of the engine regulates the amount of oil pumped to the engine's components.

Oil injection systems offer several advantages. Not only does the power equipment engine user not have to mix the oil with the gas but also perhaps more important, oil is supplied to the engine's internal components in the correct amount required to provide the best protection at different engine speeds. Most two-stroke engines using oil injection have internal oil passages to help feed more oil to those internal engine components that require more lubrication. Examples of such areas are bearings of the connecting rod big end and crankshaft main bearings. A smaller quantity of oil is fed to those engine components requiring less oil. Examples include the piston wrist pin and rings.

Oil injection systems can reduce the total oil consumption of the engine because the oil is used only as needed, on the basis of the engine's operating speed. This helps reduce oil consumption, spark plug fouling, and excessive smoke and can help to increase the engine's life. More important, oil injection pump systems supply the proper amount of oil to the moving parts, even when the carburetor slide is suddenly closed down and the engine speed remains high. This prevents engine seizure, which would otherwise be caused by lack of lubrication. Remember, with the premixed method, oil must enter the two-stroke engine with the fuel. When the carburetor slide is closed on deceleration, the oil supply to the engine's internal components is drastically reduced. An oil injection system, on the other hand, doesn't have this disadvantage.

In the oil injection system, a cable connecting the throttle housing to the oil pump controls oil pump output (Figure 7-8). Turning the throttle up causes the carburetor throttle valve and oil pump to open. This allows the oil pump to automatically increase its oil output in proportion to the air or fuel supply from the carburetor.

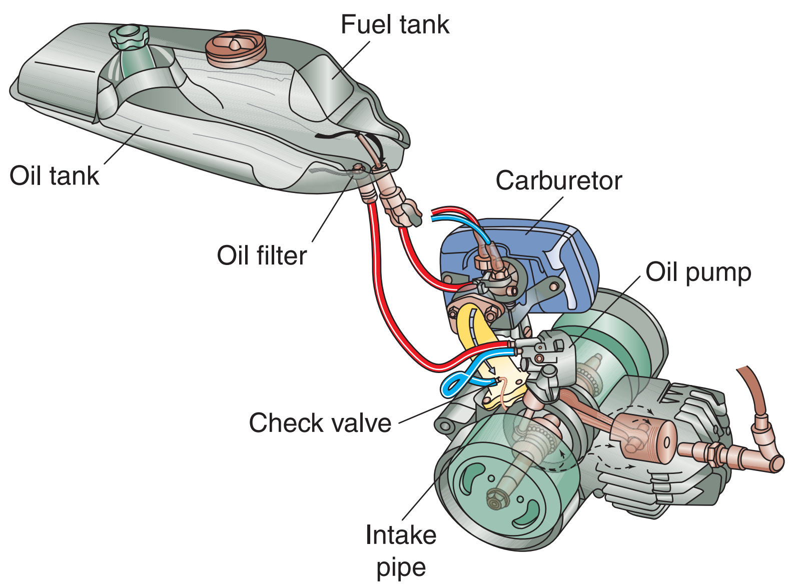

Figure 7-7 Although not very common in the power equipment two-stroke engine, the oil injection method of lubrication allows for the mixing of oil and gas automatically, assisted by an oil pump that feeds the oil from a storage tank. Oil injection is found commonly in two-stroke engines of implements such as snowmobiles.

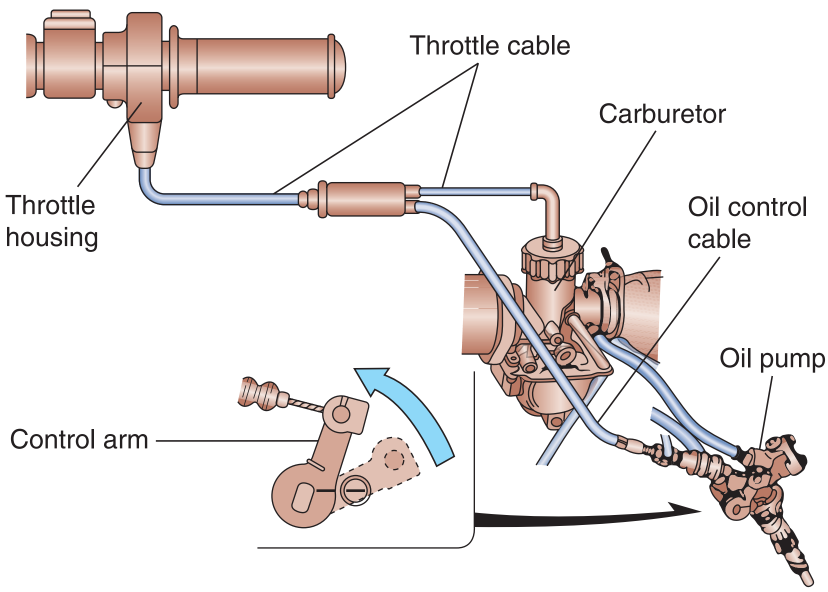

Figure 7-8 The throttle cable controls the oil-injected two-stroke engine oil pump.

Most two-stroke engines synchronize the oil pump to the carburetor throttle valve; that is, the pump is set to supply a quantity of oil to the engine in direct relation to the quantity of air–fuel mixture supplied to the engine. As a general rule, the pump lever to which the cable is connected is adjusted to move to a predetermined point when the throttle is wide open and to return to its original position when the throttle is closed.

Different methods are used to indicate the oil pump lever position in relation to the carburetor throttle valve opening. Usually a punch mark on the throttle valve is aligned with a mark on the carburetor body when the pump lever is in the proper position. This is a common procedure, but you'll need to check the power equipment engine service manual for further instructions on the type of pump design and recommended adjustment.

In oil injection systems, the oil storage tank must not be allowed to run dry. If this happens, or if the oil pump is removed, air enters the oil lines. Air in the system won't allow the oil to flow properly to the components in need of lubrication. The air must be removed to ensure that proper lubrication takes place. The method used to remove air bubbles from oil lines is called **bleeding**. This is done by removing the oil line located at the oil pump. After this line is removed, the oil flows out through the hose, bringing the air bubbles along with it. You should allow the oil to drip into an oil pan placed under the pump. How does this really work? The oil storage tank is located physically higher than the oil pump, thereby allowing gravity do the job. When the oil line is removed from the pump, gravity lets the oil flow freely from the oil storage tank. Manufacturers suggest various methods for bleeding a system. You should follow their instructions carefully.

FOUR-STROKE ENGINE LUBRICATION

Unlike the case of the two-stroke engine, the lubrication system for the four-stroke power equipment engine requires the engine oil and gasoline to be kept separate from each other. Therefore, in the four-stroke engine, the oil isn't mixed with the gasoline, nor does oil enter the combustion chamber. Consequently, oil isn't burned; rather it's recirculated throughout the engine.

Four-stroke engine lubrication systems used in power equipment engines are wet-sump systems, meaning that the engine stores all the available engine oil in the engine's crankcase.

In comparison, a dry-sump engine stores the majority of its oil in a separate storage tank with oil lines going into and from the engine.

Examples of areas needing lubrication are cam bearings, overhead valve rocker arms, push rods, pistons, cylinders, and crankshaft bearings.

Wet-Sump Lubrication

Wet-sump lubrication systems store all the oil in the engine's crankcase. Either oil is pressure-fed to all areas in need of lubrication or a system that splashes the oil to areas that require lubrication. Examples of areas needing lubrication are cam-bearing areas, pistons, cylinders, and crankshaft-bearing areas. The oil that is fed to these areas is thrown off the rotating components and drained back to the sump, where the oil recirculates to those high-friction areas that need lubrication.

Oil Circulation

Four-stroke power equipment engines use one of two ways to circulate engine oil: splash or pump. There are two basic types of oil pumps used in power equipment engines: the plunger type and the rotor type.

Oil for all lubrication systems is stored at the bottom of the engine, also known as the oil sump. The oil sump is where the engine oil is stored for lubrication purposes and also where the engine oil returns once it has been used. All engine sumps have at least two removable plugs. The oil drain bolt is located at the bottom of the engine (Figure 7-9) and is used to remove the engine oil. The oil filler cap is used to check and fill the crankcase. Sometimes a check bolt is used to verify the correct amount of oil is in the engine (Figure 7-10).

Splash Lubrication

Many older and less expensive small four-stroke engines use a splash lubrication system. Just as its name implies, the splash lubrication system relies on the splashing of the oil onto engine parts for lubrication.

To splash the oil onto the parts needing lubrication, horizontal engines commonly use an oil dipper (Figure 7-11). An oil dipper is a piece attached to the connecting rod (Figure 7-12) used to move (splash) the oil from the engine's sump to the engine parts in need of lubrication. The dipper rotates as the connecting rod and crankshaft rotate. In vertical engines, the connecting rod isn't submerged in the oil. Therefore, another method is used to get the oil to the components in need of lubrication.

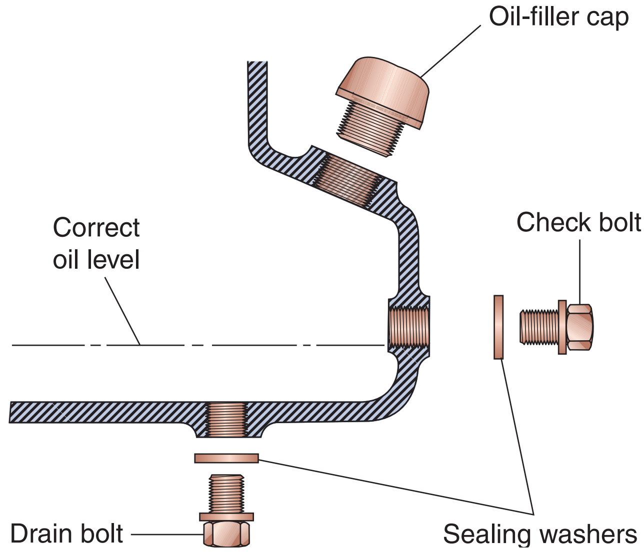

Figure 7-9 A check bolt is used to verify that the correct amount of oil is in the engine.

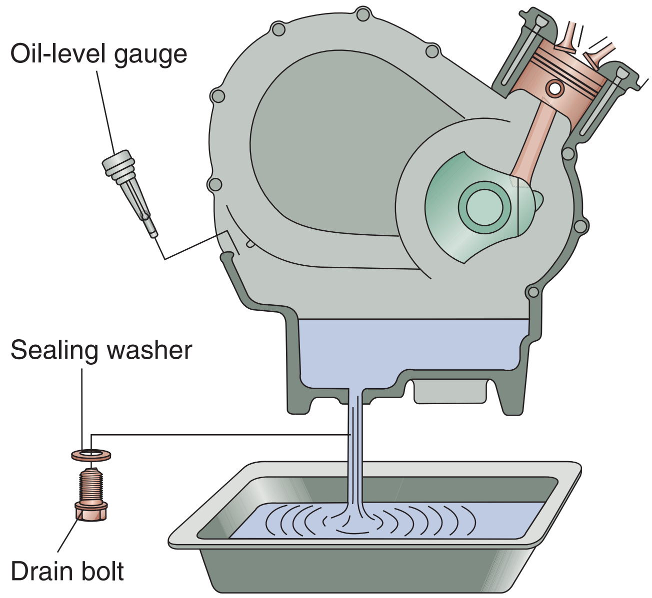

Figure 7-10 Typically, a power equipment engine will have an oil drain bolt as well as an oil filler cap.

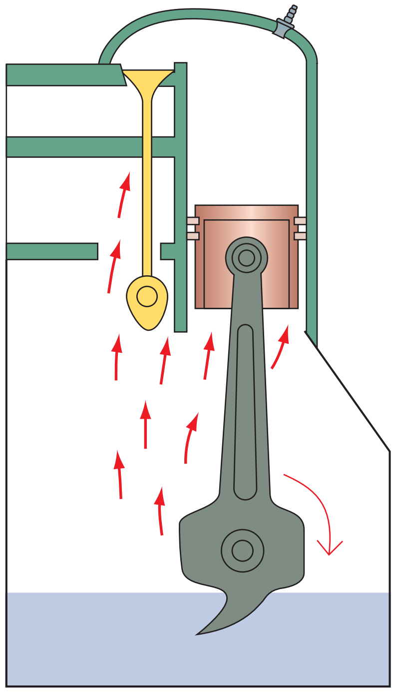

Figure 7-11 Splash-type lubrication.

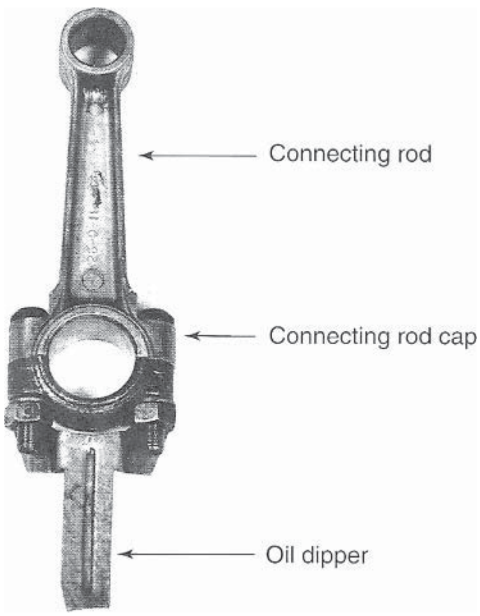

Figure 7-12 A connecting rod with an oil dipper attached.

In vertical crankshaft engines, an oil slinger is used, which consists of a gear with paddles to splash oil on the parts (Figure 7-13). The oil slinger gear meshes with the camshaft gear and as the camshaft turns, the slinger turns. The paddles dip into the oil and splash the oil to areas in need.

When the engine is running, oil is splashed upward onto the cylinder and the piston to

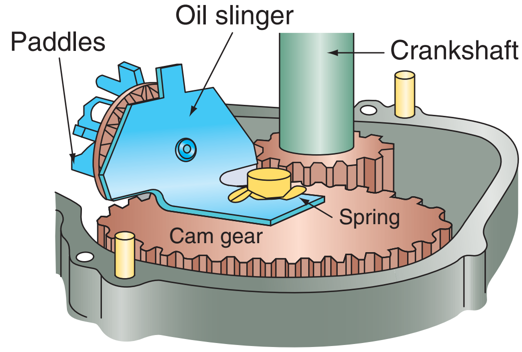

Figure 7-13 Oil slingers are often found in vertical engines using splash-type lubrication.

provide a film of oil between the piston and cylinder wall. In some engines, the oil falls back down and into holes in the connecting rod and crankshaft-bearing surfaces and then runs through return slots back into the engine sump by the force of gravity alone. All the internal engine parts are lubricated in this fashion.

As we mentioned, this type of lubrication system is used in older and inexpensive engines to cut down on costs of manufacturing. The engine's life expectancy isn't as high as we would like.

Pressure Lubrication

Pressure lubrication is a system where a pump pressurizes the oil and forces it through passageways to the specific engine parts. Pressure lubrication is much better than splash lubrication as the pressurized oil provides a constant film of oil between the parts it is directed to. The constantly moving oil also does a better job of carrying away heat and flushing away dirt from the parts. There are two types of pressure lubrication pump systems found in power equipment engines: the plunger type and rotor type.

Plunger-Type Oil Pumps The plunger-type oil pump consists of a set of check valves, a piston attached to a plunger, and a pump body or cylinder (Figure 7-14). The plunger has a large hole at one end that fits over an eccentric shaft on the camshaft. An eccentric shaft is a shaft that is off center. The pump body is like a cylinder. When the piston moves up in the oil pump's cylinder, oil is drawn in past the inlet check ball. As the piston moves back down the cylinder, the

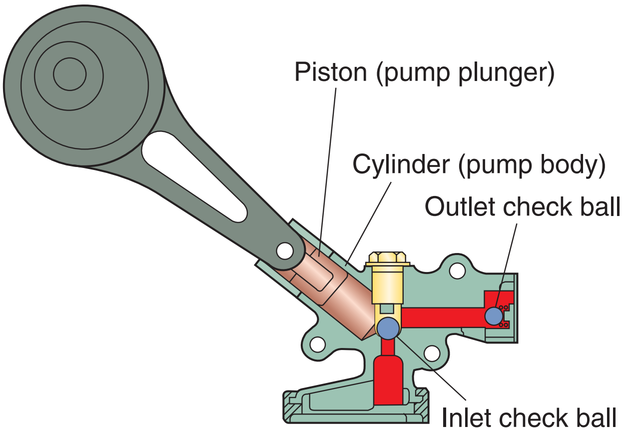

Figure 7-14 A plunger-type oil pump. It should be noted that not all plunger oil pumps use check valves, as shown in this illustration.

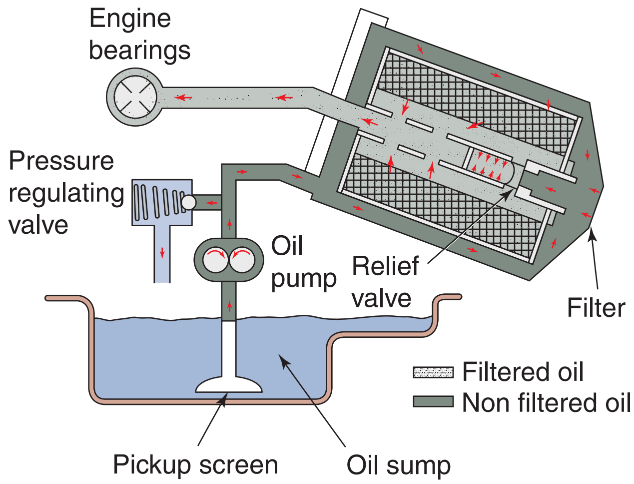

Figure 7-15 The main components of a full pressure lubrication system.

inlet check ball closes and oil is forced past the outlet check ball, and pressurized oil is delivered to the engine parts via oil holes and passageways. The pump is submerged in the oil sump to allow a constant source of oil. The pump body is stationary, whereas the plunger and piston move whenever the engine is rotating.

Rotor-Type Oil Pumps Higher-quality four-stroke power equipment engines use a full pressure lubrication system. The main components of a full pressure lubrication system are the oil sump, oil pickup screen, oil pump, oil filter, and oil passageways (Figure 7-15).

The rotor-type pump (Figure 7-16) is used commonly in full pressure lubrication systems. The rotor pump consists of a pair of rotors: an inner rotor and an outer rotor. The inner rotor is shaft driven, whereas the outer rotor is moved by the inner rotor and is free to turn in the housing. The lobes on the rotors squeeze oil through passages in the pump body. As the inner rotor rotates, oil is constantly picked up from the inlet side, transferred, and pumped through the outlet side. Oil pressure is created when the oil is squeezed between the inner and outer rotors. The rotor-type oil pump design is capable of creating both high volume and high pressure. Rotor-type pumps are also known as gerotor or trochoidal pumps. Oil pressure must be regulated in a full pressure lubrication system. This is done by the use of an oil pressure relief valve

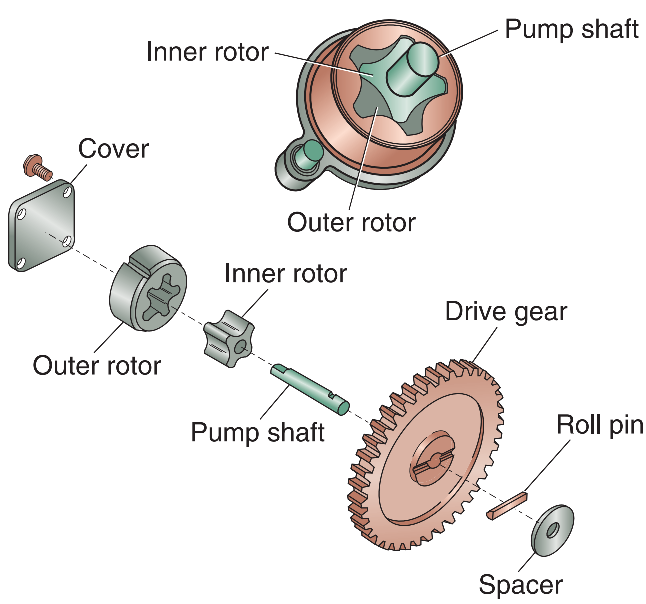

Figure 7-16 The rotor-type pump is found commonly in full pressure lubrication systems.

by the means of a spring-loaded valve used to bleed off excessive oil after the oil pressure reaches a predetermined level.

Oil Pressure Relief Valve

The oil pressure relief valve is usually located near or on the oil pump (Figure 7-17). Its purpose is to prevent excessive oil pressure from building up by bleeding excessive oil back into the crankcase. The oil pressure relief valve operates during cold starts when the oil is thicker and

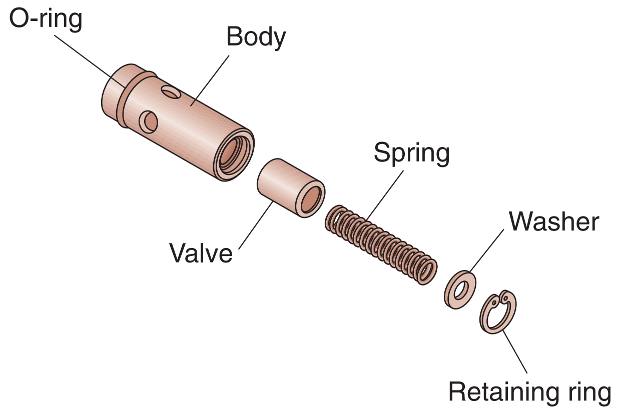

Figure 7-17 The components of the oil pressure relief valve.

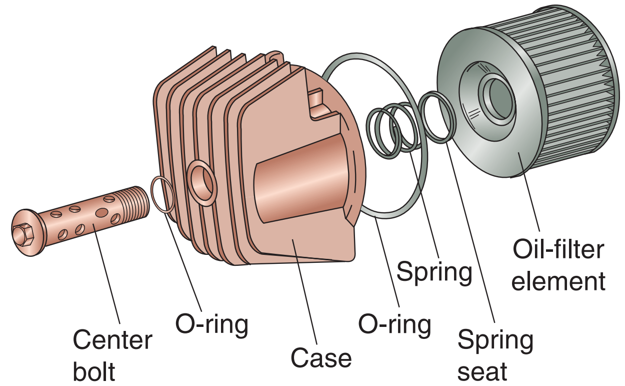

Figure 7-18 A paper-style cartridge oil filter, with components that complete the oil filter assembly.

when the engine is run outside of the designed parameters set by the manufacturer.

Oil Filters

Oil filters are used to ensure that the oil is as clean as possible before it enters the oil passageways and reaches the component parts. The paper oil filter uses treated–pleated paper; it may be of a spin-on-type or a cartridge-type (Figure 7-18). Pleated paper is used to provide a large surface area for filtering purposes. As the oil makes its way through the paper, dirt and acids stick to the outside and only clean oil gets through to the engine. If a filter is left in too long, it can clog and will not allow oil to flow to the engine parts. In such a case, an oil filter bypass valve (see following text) can prevent total engine damage. O-rings are used to seal the filter housing as it attaches to the crankcases and should be lubricated during installation. It's important to note that when oil filters are used, they must be replaced or cleaned on a regular basis.

Oil Filter Bypass Valves

Most spin-on-type oil filters and cartridge-type oil filters include an oil filter bypass valve. When oil flow through the filter is restricted because of an excessively dirty filter or extremely cold running conditions, the oil filter bypass valve allows the oil to bypass the filter, thus providing the essential lubrication to critical engine components. Notice that the oil filter bypass valve illustrated in Figure 7-19 has a bolt, which contains a spring and a ball. When pressure is excessive in the oil filter housing, the ball pushes the spring, allowing the oil to bypass the filter. Unfiltered oil is better than no oil at all!

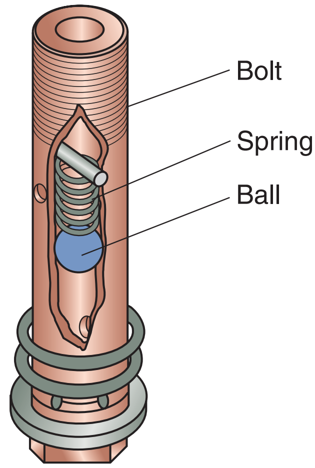

Figure 7-19 A typical oil filter bypass valve and its components.

Oil Passages

Oil passages, or pipes, deliver the oil from the pump to the crankshaft, camshaft, valves, and all other internal parts in need of lubrication. Most crankcases have holes machined into them to supply oil to the crankshaft. Some models use an external oil line to deliver oil to the top end.

COOLING SYSTEMS

As we discussed in previous chapters, heat energy created within the engine is used to produce power. The heat created in the combustion chamber of a typical engine can reach temperatures as high as 3,600°F (1,982°C)! A significant amount of heat is absorbed by the parts of the engine itself, which can quickly damage the engine if not removed (dissipated). Of course, the more heat energy that can be used, the more power the engine will produce. This is the tricky part for manufacturers, as they have to determine just how much heat the parts can take before they fail. Power equipment engine cooling systems assist in the removal of excess heat produced by the engine. They're designed to allow the engine to operate at a temperature predetermined by the manufacturer. There are two types of cooling systems found in power equipment engine engines: air cooling and liquid (coolant) cooling.

Air Cooling

Most small power equipment engines are air cooled. Air-cooled engines use cooling fins on the cylinder head and cylinder (Figure 7-20) to dissipate heat to the surrounding air. These two areas of the engine get the hottest when the engine runs. Cooling fins are thin pieces of metal cast on the cylinder and cylinder head, used to get the greatest amount of available hot metal in contact with cool air.

Figure 7-20 This cutaway photo shows the cooling fins found on a typical small power equipment engine.

As the engine runs and produces heat, it transfers the heat to the cooling fins. Air flows around the fins and carries away the heat. As the heat is pulled from the engine, the heat is reduced (Figure 7-21a) to as low as 100°F (38°C). Quite a difference from the high temperatures originally created within the engine!

The primary air-cooling method used in power equipment engines is called forced-draft cooling, which uses an engine-driven fan, typically the engines flywheel, which draws air through ductwork, also known as shrouds (Figure 7-21b). When a new charge of fuel and air is drawn into an engine, a notable amount of heat is absorbed also.

Shrouds surround the cylinder and the cylinder head. The flywheel has curved blades that are used to pull cool outside air into the engine and push it around the engine parts. The flywheel fits inside a blower housing, also known as a fan cover, which directs the air into and out of the flywheel to the shrouds. Cool air is pulled into the fan through a debris screen that keeps grass and other foreign material out of the housing, thereby preventing clogging and eventual overheating. If debris does get through the screen, the fans are designed to cut up the debris into smaller pieces to allow it to flow through the cooling system without being caught in the cooling fins.

Liquid Cooling

Although making the engine slightly heavier because of the extra components required, liquid-cooling systems are popular with large power equipment engines being built today. A liquid-cooled engine gives the manufacturer the ability to control better the engine's operating temperature. Liquid-cooled power equipment engines contain various components, including the:

- Water pump
- Radiator
- Thermostat
- Radiator cap
- Coolant
- Radiator fan

Water Pump

The purpose of the liquid-cooled engine's water pump is to circulate the coolant. The water pump is driven by the engine (Figure 7-22). It draws the coolant through the inlet pipe and discharges it into the engine's water jackets. The water pump ensures that the coolant is sent to all needed areas in a uniform manner. The pump consists of a pump shaft, impeller, bearings, mechanical seal, oil seal, and a housing.

The water pump housing includes a drain hole, known as a telltale hole. Coolant leaking out the telltale hole is an indication that the mechanical seal is leaking (Figure 7-23). This is the most common problem found in a power equipment engine liquid-cooling system. Some water pumps may be rebuilt, but in most cases, the pump is replaced if the mechanical seal fails. If engine oil appears to be leaking out through the telltale hole, the oil seal is at fault. The oil seal is generally replaceable and doesn't require replacement of the water pump.

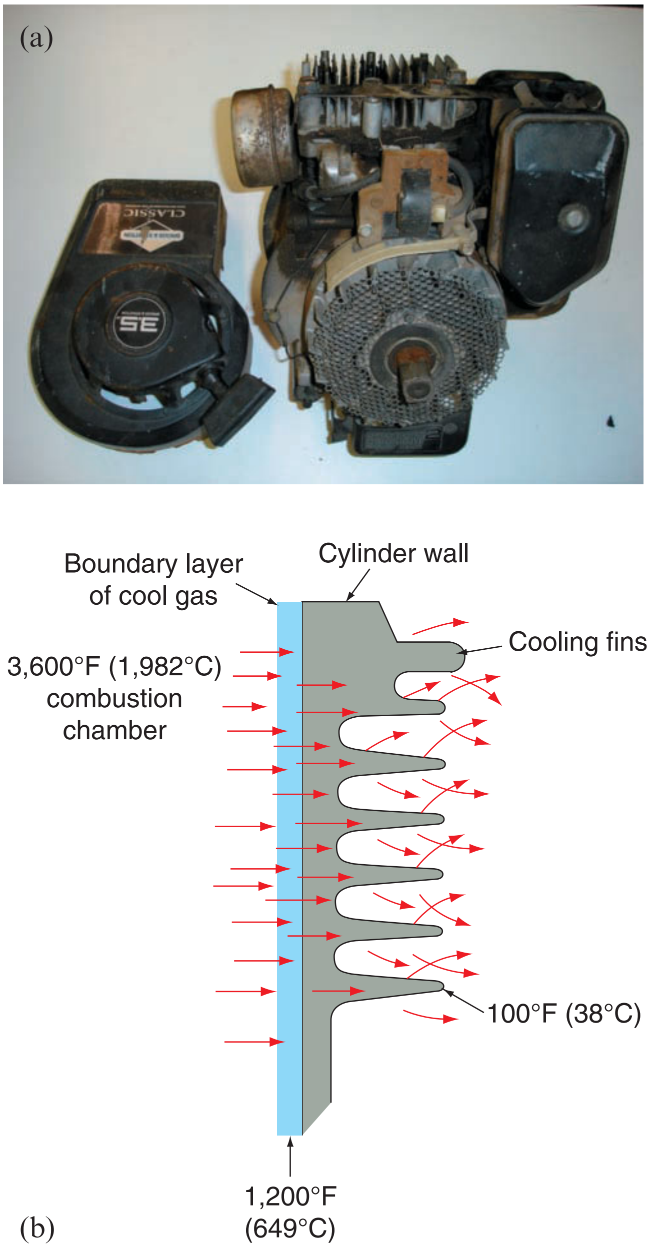

Figure 7-21 (a) Heat is transferred from the inside of the engine to the fins on an air-cooled engine. (b) The forced-draft method of air cooling uses an engine-driven cooling fan to push air through the engine shroud and to the engine's cooling fins.

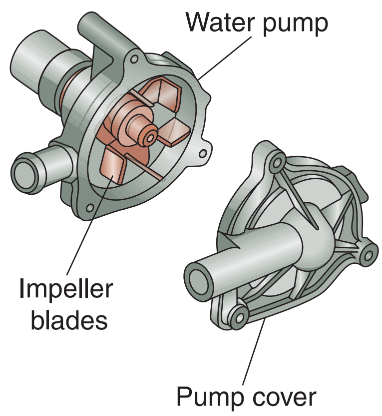

Figure 7-22 A typical water pump assembly.

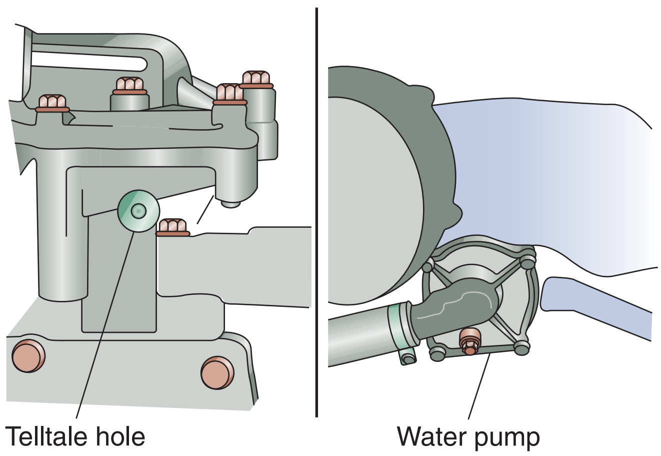

Figure 7-23 The telltale hole in a water pump gives a warning (i.e., coolant leaking out the telltale hole) when the pump needs repair or replacement.

Radiator

The **radiator** is a cooling device that allows for rapid heat removal. The radiator cools the moving liquid inside the cooling system as it's pumped through the engine. A radiator is also known as a heat exchanger. The radiator consists of small tubes or passages surrounded by very thin cooling fins (Figure 7-24). Hoses connect the radiator to the engine, are flexible, and are made of butyl rubber and generally reinforced with steel wire.

In most power equipment engines, the radiator is made of aluminum alloy. If a radiator is damaged, it generally needs to be replaced. Although it's possible to repair radiators in power equipment engines, the cost to repair them may be higher than the cost to replace them.

Thermostat

The **thermostat** is a temperature-sensitive flow valve. Its purpose is to provide a quicker engine warm-up time. It also ensures that the engine operates at a predetermined temperature. When the engine is cold, the thermostat is in the closed position. This allows the coolant to flow through the engine only and not into the radiator. When the engine reaches its predetermined operating temperature, the thermostat opens, permitting the coolant to flow through the radiator (Figure 7-25).

The thermostat may be tested by suspending it in heated water and checking the temperature with a thermometer when it opens (Figure 7-26). If the thermostat doesn't open at the correct temperature given by the manufacturer, doesn't open at all, or doesn't close, it must be replaced.

Radiator Cap

The radiator cap seals the cooling system from the outside atmosphere. It's also used to limit the cooling system's operating pressure. The boiling point of a liquid is increased by 3°F for every 1 pound per square inch (psi). Power equipment engine radiator caps are usually designed to hold 12–17 psi of pressure. They may be tested using a pressure tester (Figure 7-27). If the cap fails the test, it must be replaced.

Most radiators have a coolant reservoir, also known as a recovery tank (Figure 7-28),

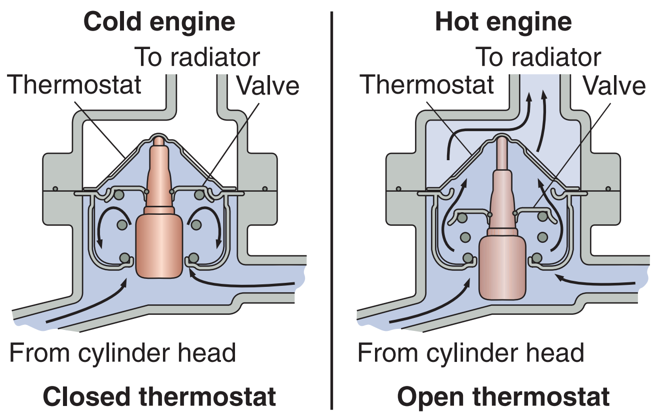

Figure 7-25 The thermostat remains closed when the engine is cold, keeping the flow of coolant from reaching the radiator. This provides for quicker engine warm-ups. When the engine reaches a predetermined operating temperature, the thermostat opens, allowing coolant to pass through the radiator.

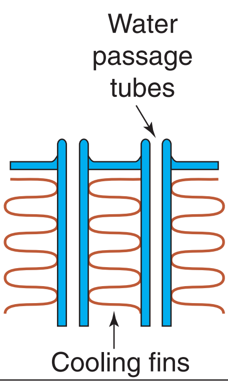

Figure 7-24 In a radiator, air flowing past the fins cools the coolant as it flows through the water passage tubes.

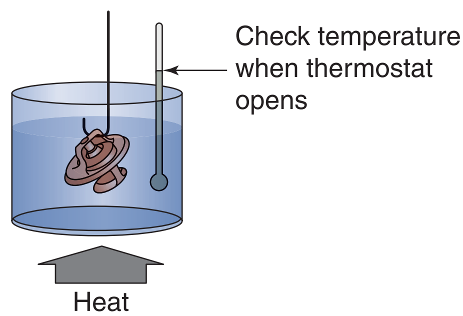

Figure 7-26 A thermostat may be tested by suspending it in heated water and checking the temperature with a thermometer when it opens.

Figure 7-27 A cooling system tester can be used to perform a radiator cap pressure test.

Figure 7-29 Different types of engine coolants can be found at most automotive part stores.

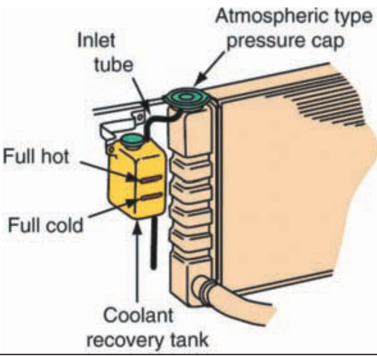

Figure 7-28 Most radiators have a coolant recovery tank, which allows for the expansion of the coolant after the radiator cap opens if pressure gets too high.

which allows for the expansion of the coolant after the radiator cap opens if pressure gets too high. During the pressure relief, coolant flows through a tube next to the radiator cap into the reservoir tank. As the system cools off, the coolant is drawn back into the radiator by vacuum. The coolant reservoir tank is normally made of clear plastic and has lines on it that show a full hot and cold line. When checking the system, the coolant should be between these two lines.

Coolant

The **coolant** for a liquid-cooled power equipment engine (Figure 7-29) usually consists of a 50:50 mixture of distilled water and antifreeze (ethylene or propylene glycol). One part water is used for every part of antifreeze because water has much better heat transfer capabilities than pure antifreeze. For the purpose of engine protection, distilled water is better than plain tap water because the former doesn't contain mineral deposits, which can cause corrosion. You must use the type of coolant recommended by the manufacturer to ensure that the engine is protected from damage due to corrosion. You should never use 100% ethylene glycol in any cooling system. Ethylene glycol is a poor coolant when used alone. The purpose of using antifreeze in a liquid-cooled engine is to lower the freezing point and raise the boiling point of the liquid (water). By mixing antifreeze with water in the proper proportion, antifreeze lowers the freezing point of water to less than 30°F. (Water normally freezes at 32°F.) At the same time, antifreeze and the cooling system pressure raise the boiling point of water to more than 225°F. (Water normally boils at 212°F.)

Antifreeze also contains lubricants, antifoaming additives, and corrosion inhibitors that help protect the engine. The antifreeze-and-water coolant is pumped along water jackets through the cylinder head and cylinder. The heated coolant then flows through the radiator, where heat is dissipated to the surrounding air.

Radiator Fan

The fan used with the liquid-cooled engine system helps to move air through the radiator when the engine isn't in motion or when it's moving too slowly to get the correct amount of air through the radiator. The fan may be driven by a pulley-and-belt arrangement, which turns whenever the engine is running. It may also be made to turn by an electric motor using DC (battery) voltage (Figure 7-30) and controlled by a temperature-sensitive sensor. Electric-powered fans are designed to operate only when the engine reaches a predetermined temperature. The fan may be designed to continue running even if the power equipment engine is shut off.

Liquid-Cooling System Testing

Liquid-cooled systems can be pressure tested to check for leaks (Figure 7-31). Pressure testing verifies that the system can hold a specified pressure for a required period of time. Specifications for this test are available in the manufacturer's service manual for the specific model. If the system fails the pressure test, check the hoses, pipe connections, the water pump installation, and seals. The radiator cap can also be pressure tested, as mentioned earlier. If the system does not hold pressure after it has been determined that all outside components are working well, there may be an internal leak that will require deeper investigation into areas such as the head gasket.

Another common test for liquid-cooled engines is a specific-gravity test. This test uses a **hydrometer**, which measures the weight of liquid as compared with the weight of water (Figure 7-32). When antifreeze is added to water, the hydrometer measures the weight change. Another tool used to test specific gravity is a refractometer.

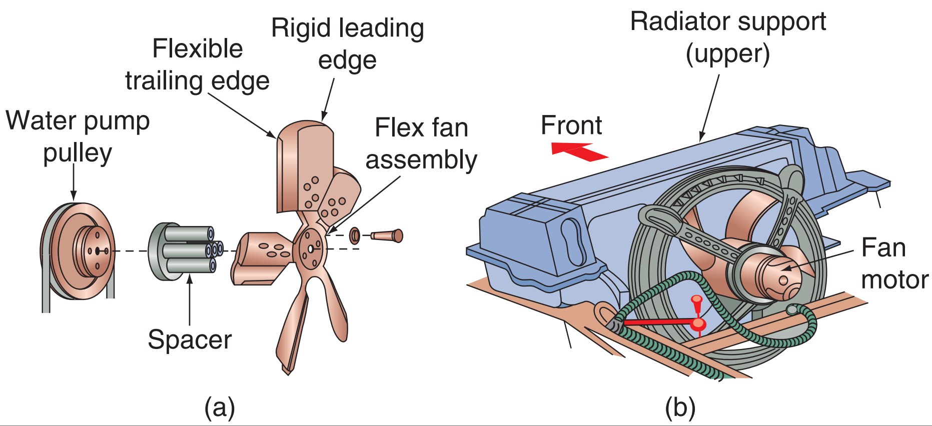

Figure 7-30 Cooling fans can be driven by a pulley and belt (a) or they may be controlled by an electric motor (b).

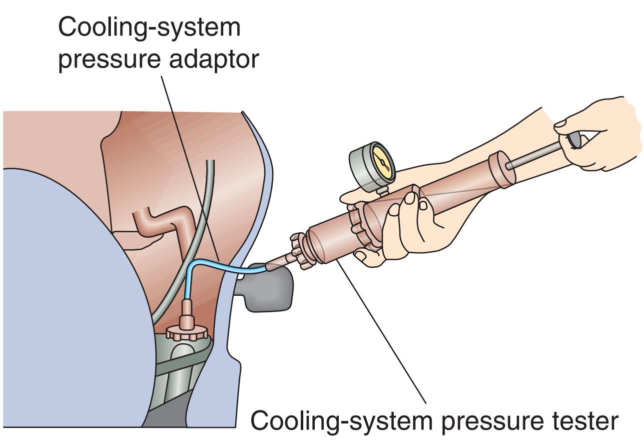

Figure 7-31 A cooling system pressure tester can be used to ensure that there are no leaks in the system.

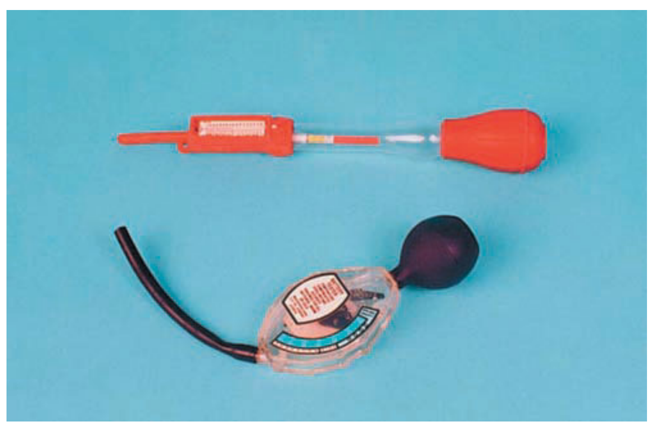

Figure 7-32 Two hydrometers are shown here. Hydrometers are used to measure the specific gravity of a liquid. When antifreeze is added to water, the hydrometer measures the weight change.

Summary

- There are the four key purposes of lubrication: cooling, cleaning, sealing, and lubricating to reduce friction.
- There are various types of oils, classified by letter codes and viscosity ratings.
- Bearings, bushings, and seals are needed in an engine to reduce friction.
- Both two-stroke and four-stroke engine lubrication systems have specific purposes.
- There are two different types of lubrication systems used in two-stroke engines and three types of lubrication systems found in four-stroke power equipment engines.
- Most power equipment engines are air cooled but can also be liquid cooled to prevent over-heating.

Chapter 7 Review Questions

1. Name four purposes of oil lubrication.
2. _____ is the term used to refer to the thickness of oil.
3. The abbreviation API stands for _____.
4. The abbreviation SAE stands for _____.
5. What special type of lubricant is manufactured in gel form?
6. Oil that has the letter "W" after its number rating indicates that it was tested at _____ temperature.
7. When premixing a two-stroke engine's gasoline and oil, what does the ratio 50:1 represent?
8. Using the steps described in this chapter, what's the correct amount of oil to premix with 5 gallons of gasoline using a 20:1 fuel-to-oil ratio?
9. The type of air-cooled engine that uses an engine-driven fan and shrouds is called a _____ system.
10. The component used as a heat exchanger in a liquid-cooled engine is called the _____.

CHAPTER

8 Fuel Systems

Learning Objectives

- Define fuel octane rating and state the factors that affect fuel octane ratings
- Explain the primary principles of carburetor operation
- Identify various fuel delivery systems used in power equipment engines
- Identify the components of each type of carburetor
- Describe the operation of circuits in each type of carburetor
- Understand the purpose of fuel injection
- Identify the components of an electronic fuel injection system

Key Terms

Atomization
Carburetor
Catalytic converters
Detonation
Electronic fuel injection (EFI)
Fractional distillation
Fuel circuits
Fuel filters
Fuel injector
Fuel lines
Fuel valves
Gasoline
Lean mixture
Octane rating
Rich mixture
Sequential fuel injection
Stoichiometric ratio
Vent hoses
Venturi principle

INTRODUCTION

All engines require fuel and a way to mix the fuel with air to operate. For power equipment engine repair, it's important to have a good understanding of both engine requirements. In this chapter, you'll first learn about the fuels used for power equipment engines. You'll then learn about the principles of carburetion. We'll discuss the types of fuel delivery systems used to get the fuel from the fuel tank into the engine. Finally, we'll discuss the different types of carburetors found in power equipment engines and will cover basic fuel injection systems.

FUEL

When we speak of fuel in relation to the gasoline-powered internal combustion engine, we're referring to gasoline. **Gasoline** (or a gasoline-and-oil mixture) is the fuel used in most standard power equipment engines. Gasoline is a volatile (vaporizes easily), flammable (burns easily), hydrocarbon (chemical compound of carbon and hydrogen) liquid mixture used as a fuel. Oxygen must be present for gasoline to combust (burn).

Gasoline is obtained from crude oil by a process called **fractional distillation**, which is based on the fact that each hydrocarbon boils or vaporizes within a certain temperature range. Thus, crude oil is heated in stages until all the various hydrocarbon classes have been individually vaporized and collected. Additives are then blended with the gasoline to give it required properties.

The primary requirement of a fuel is that it gives satisfactory engine performance over a wide range of conditions. Fuel is rated by a method known as fuel octane rating or knock rating. **Octane rating** is a measure of a fuel's ability to resist detonation. The higher the octane rating, the higher the fuel's resistance to detonation. **Detonation**, also known as engine knocking, is the explosion of highly compressed air and the unburned fuel mixture in the cylinder. Excessive detonation can cause catastrophic damage to the inside of the engine, by breaking a piston or cracking a cylinder head. Today, isooctane and heptanes are the main additives used in gasoline to help it resist detonation.

There's no advantage to using gasoline of a higher rating than what the engine needs to operate detonation free. There are several factors that influence the octane rating needs of a power equipment engine. On the same line, it's important to use the recommended octane rating given by the manufacturer to prevent damage to the engine. Listed in following text are factors that influence detonation.

- Higher engine and air temperatures encourage detonation.
- Higher altitudes discourage detonation.
- An air–fuel mixture that is too lean (a mixture in which the mass of air is more than 14.7 times the mass of fuel) encourages detonation.

How the engine is run also affects chances of detonation. The heavier the load the user applies to the engine, the greater the chance that detonation will occur.

As you can see, different factors can influence the octane rating needs of a power equipment engine. The most important thing to remember is to use a gasoline with an octane rating that meets the power equipment engine manufacturer's minimum requirements. This information is provided by every engine manufacturer and can be found in the owner's manual of the machine. Discussed in following text are two fuel mixtures commonly used.

Oxygenated fuels have an oxygen-based component such as alcohol or ether that contains more oxygen than is normal. Adding oxygen to fuel helps the fuel to reduce harmful carbon monoxide emissions from the engine.

Ethanol alcohol (also known as gasohol) is an engine fuel made by blending gasoline with alcohol distilled from farm grains like corn. Alcohol is a clean burning fuel, and up to 10% can be blended with gasoline. Such a mixture burns with combustion results similar to those of straight gasoline. Alcohol, however, can damage rubber, plastic, and brass used in fuel systems, and some kinds of alcohol can damage the metals used in the casting of carburetors. Also, water is easily absorbed by alcohol. Therefore, it's important to make sure if the engine manufacturer has approved the use of any blended alcohol in engines, as it's used in abundance in some parts of the country. Generally, state law requires that consumers at the pump be informed when the fuel supplied carries gasoline blended with alcohol.

OXYGEN

Oxygen is a tasteless, odorless, colorless gas that's present in the very air we breathe, which holds about 21% oxygen. It's drawn into the engine and combines with gasoline to form a combustible vapor. Pure oxygen has the ability to explode if submitted to extreme compression, and ignited oxygen produces a very high temperature and a great amount of energy. However, internal combustion engines don't receive pure oxygen and the compression ratio used is too low to cause the oxygen present to ignite on its own. Instead, a fuel mixture is combined with the intake air. The air–fuel mixture permits combustion to take place at a compression ratio lower than that required for pure oxygen to burn. Therefore, a combination of air (oxygen) and fuel (gasoline) is necessary to obtain the explosion characteristics required to operate an internal combustion engine safely and efficiently.

THE CARBURETOR

The amount of power produced by an engine is directly related to the heat energy put forth by the air–fuel mixture. The more combustible the mixture becomes, the greater the amount of heat that's generated. Power equipment engines, as we know, have the ability to transform heat energy into usable power. The greater the amount of productive heat produced by combustion, the more power you can expect from the engine.

The **carburetor** is a device used to mix proper amounts of air and fuel together in such a way that the greatest amount of heat energy is obtained when the mixture is compressed and ignited in the combustion chamber of the engine.

The function of the carburetor is to mix the correct amount of fuel with sufficient air so the fuel atomizes (breaks up), allowing it to become a highly volatile vapor. When this vapor enters the combustion chamber of the engine and is compressed by the action of the piston, a spark ignites it, enabling combustion and creating the power to operate the engine. Maximum power from the fuel supplied will be obtained only if exact proportions of air and gas reach the combustion chamber of the engine in vapor form of precisely the right consistency.

When the fuel and air are combined within the engine's combustion chamber, a chemical balance is created, known to be the **stoichiometric ratio**. A stoichiometric mixture is the working point that modern engine designers attempt to achieve in their design of fuel induction systems. The term *stoichiometric ratio* describes the chemically correct air-fuel ratio necessary to achieve complete combustion of fuel. The ratio of air to fuel in a theoretically perfect stoichiometric mixture is 14.7:1; that is, the mass of air is 14.7 times the mass of the fuel. This means that, in a perfect situation, there would be 14.7 parts of air for each part of fuel. Any mixture in which the ratio is less than 14.7:1 is considered to be a **rich mixture**; any mixture in which the ratio is more than 14.7:1 is considered to be a **lean mixture**. It's important to note that this ratio is measured by mass and not by volume.

Table 8-1 lists the proper amounts of air and fuel, with regard to different engine running conditions.

You learned earlier that liquids don't burn. Gasoline is a liquid. Oxygen, on the other hand, is a gas and has the ability to burn. The most efficient combustion of gasoline and oxygen occurs only when they're combined and turned into a vapor from the heat produced by the engine. This is a delicately balanced mixing process accomplished by the carburetor. Two primary principles are involved in carburetion operation:

- The principle of atomization
- The Venturi principle

Let's look at each of these principles in detail.

Table 8-1 Air–fuel mixtures at different engine running conditions	
Engine running condition	**Ratio of the air–fuel mixture (mass)**
Starting, cold engine	10:1
Accelerating	9:1
Idling (no load on the engine)	11:1
Partly open throttle	15:1
Full load, wide-open throttle	13:1

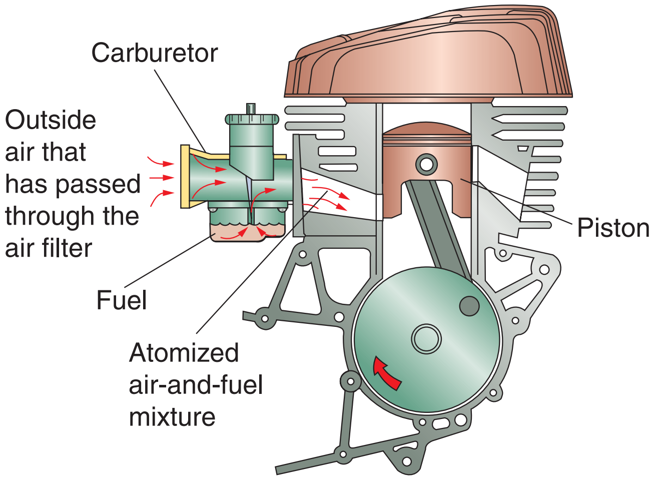

Figure 8-1 Atomization is the process of combining air and liquid to create a mixture of liquid droplets suspended in air. This illustration shows how atomization takes place in an engine.

Principle of Atomization

Atomization is the process of combining air and liquid, in this case fuel, to create a mixture of liquid droplets suspended in air.

As the piston begins the intake stroke, the air pressure in the cylinder is reduced. The pressure difference causes the higher-pressure, outside air to flow through the air filter and carburetor, and into the engine. Atomization takes place when the carburetor meters gasoline into the fast-moving air passing through it using the same principle of pressure difference (Figure 8-1). Air at high pressure from the outside becomes air at low pressure in the carburetor, which allows the high-pressure air at the fuel source to be pushed into the throat of the carburetor. The primary function of the carburetor is to atomize the fuel to create an air–fuel mixture.

The Venturi Principle

Carburetor design is based on the Venturi principle. The **Venturi principle** simply states that a gas or liquid that's flowing through a narrowed-down section (venturi) of a passage will increase in speed and decrease in pressure compared with the speed and pressure in wider sections of the passageway (Figure 8-2).

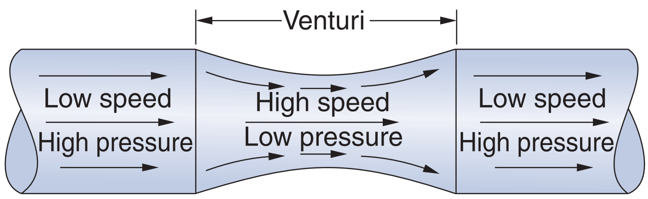

Figure 8-2 The Venturi principle.

A venturi has a particular shape—a modified hourglass figure, you might say. Air from the carburetor, on its way to the combustion chamber, passes through the venturi. The hourglass shape of the venturi causes the stream of air to increase in speed and decrease in pressure, creating a pressure difference in the venturi. This pressure difference is important, as it allows for fuel to be drawn into the air stream and atomized.

The major air passage in the carburetor body is called the carburetor bore. The air entering the carburetor bore is controlled by its speed and by the size of the venturi. A typical main carburetor bore may have a diameter of 1 inch, compared with a venturi diameter of ¾ inch. When air rushes to fill the cylinder, the speed of the air is faster if it must pass through a small opening than if it must pass through a large opening. As mentioned earlier, as air speed increases, air pressure decreases. The speed of air as it passes through the carburetor is an important factor in the breaking up (or atomization) of the fuel, as well as controlling the amount of fuel that's delivered into the venturi. You can see from Figure 8-3 that air is drawn into the

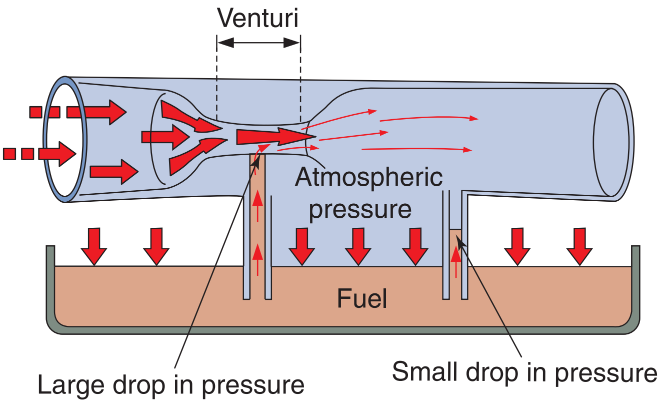

Figure 8-3 The effect of low pressure in a venturi.

carburetor through the venturi, where it gains considerable speed. This increase in air speed is directly related to a fall in air pressure in the venturi, which then draws fuel from an outlet nozzle. The fuel is atomized under the influence of atmospheric pressure as it's mixed with the incoming air.

Venturi size and shape are of considerable importance. If the venturi is too large, the flow of air is slow and won't atomize sufficient fuel to make a balanced mixture. If the venturi is too small, not enough air passes through to fill the vacuum created by the engine inside the cylinder. A large engine that creates a high vacuum uses a carburetor with a large venturi. A small engine requires a smaller venturi to be most effective.

Carburetors are equipped with mechanisms for regulation of the air and fuel volumes that are allowed to pass through the venturi. All carburetors have a venturi that operates on the same basic principle. Variations are in size, method of attachment, or in the system used to open and close the venturi. The principle of operation is the same for all carburetors.

FUEL DELIVERY SYSTEMS

The various components of the fuel delivery system of most gasoline-powered engines will be discussed in this section. Servicing fuel delivery systems is important and involves inspecting, cleaning, and replacing many of these components.

Fuel Tank

The fuel tank is designed to store fuel (gasoline). Fuel tanks can be made of steel, aluminum, or plastic. Fuel tanks of almost all modern power equipment engines are made of a light, thin steel or plastic. The important thing to remember is that the fuel tank is a reservoir that safely stores a supply of fuel for the carburetion system (Figure 8-4). In many cases, the fuel tank uses a gravity feed system to allow fuel to flow into the carburetor. The fuel tank will always be placed higher than the carburetor when using the gravity feed system.

Typically, the fuel tank is vented to the atmosphere, but some states (California, for example) require fuel tanks to be vented into a charcoal canister. This canister retains the hydrocarbon vapors, keeping them from entering the air we breathe.

Fuel Valves

Fuel valves, also known as fuel petcocks, are on/off valves that control the flow of gasoline from the fuel tank to the carburetion system (Figure 8-5). Fuel valves are generally operated manually by turning the valve either on or off. When turned to the "on" position, fuel flows to the carburetor from the main fuel tank. When turned to the "off" position, the flow of fuel stops. These valves are useful when the engine is

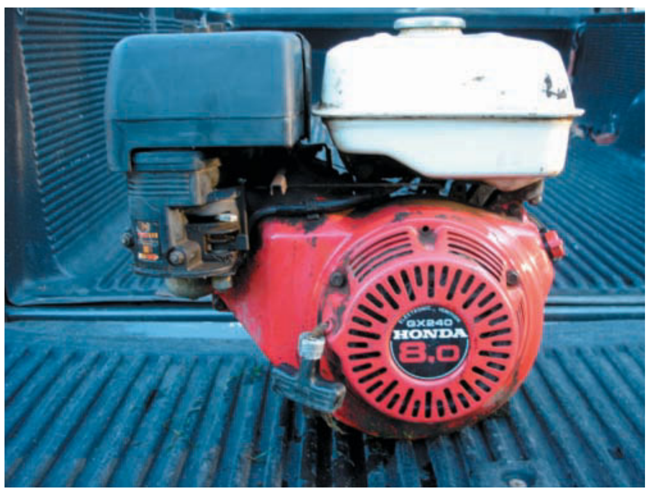

Figure 8-4 A typical fuel tank. Note that the fuel tank is placed higher than the carburetor and therefore uses a gravity feed system.

being transported or if the engine isn't going to be used for a long period of time.

Fuel Lines

Fuel lines are used to flow gasoline from the fuel valve to the carburetion system and are usually made of metal or neoprene, which is a synthetic rubber material. It's important to use manufacturer-recommended fuel lines. Because of some additives and alcohol (in certain cases where it's used as an additive) in gasoline manufactured nowadays, inferior fuel line hose can be affected or damaged.

Fuel Pumps

Some power equipment engines use a fuel pump. The purpose of a fuel pump is to deliver fuel from the fuel tank to the carburetion system. A fuel pump is also required when the power equipment engine's fuel tank is placed lower than the carburetor. The fuel pump supplies fuel under pressure to keep the carburetor filled with fuel. Fuel pumps are found always in engines with fuel injection systems. Fuel injection is a type of carburetion and is discussed later in this chapter.

There are three types of fuel pumps—mechanical, vacuum, and electric. Although some larger power equipment diesel engines use mechanical fuel pumps, two types of pumps are commonly seen on modern power equipment engines: vacuum and electric.

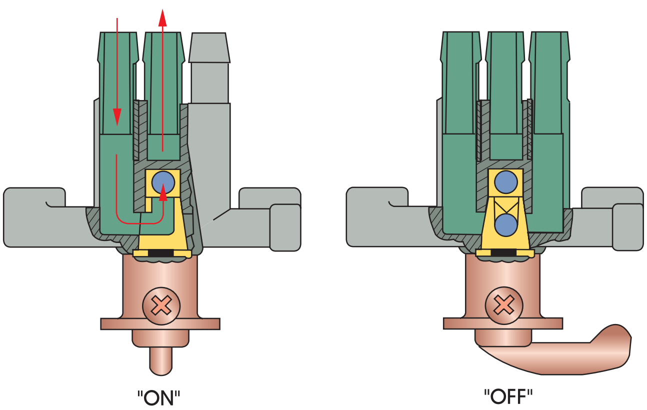

Figure 8-5 Fuel valves are designed to open and close the flow of fuel to the carburetor.

Mechanical Fuel Pumps

The mechanical fuel pump is a pump that uses a diaphragm operated by a rocker arm. The rocker arm is opened by the camshaft and closed by a spring to pump fuel from the tank to the carburetor (Figure 8-6). Mechanical pumps are generally located on the side of the engine block. The rocker arm enters the engine and rides on a camshaft lobe. As the cam rotates, the rocker arm moves up and down. The lever is connected to a diaphragm. A diaphragm is a flexible pumping element in the pumping chamber that, when moved, changes the volume of the chamber. There is an inlet and an outlet check valve located in the pumping chamber. Pumping occurs when the diaphragm is moved up and down by the rocker arm. When the diaphragm is pulled down, the pressure difference pulls in fuel from the tank, and when the diaphragm is pushed back up, the check valve in the inlet side closes and the fuel is delivered to the carburetor.

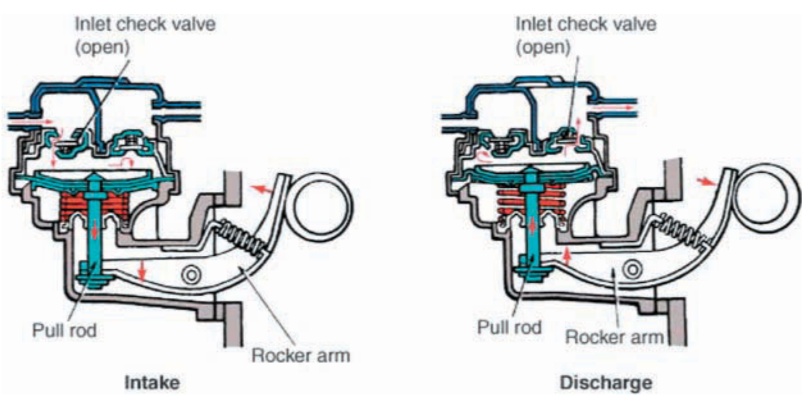

Figure 8-6 A mechanical fuel pump.

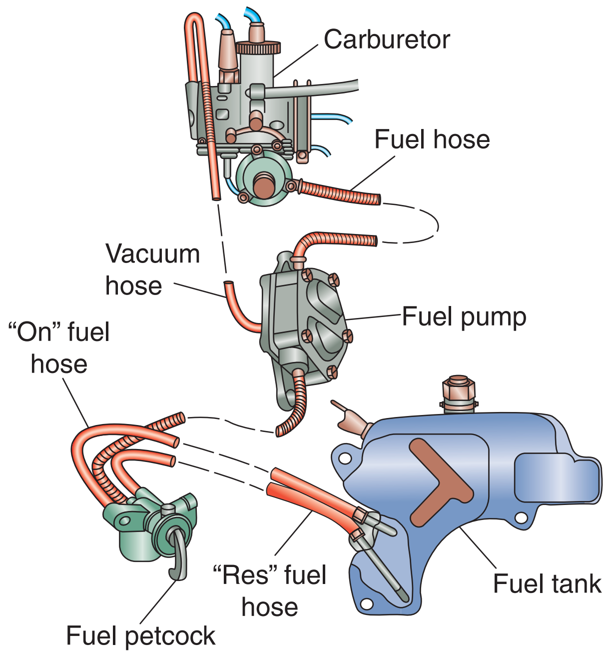

Figure 8-7 A vacuum-operated fuel valve uses engine vacuum to allow fuel to flow by use of a diaphragm, as shown here.

Vacuum Fuel Pumps

The vacuum fuel pump (Figure 8-7), also called an impulse fuel pump, uses a diaphragm that's moved by the pressure differences of engine vacuum and atmospheric pressure. It works in the same manner as the mechanical fuel pump but instead of a mechanical lever, the diaphragm is moved by pressure and vacuum made by the engine.

Electric Fuel Pumps

The electric fuel pump is operated electronically by the use of an electric motor and solenoid that pumps the fuel from the fuel tank to the carburetor (Figure 8-8). An electric fuel pump operates only when the power equipment engine is running, unless it's bypassed.

Vent Hoses

Vent hoses are used on most fuel tanks and carburetors to permit atmospheric air pressure to enter into certain important areas within the fuel system. If these hoses become plugged, twisted, or curled, the fuel will not flow correctly. Engines that can be used in multiple positions, such as handheld-based engines, don't use vent hoses; instead, they rely on a pressurized fuel tank to ensure delivery of fuel.

Fuel Filters

Fuel filters help remove contaminants from the fuel before they reach the carburetor. Common locations are on the top of the fuel valve or petcock in the fuel tank, in the fuel valve, in line with the fuel hose, or in the carburetor.

Adjustment Screws

The engine needs a large volume of air and fuel when it runs at high speed. Fuel for high-speed operation comes from the venturi pickup tube. The amount of fuel that goes up the pickup tube can be regulated and adjusted with a screw or a fixed jet. A high-speed adjustment screw (Figure 8-9) is a carburetor screw used to regulate the amount of fuel that goes up the main pickup tube during high-speed operation. The screw has a tapered end (Figure 8-10) that fits in the bottom

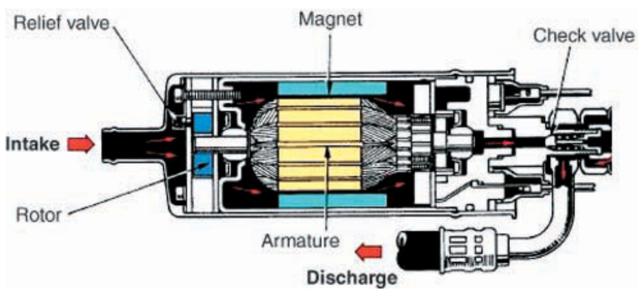

Figure 8-8 A typical electric fuel pump.

Figure 8-9 A high-speed mixture screw.

Figure 8-10 The high-speed mixture screw has a taper in it to adjust the flow of fuel in through the carburetor.

Figure 8-11 A low-speed adjustment screw is typically on the side of the carburetor, as seen here.

of the carburetor float bowl and into the pickup tube. The screw is used to increase or decrease the size of the passageway for fuel to move up the pickup tube. If the screw is turned in, a smaller amount of fuel can go up the tube. If the screw is turned out, more fuel is allowed into the carburetor. A spring is used on the adjustment screw to prevent it from vibrating loose.

The throttle valve is in a nearly closed position when the engine is running slowly or at idle speed. A closed throttle valve allows very little air to flow through the venturi. During this phase of operation, very little or no fuel is pulled up the pickup tube. Fuel must be allowed into the engine so that it will run. This is done with a slow-speed circuit behind the throttle valve. During idle, low pressure created at the throttle plate draws fuel through a passage and into the carburetor bore. The amount of fuel that comes out the hole can be controlled and regulated by a mixture screw (Figure 8-11) or a fixed jet. The low-speed fuel mixture screw is a carburetor screw used to regulate the amount of fuel that gets behind the closed throttle plate during low-speed or idle operation. The low-speed fuel mixture screw has a pointed end (Figure 8-12) that goes through the side of the carburetor and into a low-speed fuel passage. If the screw is turned all the way in, very little mixture can pass through the circuit. If the screw is turned out, more fuel can pass through the circuit.

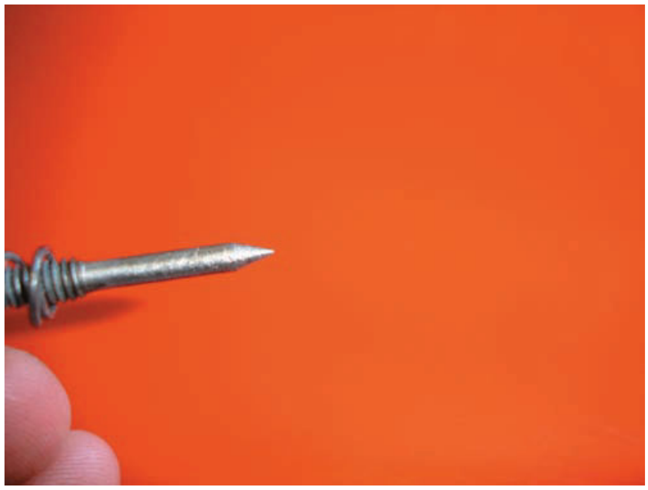

Figure 8-12 The tip of the low-speed mixture screw is pointed, to allow for a more precise adjustment.

The low-speed fuel mixture screw should not be confused with the engine's idle screw, which is used to control the opening of the throttle valve. Always inspect the fuel adjustment screw tips to ensure that they're not damaged or bent. Damage can occur by overtightening the screw when cleaning or adjusting.

Air Filters

Air filters are designed to filter the incoming air to the carburetor. Air filters are important to the life of an engine. If dirt or other contaminants are allowed to go through the carburetor with the air–fuel mixture, they'll damage the engine quickly. The two most popular materials used for air filters are paper and foam.

Paper Air Filters

The paper air filter (Figure 8-13) consists of laminated paper fibers that are sealed at the ends or sides of the filter. Some paper air filters include a supportive inner or outer shell of metal screen. The paper used in these air filters is molded in an accordion-style pattern. This design increases the surface area and decreases the restriction to air passing through it. The paper air filter design must be kept dry and free of oil. If it becomes excessively dirty or has oil in it, the paper air filter must be replaced. Don't try to clean a paper air filter with soap and water. This will damage the paper fibers, rendering them unusable.

Foam Air Filters

Foam air filters (Figure 8-14) use a special foam and oil to aid in trapping dirt and other contaminants. The foam air filter usually fits over a metal apparatus to help hold its shape. These filters work by slowing down the incoming air and collecting particles of dirt as the air passes through the filtering material. The dirt sticks to the filter and remains there until the filter is serviced. When the filter becomes dirty, it can be cleaned in a warm, soapy water solution and then rinsed and dried. After drying, it must be oiled (Figure 8-15). Some foam air filters are used in conjunction with paper air filters as a pre-filtering device (Figure 8-16). In this case, it's sometimes recommended that a pre-filter not be oiled, to prevent saturation of the paper filter.

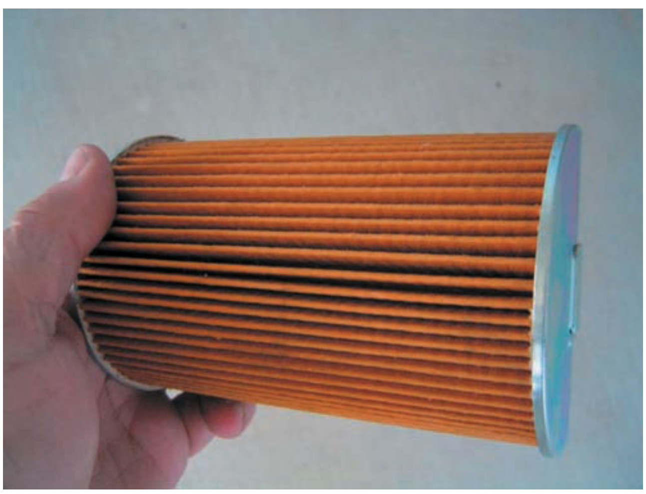

Figure 8-13 The paper air filter is molded in an accordion-style pattern to provide greater surface area.

Oil Bath Air Filters

The oil bath air cleaner is a common type of air filter used in older engines. An oil bath air filter directs incoming engine air over an oil sump that catches dirt particles (Figure 8-17). Like other air filters, the oil bath type is mounted to the carburetor. All the air going into the carburetor must go through the filter first. The housing is the main part of the oil bath air filter. The housing has air passages that direct the incoming air. Incoming dirty air comes in the top of the housing. It's then directed down the inside of the housing. The housing passages cause the air to change direction and start back up the housing.

There is a small oil sump in the bottom of the housing. The air entering the housing is made to change direction over the oil. Dirt in the air is too heavy to make the quick turn so it keeps going straight into the oil. The oil traps the dirt and the filtered air goes through an oiled screen. Any dirt left in the air sticks to the oiled screen. Filtered air then goes down the center of the housing and into the carburetor.

Oil bath air filters are not used in newer engines. The oil in the housing requires frequent service. The complicated air routing inside the housing limits the air flow into the engine, which limits engine power.

CARBURETOR TYPES AND OPERATION

Now we'll learn what makes up a carburetor as well as what happens inside during its various phases of operation. But first, recall that all carburetors work using the same basic principle. The carburetor has the task of combining the air and fuel into a mixture that produces power for the engine. First, the engine draws in air. The pressure difference between the outside

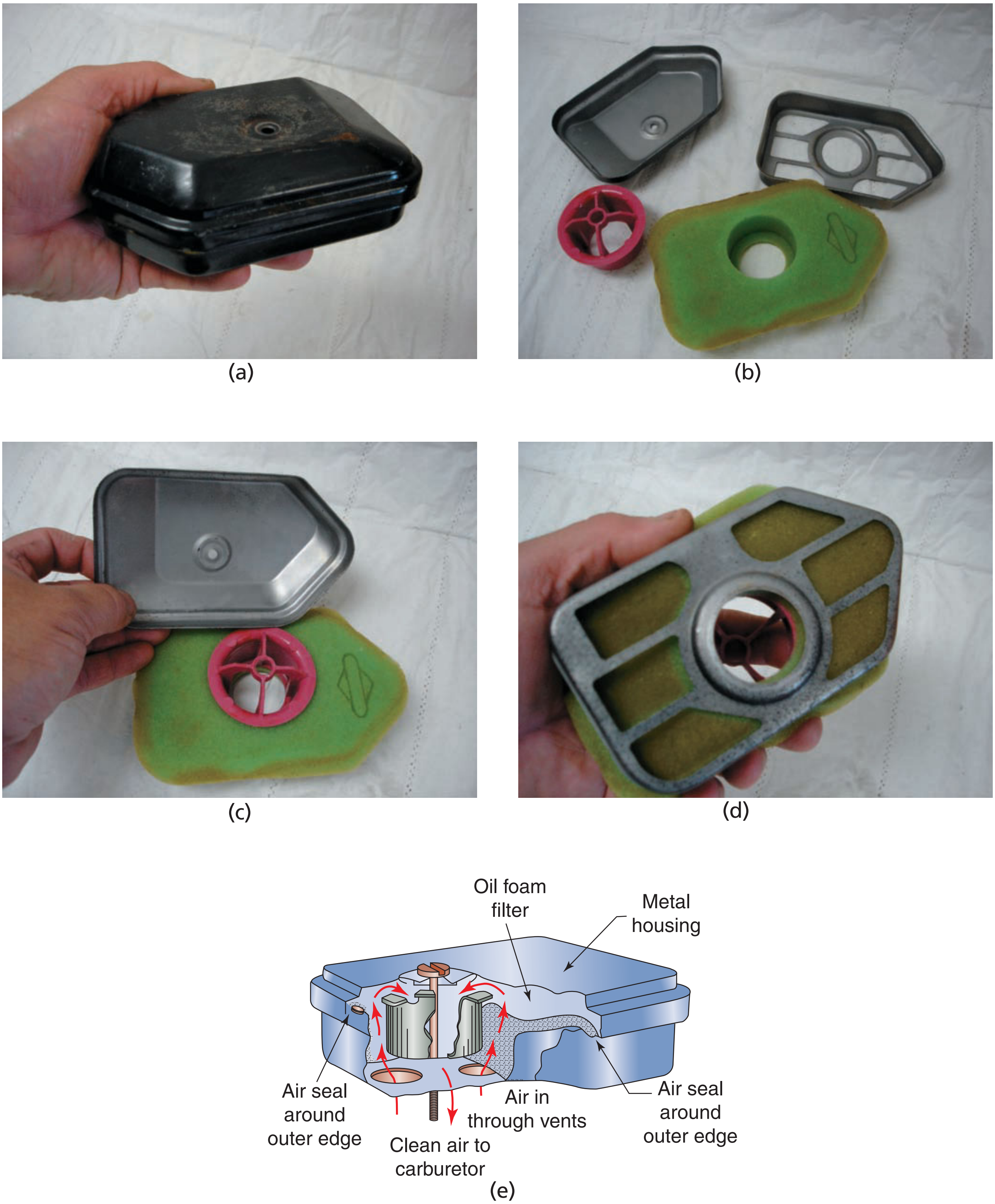

Figure 8-14 A typical foam type air filter. (a) The assembled filter, (b) the individual components of the filter, (c) the top of the filter, (d) the bottom of the filter, which is where the air comes through, and (e) the filtering process.

atmosphere (higher pressure) and the inside of the cylinder (lower pressure) forces the air to pass through the carburetor. The air mixes with a predetermined amount of fuel, which is also moved by pressure differences, into the air stream of the carburetor venturi. Carburetors

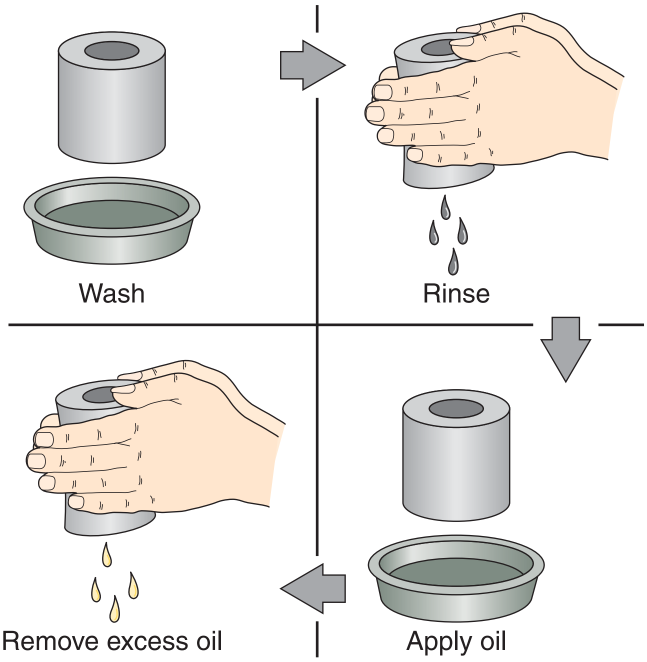

Figure 8-15 When cleaning a foam air filter, wash it with soap and water, rinse well and dry, apply proper oil as stated by the filter manufacturer, and finish by removing the excess oil.

Figure 8-16 Many power equipment engines use a combination of a foam and paper air filter.

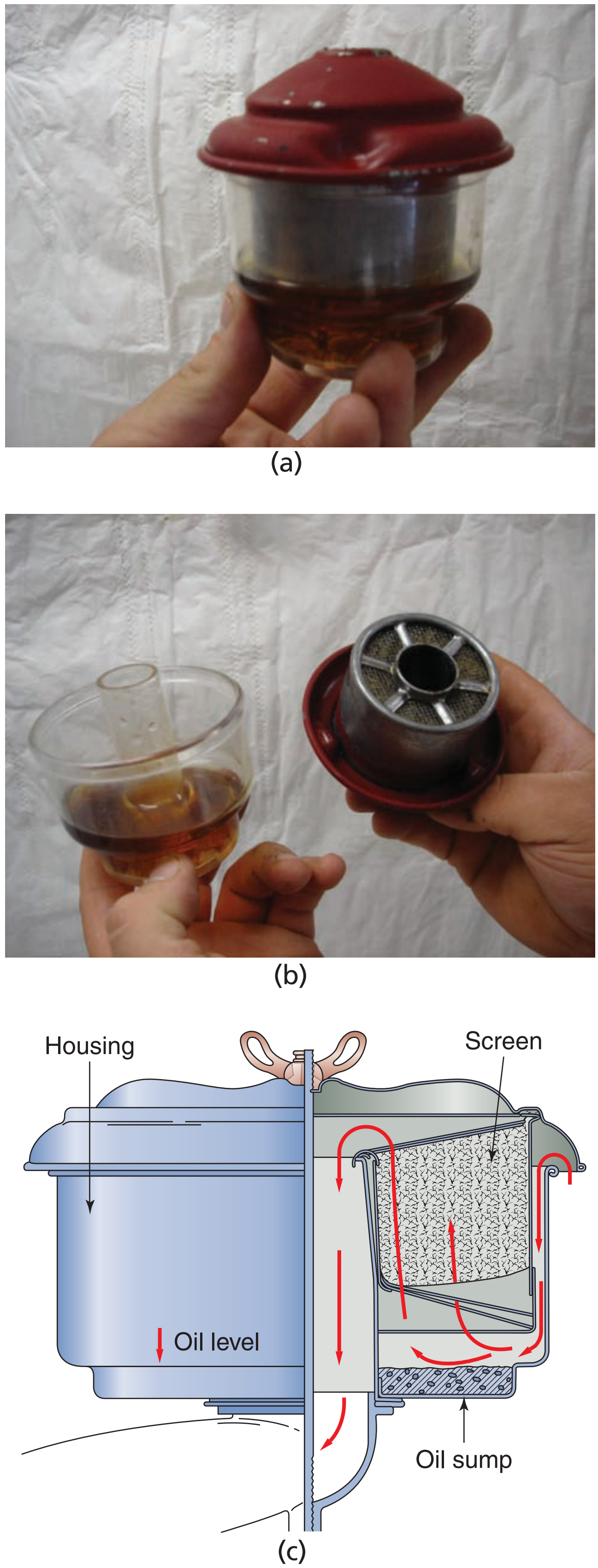

Figure 8-17 While rarely seen now, the oil bath air filter was used on most engines up until the 1960s. Courtesy of Kohler Co.

use different fuel metering systems, which supply fuel for the air–fuel mixture in regulated amounts. These metering systems are called **fuel circuits**, and their operating ranges overlap. We'll discuss these circuits as well as the operation of the common carburetors that you'll see in power equipment engines. Let's begin by discussing starting a cold engine.

Cold Start Systems

For the cold start phase of engine operation, a rich fuel mixture is needed because the engine metal is cold. When the engine is cold, the air–fuel mixture is also cold and won't vaporize or combust readily. To compensate for this reluctance to burn, the amount of fuel in proportion to the amount of air must be increased. This is accomplished by the use of a cold start system. Cold start systems are designed to provide and control a richer-than-normal air–fuel mixture, which is necessary to quickly start a cold power equipment engine. Most carburetor cold-start mixtures are designed to operate at a ratio of approximately 10:1, that is, 10 parts of air to 1 part of fuel. Carburetors manufactured today usually include one of three types of cold start devices.

Primer Cold Start System

A primer cold start system is a rubber squeeze bulb used to force fuel into the combustion chamber past the carburetor to help start a cold engine (Figure 8-18). There are two different types of the primer cold start system in power equipment engines: wet bulb and dry bulb. They can be mounted to the side of the carburetor or as a separate assembly mounted elsewhere in the engine. To start a cold engine with a wet bulb primer, the operator squeezes the bulb, which forces fuel out of the bulb-holding chamber past a check valve through the carburetor and into the engine. When the bulb is released, fuel is refilled back into the bulb from the fuel source. There are two check valves on a wet bulb primer: one to prevent fuel from entering the engine under low pressure (when the bulb is released) and one to prevent fuel from entering into the source under high pressure (when the bulb is being pushed). When used, the engine receives raw fuel in the intake port for an easier cold engine start.

The dry bulb primer pushes air into the carburetor bowl, which increases pressure in the bowl. The increase in pressure forces fuel through the carburetor and into the engine.

Choke Plate Cold Start System

The choke plate cold start system is an air restriction system that controls the amount of air available during a cold engine start. This system uses an operator-controlled plate, called a choke valve, to block air to the carburetor venturi at all throttle openings (Figure 8-19). This plate has a small hole cut into it, a cut out in the plate, or both to allow some air into the carburetor venturi (Figure 8-20). This gives the engine enough air to run, by creating a very rich

Figure 8-18 A primer cold start system pushes fuel directly into the engine.

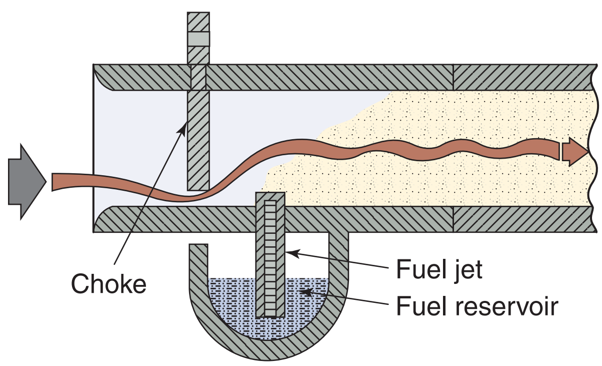

Figure 8-19 The choke plate cold start system closes off air to the engine.

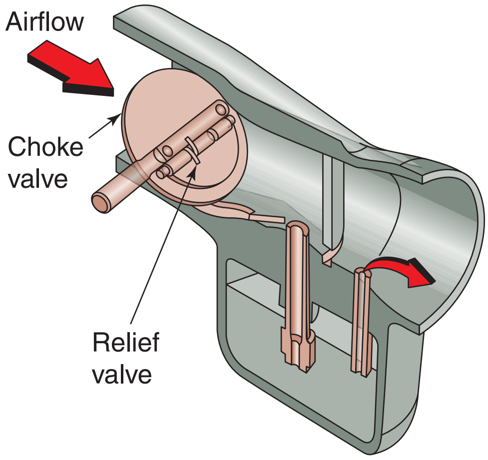

Figure 8-20 The choke plate cold start system allows a predetermined amount of air to flow into the intake tract.

mixture, in comparison with the mixture created had the plate been in the open position. The choke valve is located on the air-filter side of the carburetor.

Choke Plate Operation The choke plate can be operated manually or by an automatic choke, as in some engines. An automatic choke is a valve connected to a diaphragm or bimetal spring that automatically opens or closes the choke valve.

The diaphragm-type automatic choke uses a diaphragm mounted to the carburetor (Figure 8-21). It's connected to the choke valve shaft by a link. A spring under the diaphragm holds the choke valve closed when the engine isn't running. When the engine is started, low pressure is created in the cylinder during the intake stroke. The low pressure acts on the bottom of the diaphragm through a small passage and pulls the diaphragm down. The link attached to the diaphragm also travels down. The link pulls the choke valve into the open position.

The vacuum under the diaphragm leaks away when the engine is stopped. The spring moves the diaphragm in a direction to close the choke valve. The choke is ready for another starting cycle.

The bimetal-type automatic choke uses a spring (Figure 8-22) made from two metals, which have different amounts of heat expansion. The two metals cause the spring to move

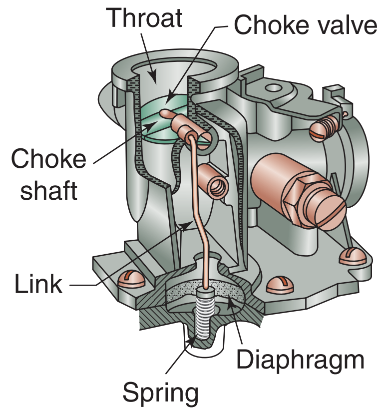

Figure 8-21 A diaphragm type automatic choke and its related components.

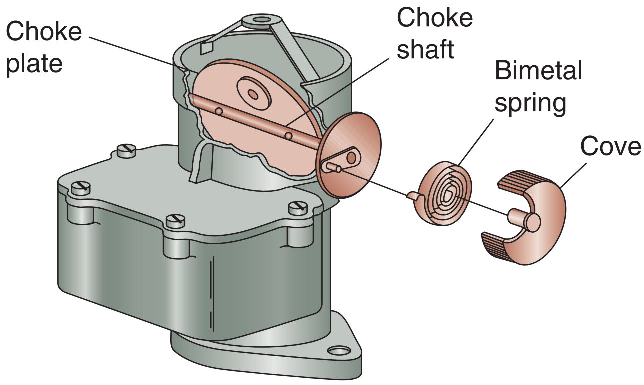

Figure 8-22 A bimetal type automatic choke and its related components.

as it changes temperature. The choke spring is mounted in a small housing next to the choke valve. One end of the choke spring is connected (directly or by linkage) to the choke valve. The other end is anchored to the housing.

When the engine is cold, the bimetal spring contracts. The end of the spring moves the choke valve to a closed position. As the engine warms up, the spring expands. The expanding spring moves the choke valve into an open position. The spring is located near the muffler to heat quickly and turn the choke off at a predetermined temperature.

Types of Carburetors

There are many types of carburetor designs, but as you've learned, the fundamental operation is the same for each design. Carburetors must atomize the fuel before the fuel reaches the engine. Proper atomization ensures that the air–fuel mixture is vaporized so that the engine performs at its best. Most carburetors used in power equipment engines have a fixed venturi, meaning that the venturi remains the same size at all engine running speeds, in contrast to carburetors used on motorcycles or all-terrain vehicles (ATVs), where a variable venturi carburetor is used by implementing a slide that moves up and down at different engine speeds. The carburetors used in power equipment engines can be grouped into four categories: vacuum, float, diaphragm, and suction feed diaphragm.

Vacuum Carburetors

The vacuum carburetor, also called the suction carburetor, is a common carburetor often found installed in smaller, less expensive engines. A vacuum carburetor uses vacuum to pull fuel out of the fuel tank and mixes it with air entering the engine. These carburetors are always mounted on top of the fuel. All vacuum carburetors work the same basic way.

A vacuum carburetor has a simple one-piece housing (Figure 8-23). The housing is basically a tube with an opening at one end for intake air to enter. A choke valve in the air opening can be opened or closed to regulate air flow. The other end of the housing acts as an outlet for the air–fuel mixture. The mixture goes through the outlet and enters the engine intake port. This end has holes to mount the carburetor to the engine.

There is a throttle valve inside the carburetor just past the air entrance. Below the throttle valve is a tube called the fuel pipe (Figure 8-24). The fuel pipe brings fuel up into the carburetor from the fuel tank. The bottom of the fuel pipe has a small screen that filters dirt from going up the pipe and into the carburetor. A small ball check valve fits in the bottom of the pipe. The ball check valve allows fuel to go up the pipe but will not let fuel run back out of the pipe.

The fuel tank fits on the bottom of the carburetor. The carburetor fuel pipe goes down into the bottom of the fuel tank. The cap on the fuel tank is vented to allow atmospheric pressure into the tank. Without a vent, a vacuum could form in the tank, which would prevent fuel from going up the fuel pipe.

A low pressure (vacuum) is created inside the carburetor as the piston moves down on the intake stroke. This low pressure pulls fuel up the fuel pipe (Figure 8-25). The throttle valve is in the way of the flow of air entering

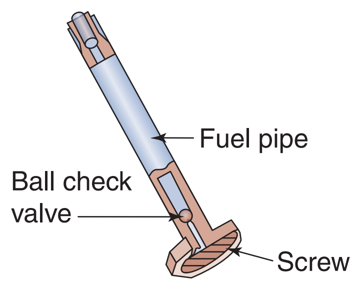

Figure 8-24 A typical fuel pipe.

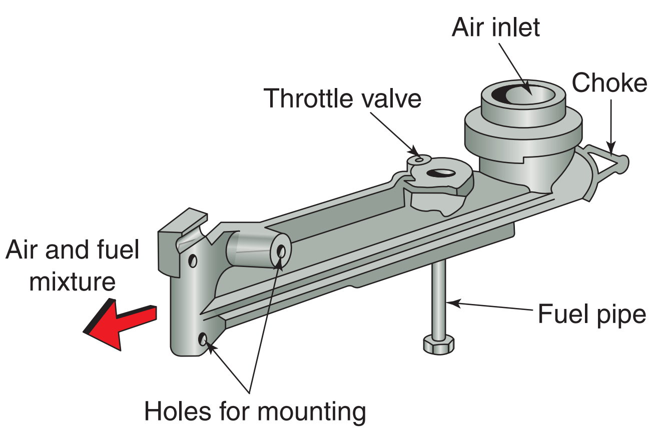

Figure 8-23 The vacuum type carburetor uses a simple, one-piece housing.

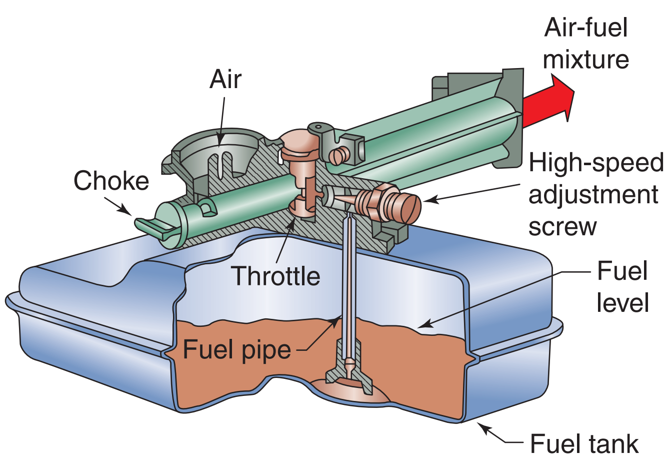

Figure 8-25 Fuel delivered to the engine with a vacuum type carburetor.

the carburetor. It creates a low pressure area, as in a venturi. The low pressure helps pull fuel up the fuel pipe. The fuel is mixed with the intake air passing through the carburetor housing. The amount of fuel that comes out the fuel pipe is regulated by a high-speed fuel adjustment screw.

There are two circuits in the carburetor housing: low speed and high speed (Figure 8-26). Fuel flows through either or both these circuits, depending on the speed of the engine. When the throttle plate is open, there is maximum flow out of both circuits. When the throttle plate is closed, only the slow-speed circuit allows fuel to flow. This circuit allows a small amount of fuel flow for idle, which allows the engine to run with a nearly closed throttle.

Float Carburetors

Many power equipment engines use a float carburetor (Figure 8-27), which is a carburetor that has an internal fuel storage supply controlled by a float assembly. The fuel tank on the float carburetor system is attached to another part of the engine, often mounted higher than the carburetor. Gravity causes fuel to flow from the tank through a fuel line to the carburetor. Some engines use a fuel pump to transfer the fuel from the tank, to the carburetor. A float assembly in the carburetor controls the flow of fuel from the tank.

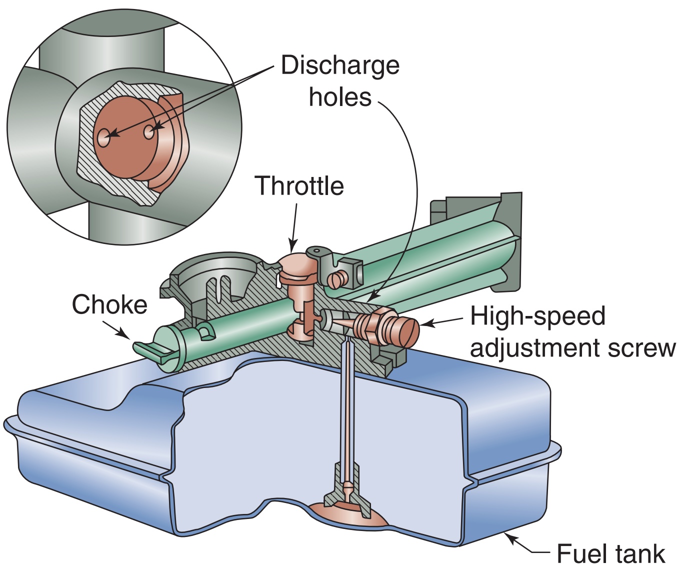

Figure 8-26 Discharge holes are used in low- and high-speed circuits for the fuel system in a vacuum type carburetor.

The fuel line from the fuel tank provides fuel to the carburetor. The fuel line is connected to a carburetor fuel inlet fitting. The fuel flows past an inlet seat. The inlet seat is a carburetor part that houses and provides a matching seat for the tapered end of a float needle valve. The fuel goes through the inlet seat into the carburetor float bowl. The valve is used to allow fuel to flow or stop the flow of fuel into the float bowl. A float pivots against the needle valve (Figure 8-28).

The float bowl is a component that provides a storage area for fuel in the carburetor. There is a small vent in the top of the bowl to allow atmospheric air in. The float is a component that floats on top of the fuel and controls the amount of fuel allowed into the float bowl. It shuts off the flow of fuel once the float rises far

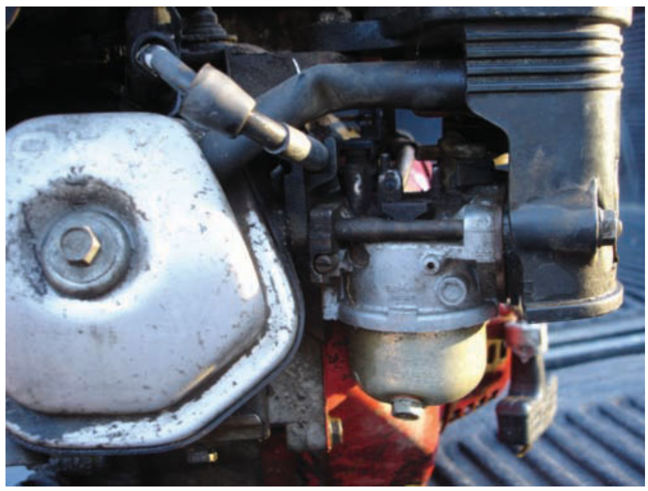

Figure 8-27 A float type carburetor. The float bowl is on the bottom of the carburetor.

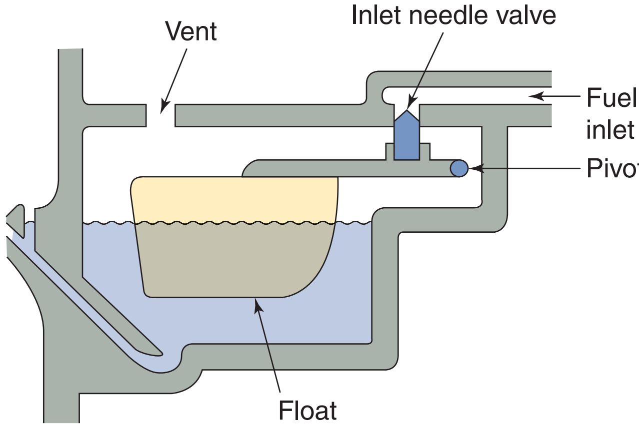

Figure 8-28 A typical float chamber.

enough and "seats." Once the float rises and the needle seats, fuel is no longer allowed to flow into the float bowl.

As the engine runs, fuel in the float bowl is used up. The fuel level in the bowl drops. As the fuel level drops, the float drops. When the float moves down, the inlet needle valve connected to it moves out of the inlet seat. Fuel is allowed to come in through the inlet passage from the fuel tank. The fuel level rises as more fuel comes into the bowl. The float also rises, pushing the inlet needle valve into the inlet seat. This action repeats itself to maintain the required level of fuel in the float bowl (Figure 8-29).

Float Carburetor Types All float carburetors use a float to control the fuel level. There are, however, different styles of float carburetors. These carburetors are identified commonly by the direction of air flow into the carburetor throat. A carburetor throat is the part of the carburetor that directs air flow in toward the venturi.

Updraft, downdraft, and sidedraft are common float carburetor designs. An updraft carburetor (Figure 8-30) is a carburetor in which the air flows into the venturi in an upward direction. Updraft carburetors are installed commonly in older, larger engines.

A downdraft carburetor (Figure 8-31) is a carburetor in which the air flows into the venturi in a downward direction. Downdraft carburetors are used in some multiple cylinder engines. An intake manifold is used to connect a downdraft carburetor to the intake ports of each cylinder.

A sidedraft carburetor (Figure 8-32) is a carburetor in which the air flows into the venturi from the side. The sidedraft carburetor is common and is used in many sizes and styles of engines.

Float Carburetor Operation Most float carburetors operate in the same fashion. The operation of the carburetor can be divided into different systems:

- Float operation
- Idle (low-speed) circuit operation
- Part throttle circuit operation (transition from low speed to high speed)
- Main (high-speed) circuit operation

The float system operates at all times and at all engine speeds (Figure 8-33). It provides fuel

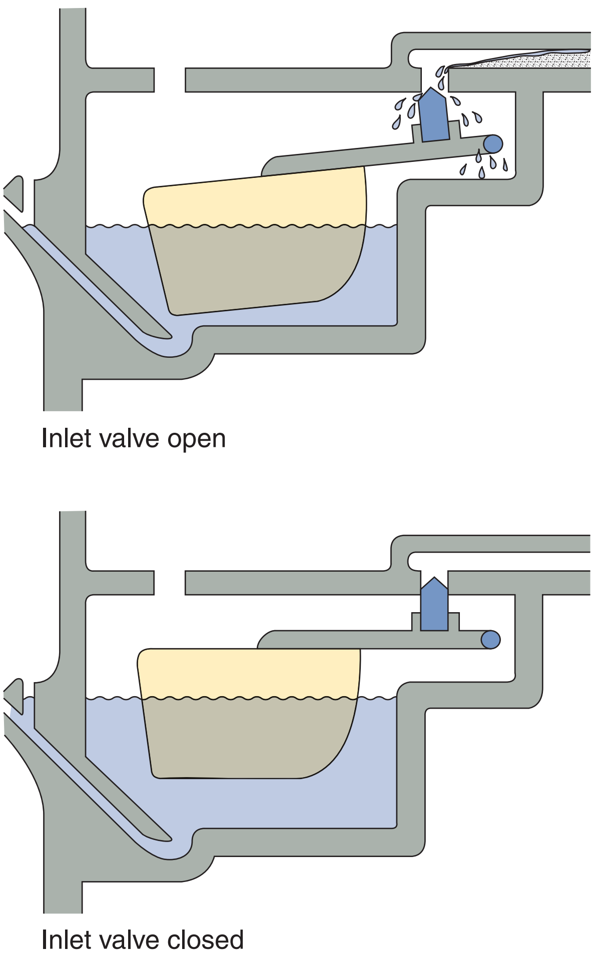

Figure 8-29 A functioning of a typical float valve.

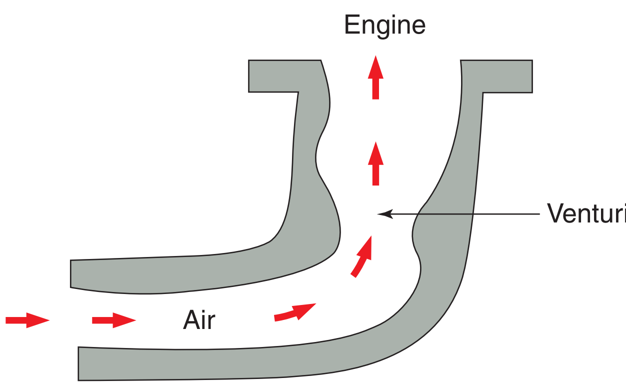

Figure 8-30 An updraft float carburetor system.

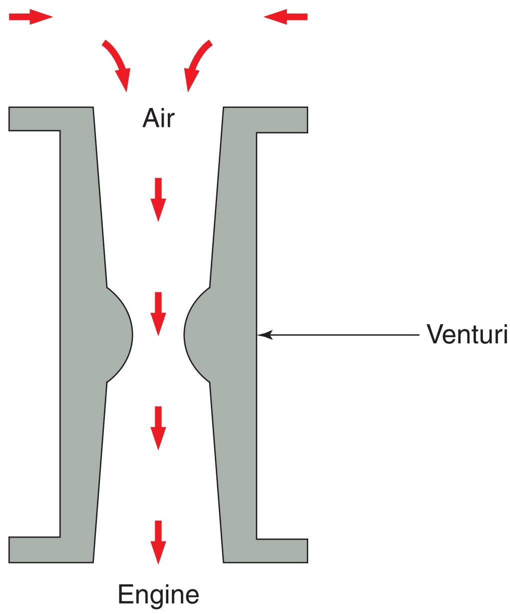

Figure 8-31 A downdraft float carburetor system.

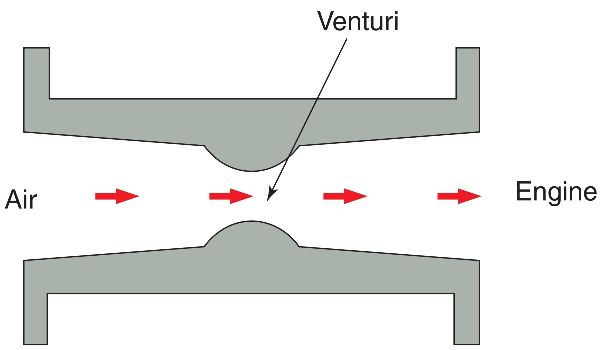

Figure 8-32 A sidedraft float carburetor system.

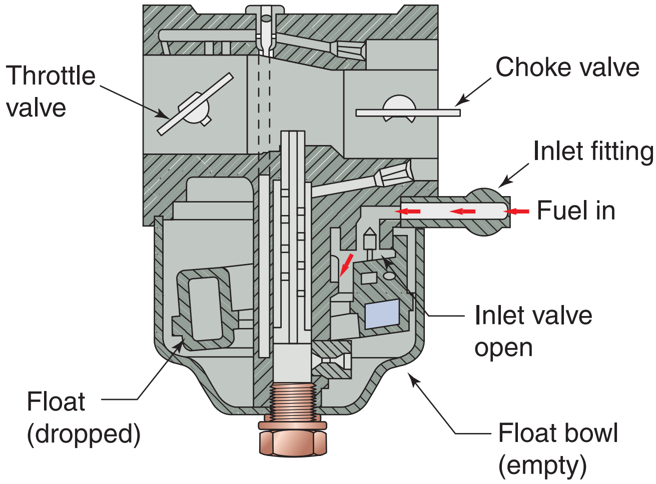

Figure 8-33 Fuel flows into the float bowl when the float bowl is low (dropped).

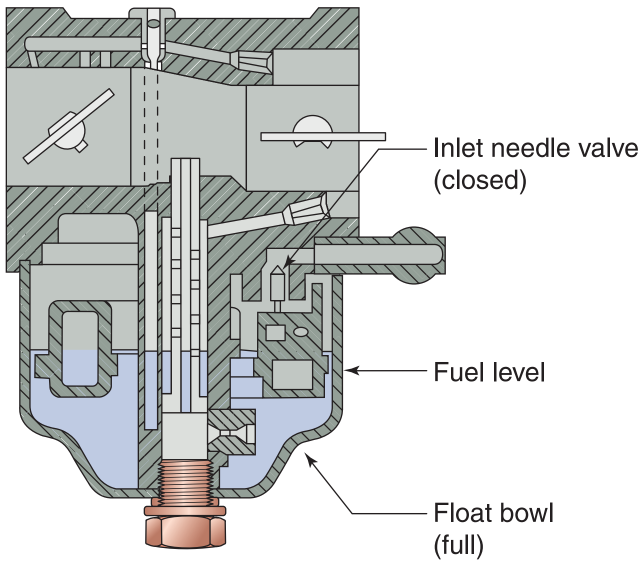

Figure 8-34 When the float bowl is filled, the flow of fuel is stopped.

for all the carburetor circuits. Fuel flows from the fuel tank to the carburetor by gravity or a fuel pump. Fuel enters the carburetor through the inlet fitting. It goes past the inlet needle valve and begins filling the carburetor bowl.

As the bowl fills, the float rises, raising the inlet needle valve toward the inlet seat (Figure 8-34). When the inlet needle closes, fuel flow into the bowl stops. Fuel remains at this level until engine operation begins to draw fuel from the bowl. When the fuel level drops again, the float moves down, causing the inlet needle valve to move away from the inlet seat. Fuel again flows into the float bowl. This happens over and over to provide a constant fuel supply.

When the engine is idling, the throttle valve is in the closed (or nearly closed) position. The idle circuit delivers air–fuel mixture to the intake port side of the throttle valve (Figure 8-35). Without this system, the engine would not run at idle speed.

When the cylinder is on an intake stroke, a low-pressure area is created in the intake port. The carburetor throttle plate area also has low pressure at this time. Higher atmospheric pressure in the carburetor bowl pushes fuel through a fixed-sized, high-speed jet through the low pressure area. Fuel continues up a small passage called the idle passage.

The atmospheric pressure from the intake stroke also pulls air into the throat of the carburetor. Some of this air goes through a passage called the idle air bleed. As the fuel comes up the idle passage, it enters the center of the idle speed jet. Here it mixes with air from the idle air bleed. The air–fuel mixture is then pulled through a passage, called the primary idle port. It then goes into the carburetor throat. Here, it mixes with air flowing through the carburetor throat and goes into the engine's cylinder.

When an operator wants a speed increase, the throttle linkage is used to open the throttle valve. The carburetor uses the part throttle system (Figure 8-36) when the throttle valve is open part of the way. The part throttle system has the same air–fuel flow as the idle system, with one exception. There are several secondary idle ports in the carburetor throat. These are uncovered as the throttle plate opens. The secondary ports give additional routes for the air–fuel mixture for part throttle engine speeds. The part throttle system can operate momentarily as the throttle passes from idle to high speed. It can also operate continuously if the throttle stays in the part throttle position.

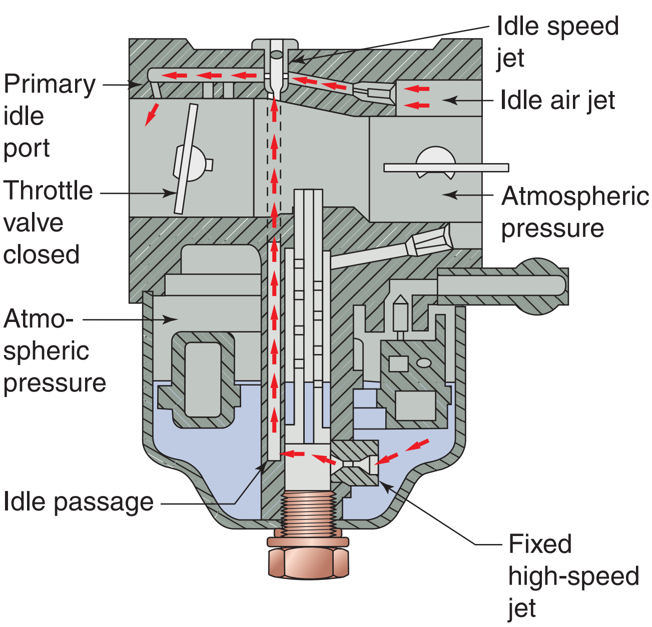

Figure 8-35 A typical idle circuit.

When the operator moves the throttle linkage past the part throttle position to more fully open position, the carburetor uses the high-speed system (Figure 8-37). The intake stroke causes a low pressure in the carburetor throat.

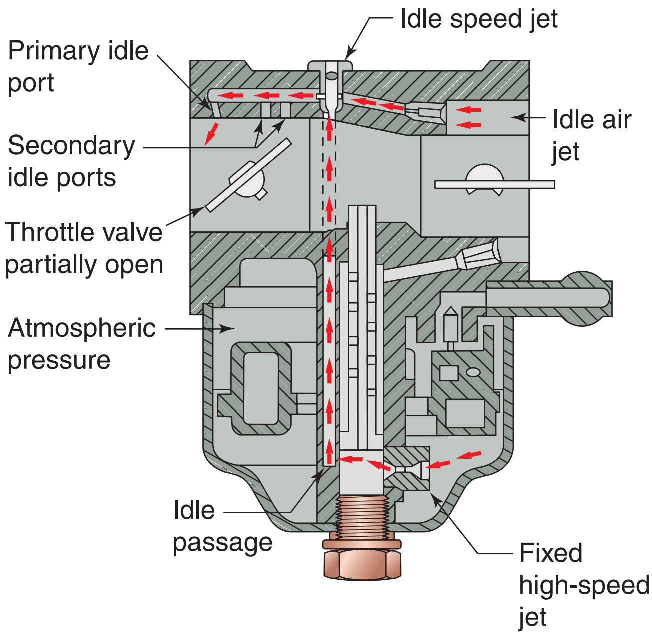

Figure 8-36 The secondary idle ports are used to assist when the user applies an increase in throttle.

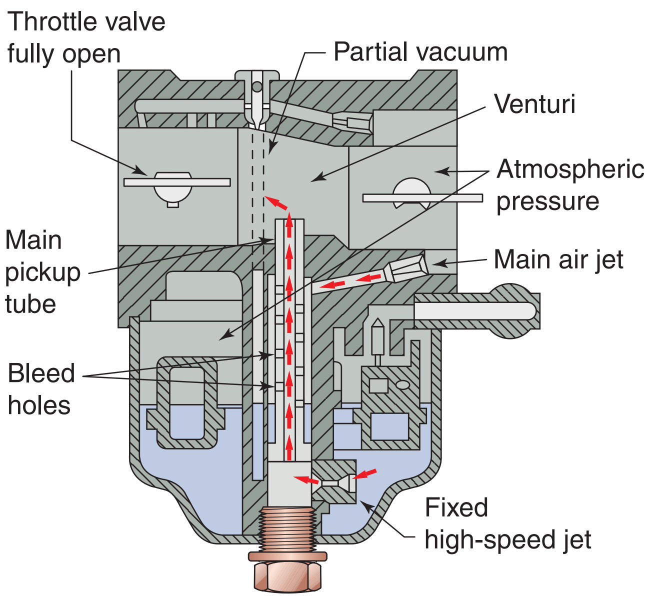

Figure 8-37 The high-speed circuit comes into play when the throttle valve is opened over half way.

Atmospheric pressure pulls air through the venturi in the middle of the carburetor throat. There is a drop in pressure at the venturi. Atmospheric pressure pushes fuel through the fixed high-speed jet. From there, it goes through a large passage called the main pickup tube.

Atmospheric pressure also pushes air through a large air passage, called the main air bleed. From this, air flows to the outside of the main pickup tube. This air enters through the main pickup tube bleed holes. There, it mixes with the fuel coming up the inside of the main pickup tube. The air–fuel mixture is pushed up and out of the main pickup tube into the incoming air at the venturi.

Diaphragm Carburetors

A diaphragm carburetor (Figure 8-38) is a carburetor that has a flexible diaphragm to regulate the amount of fuel available inside the carburetor. It can be operated in any position.

Float- and vacuum-type carburetors work only in engines that are used in the upright position. For this reason, an engine equipped with a float or vacuum carburetor cannot be turned on its side or upside down, in which case the float or fuel tube would not be able to regulate the fuel level, and the engine would run out of fuel and stop. Handheld outdoor power equipment such as a chainsaws, leaf blowers, and string trimmers, which must work in any position, use engines equipped with diaphragm carburetors, as they can operate in any position.

Diaphragm Carburetor Operation The diaphragm carburetor is, in many ways, very much the same as a float carburetor. It has a throat, throttle valve, and venturi. But the diaphragm carburetor does not have a float bowl. Instead, it uses a diaphragm similar to that used in a fuel pump. The diaphragm controls a small amount of fuel in a fuel chamber. A fuel inlet needle valve similar to that in a float carburetor is used to control fuel flow into the carburetor (Figure 8-39).

The diaphragm is made from a flexible, rubber-like material. It's stretched across a small

Figure 8-38 A diaphragm carburetor can be turned in any angle without impairing operation.

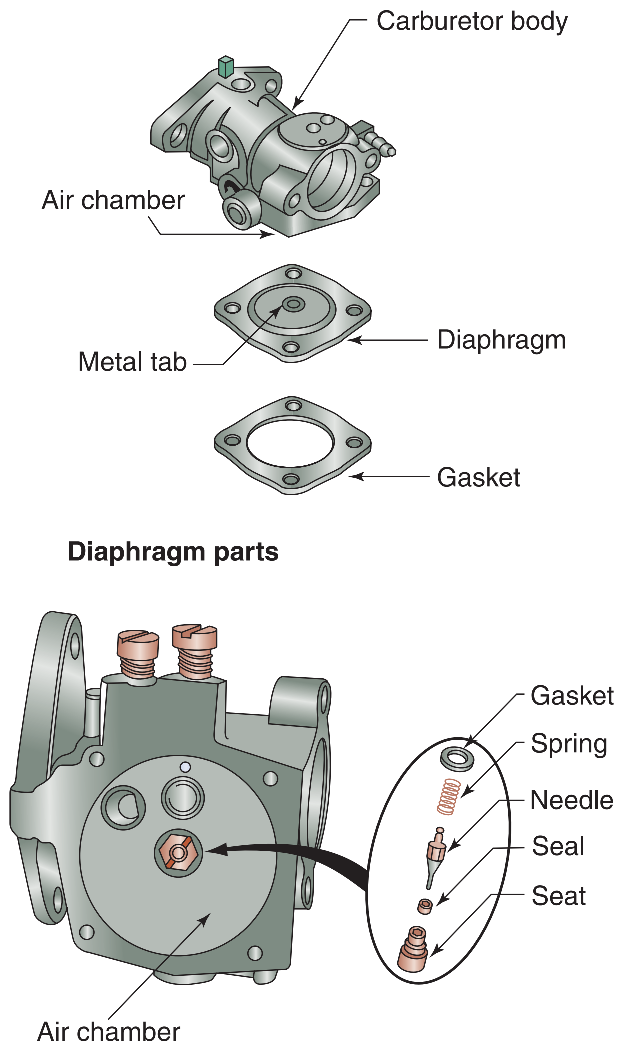

Figure 8-39 The parts of a diaphragm carburetor.

space above the diaphragm, called a fuel chamber. The center of the diaphragm has a metal tab (or lever in some designs) that contacts the inlet needle valve. The inlet needle valve works the same way as the needle valve in a float carburetor. The space below the diaphragm is called an air chamber, which has an air vent that allows air at atmospheric pressure below the diaphragm. The air chamber provides the space for diaphragm up-and-down movement (Figure 8-40).

As fuel flows from the fuel tank to the fuel inlet, the spring pushes down on the control lever, causing the needle valve to drop down and allowing fuel to come in around the inlet needle valve. As the fuel fills up the chamber, its weight pushes down on the diaphragm (Figure 8-41). Downward movement of the diaphragm causes the control lever to pivot upward. This

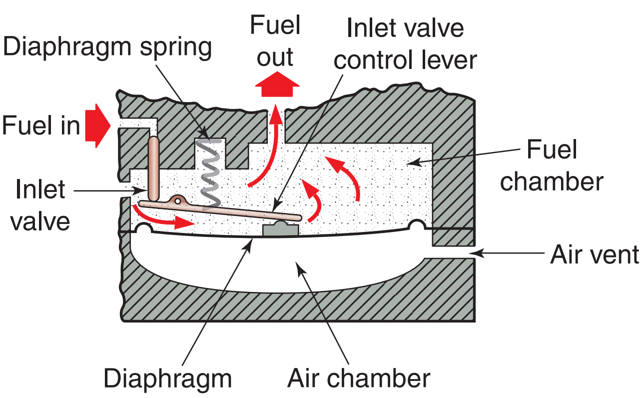

Figure 8-40 A diaphragm carburetor has two chambers: one for fuel and one for atmospheric pressure.

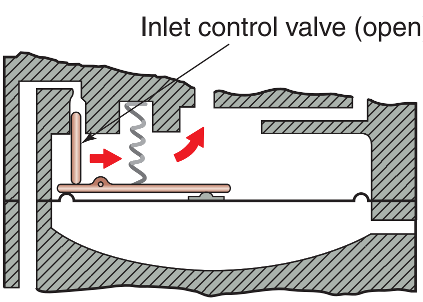

Figure 8-41 The inlet valve of the diaphragm carburetor in the open position. As fuel enters the chamber, it pushes down on the diaphragm.

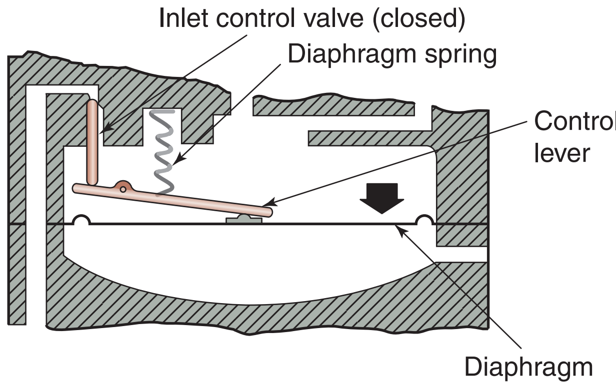

Figure 8-42 Once fuel has filled the chamber of the diaphragm carburetor, the inlet control valve closes off the flow of fuel, just as on a float type carburetor.

movement pushes up on the inlet needle valve, closing the fuel inlet (Figure 8-42). When fuel is used up, the diaphragm comes back up, allowing the inlet needle valve to open to let fuel in again.

Many diaphragm carburetors use two diaphragms: one to control the fuel flow into the carburetor and the other as an impulse fuel pump. The pump section pumps fuel from the fuel tank to the carburetor.

Modes of Operation of a Diaphragm Carburetor Just as with every other type of carburetor, the diaphragm carburetor provides the correct air–fuel mixtures for several modes (circuits) of operation (Figure 8-43). These include:

- Cold starting
- Idle
- Intermediate speed
- High speed

When the engine is cold, a rich mixture is required for starting. The choke system has a valve in the carburetor throat, as we had discussed earlier in this chapter. In the choke mode, the choke valve is closed. The only air that can get into the engine enters through openings around the choke valve. When the engine is cranked during starting, the intake stroke creates a low pressure in the venturi. The low pressure pulls fuel from the diaphragm chamber up

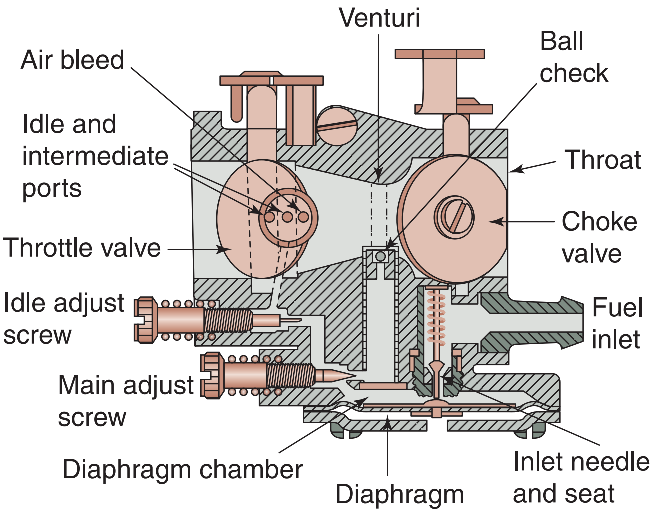

Figure 8-43 The various circuits of a diaphragm carburetor.

the main nozzle. Fuel is also pulled from idle fuel discharge ports. The fuel mixes with the air that passes around the choke valve. A very rich air–fuel mixture is used to start the cold engine.

During idle speeds, only a small amount of fuel is needed to keep the engine running. The throttle valve is almost closed during idle. A small idle discharge port is located on the engine side of the closed throttle valve. The low pressure in this area pulls fuel from the diaphragm chamber. Fuel goes past an idle adjusting screw and is delivered behind the throttle valve. The fuel is mixed with air that gets through the almost closed throttle valve. Additional air comes through an idle air bleed passage. The idle adjusting screw adjusts the amount of fuel that is delivered out the idle discharge port.

When the throttle valve is moved past the idle position, it uncovers two more discharge ports, called the intermediate ports. They provide more fuel to mix with the air flowing into the engine. The fuel flows from the diaphragm chamber past the idle mixture adjusting screw. Fuel and air flows are the same as in the idle mode. The additional fuel from the intermediate ports allows the engine to operate at higher speeds.

The high-speed circuit is used when the throttle valve is opened further. Air flows through the carburetor throat at high speed. The venturi further accelerates the air flow and creates a low pressure in the venturi area. This low pressure pulls fuel into the air stream through a delivery tube called the main nozzle. Fuel flows into the main nozzle through a passageway from the diaphragm chamber. Fuel going up the main nozzle must pass the main adjusting screw, which is used to adjust the amount of fuel for high-speed operation.

Suction Feed Diaphragm Carburetors

The suction feed diaphragm carburetor is a carburetor that combines the features of a vacuum carburetor and the impulse fuel pump (Figure 8-44). This carburetor is used primarily in four-stroke engines. These engines are not usually used in a variety of positions. The carburetor is mounted on the top of the fuel tank. It meters fuel the same way as the vacuum carburetor. Some carburetors have the diaphragm mounted in a side chamber. Others have the diaphragm located between the carburetor body and the fuel tank.

This carburetor is different from the vacuum carburetor. It has two different-length fuel pipes

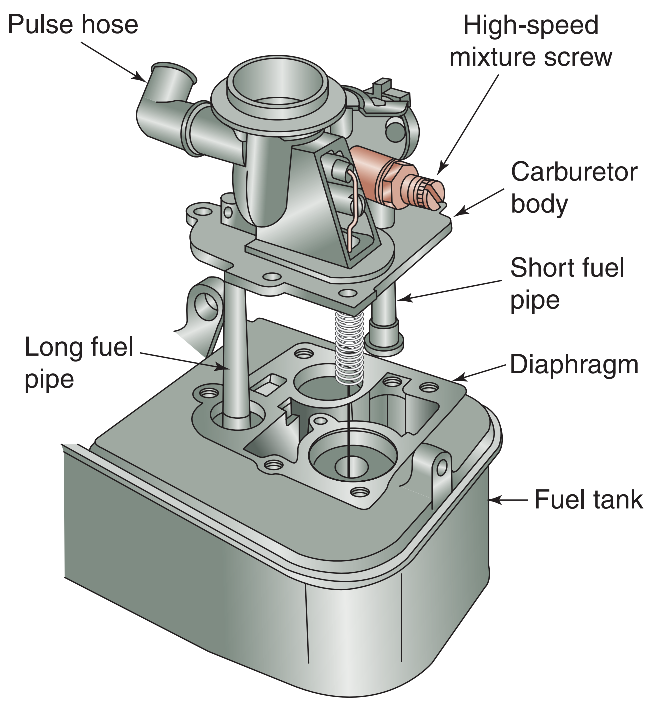

Figure 8-44 The suction feed diaphragm carburetor is one that combines the features of a vacuum carburetor and the impulse fuel pump.

(Figure 8-45). The longer fuel pipe goes into the fuel tank and is used to pull fuel out of the tank and into a small chamber. The shorter fuel pipe goes into a small chamber of the fuel tank. The chamber is called the fuel cup or fuel well. A diaphragm fits between the carburetor and the fuel cup. The diaphragm works like an impulse fuel pump, transferring fuel between the tank and the fuel cup (Figure 8-46). This system gives a constant level of fuel, regardless of fuel tank level.

A pulse hose connects the pumping chamber to the intake manifold (or crankcase in some designs). When the engine is running, the pulse hose transmits a pulse to the diaphragm chamber. The diaphragm moves up and down with the pressure pulses, pumping fuel up the long–fuel pipe into the fuel tank cup. Fuel goes out of the fuel cup into the venturi through the short–fuel pipe.

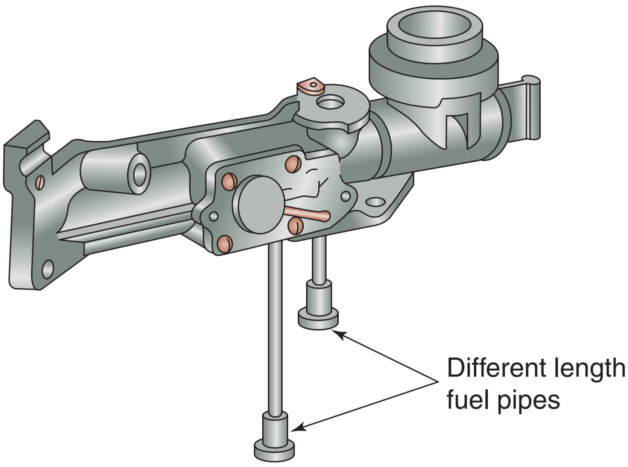

Figure 8-45 The suction feed diaphragm carburetor has two, different-length fuel pipes. The longer fuel pipe goes into the fuel tank and is used to pull fuel out of the tank. The shorter fuel pipe goes into a small chamber of the fuel tank.

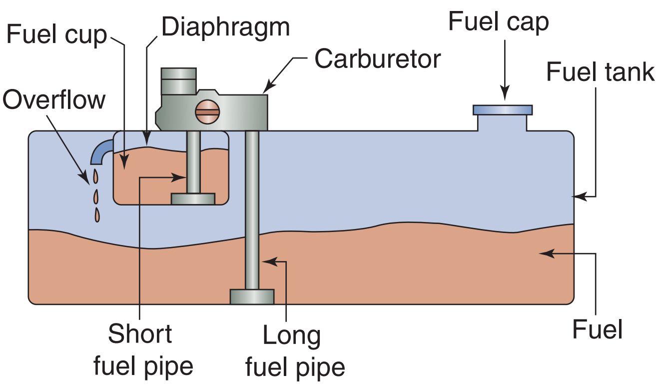

Figure 8-46 The suction feed carburetor drawing fuel from the fuel tank.

FUEL INJECTION

Fuel injection is the most modern method for carburetion in today's power equipment engines. The purpose of fuel injection is to allow a precise metering of air–fuel mixture ratios at any given engine condition. This results in the engine getting only the amount of fuel it needs at all times, instead of a preset amount being delivered at all times, as with traditional carburetors. Other than the method of getting fuel into the engine, the basic components of this system aren't much different from those of a standard carburetor engine. In today's power equipment engines, fuel injection is relatively new but is becoming popular as using it leads to easier compliance with the strict guidelines of the United States Environment Protection Agency (EPA). Compliance ensures that the air we breath remains as clean as possible, by ensuring that our modern power equipment engines are as fuel efficient as possible—combustion-wise—while setting a performance level unlike anything we've seen in the past.

The primary advantage of fuel injection over traditional carburetion is the ability of a fuel-injected engine to automatically adjust to the constantly changing atmospheric conditions to which it's exposed. Conditions such as temperature, humidity, and altitude affect traditional carburetion, altering the efficiency of a carbureted power equipment engine, unless one were to make physical adjustments to the carburetor settings. But with an engine using fuel injection systems, these conditions are compensated for by the use of sensors found within the fuel injection system.

The disadvantage of fuel injection? Cost. Due to the high cost of fuel injection systems, almost all small power equipment engines continue to use carburetors, whereas larger engines are beginning to move up to the higher technology of fuel injection.

The primary type of fuel injection found in today's power equipment engines is called indirect fuel injection. There is also another type of system known as direct fuel injection.

Direct Fuel Injection

With the direct fuel injection system, fuel is injected directly into the combustion chamber. This type of fuel injection is found primarily in diesel engines and not generally found in power equipment engines. The direct system injects an extremely fine mist of fuel into the combustion chamber just prior to the top-dead center (TDC) of the engine's compression stroke.

Indirect Fuel Injection

The indirect fuel injection system is the most common type of fuel injection system found in power equipment engines. When an indirect fuel injection system is used, fuel is injected into the intake tract before the intake valve. All modern fuel-injected power equipment engines use a type of **electronic fuel injection** (**EFI**). Some manufacturers may use different terms to refer to EFI: computerized fuel injection (CFI) or programmed fuel injection (PGM-FI). All these systems use an electronic control module (ECM) to control the amount of fuel being delivered to the engine.

Indirect EFI systems give engines the ability to provide excellent performance as well as meet future EPA standards—standards that are getting tougher to achieve with each passing year.

Fuel Injection System Components

Although most small power equipment engines don't use fuel injection now, their use in future is inevitable. Therefore, we'll summarize a description of the components found in a typical EFI system. Let's start our discussion on EFI-related system components with the area of fuel delivery.

Fuel Pumps

Fuel pumps used with electronic fuel-injected power equipment engines have three primary requirements:

- They must be electric powered.
- They must have the ability to handle a high volume of fuel.
- They must have the ability to supply high pressure to the injectors.

Many modern power equipment engine EFI fuel pumps are located inside the fuel tank of the power equipment engine to save space as well as to prevent vapor lock, a condition that is caused when gasoline overheats and begins to actually boil within the fuel pump. An ECM controls the operation of the fuel pump. The fuel pump will generally operate for a couple of seconds after the key is first turned on to pressurize the fuel injectors.

The fuel pump consists of an electric armature that spins between two magnets and turns an impeller that draws fuel in and through the pump (Figure 8-47). A check valve is incorporated to maintain pressure at the fuel injectors to allow for quick engine starts. Fuel is sealed in this system and therefore cannot evaporate or deteriorate during long periods of nonuse, as during winter months. A relief valve is also located within the fuel pump and is opened to send fuel back into the fuel tank if a fuel line were to become restricted and cause excessive pressure buildup.

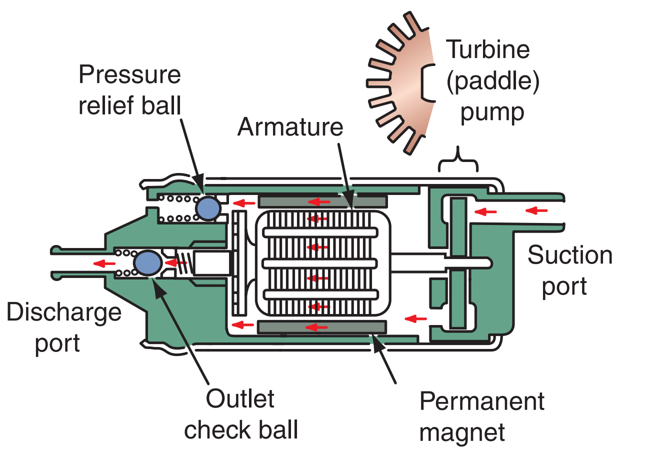

Figure 8-47 The components of an electronic fuel pump for a fuel injection system.

Fuel Filters

There are generally at least two fuel filters used in EFI systems. Before fuel enters the fuel pump, it must go through a mesh filter that prevents grit and rust from entering the pump and damaging it. Another filter used is a large inline type and can be mounted inside or outside the fuel tank (Figure 8-48). The operation of fuel filters is critical in a fuel-injected system because clogged fuel injectors won't function properly.

Fuel Lines

EFI systems use special, high-pressure fuel lines from the fuel pump to the injectors, which can be damaged by mishandling due to excessive bending or stretching. The damage in many cases will be internal and therefore you'll not see it until the line breaks under pressure. When servicing EFI power equipment engines, be sure to adhere to the appropriate service manual to avoid damaging the fuel lines.

Fuel Pressure Regulators

The fuel pressure regulator maintains correct fuel pressure and keeps it above the pressure of the intake manifold. Excessive pressure is returned to the fuel tank by a separate return hose (Figure 8-49).

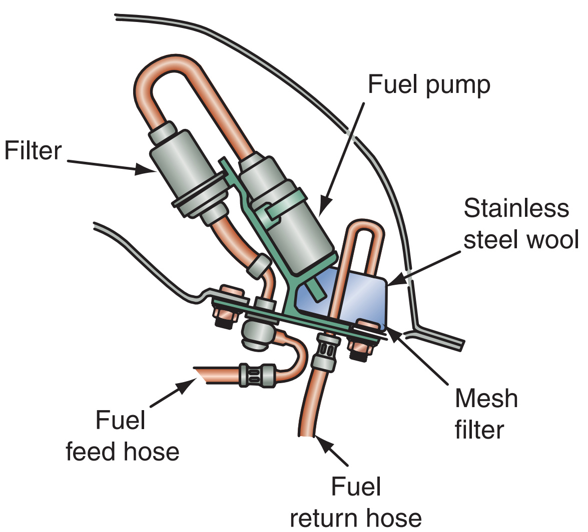

Figure 8-48 The fuel filters located inside the fuel tank.

Fuel Injectors

The **fuel injector** is an electronically operated solenoid that turns fuel on and off (Figure 8-50). They're generally closed and are either fully closed or fully open. The ECM "tells" the fuel injector when to turn on and off. The control unit also determines how long the injector must stay on, therefore telling the injector how much fuel has been injected into the engine. This is known as injector discharge duration. The length of time for which the fuel injector is turned on is known as discharge duration. Three factors influence fuel atomization in an EFI system: the shape of the injector, fuel pressure, and turbulence in the air intake tract. Inside the injector, there's a spring-loaded plunger that closes against a valve seat. Once seated, the flow of fuel is blocked. When the solenoid coil within the injector assembly lifts the plunger, the pressurized fuel sprays into the cylinder. A battery supplies the power for the solenoid coil, and the ECM controls the ground side of the injector, therefore making the injectors "switch to ground circuits." Each injector is controlled by the ECM, and fuel is delivered to the cylinder only as it's needed. This is known as **sequential fuel injection**.

Fuel injector tip openings are designed to provide a spray pattern that atomizes the fuel to help it mix with the incoming air. There are different types of fuel injector tips, the most common having a single outlet, although some engines use multiple outlets (Figure 8-51). These outlet designs are used to vary the spray pattern to the manufacturer's design needs for different performance requirements as well as manufacturing costs.

Fuel Injector Failures Fuel injectors can have two types of failures: electrical and mechanical. There are three possible electrical failures for an injector:

- High resistance
- An open electrical circuit; one in which current cannot complete its path
- A short circuit; one in which current takes an unintended path

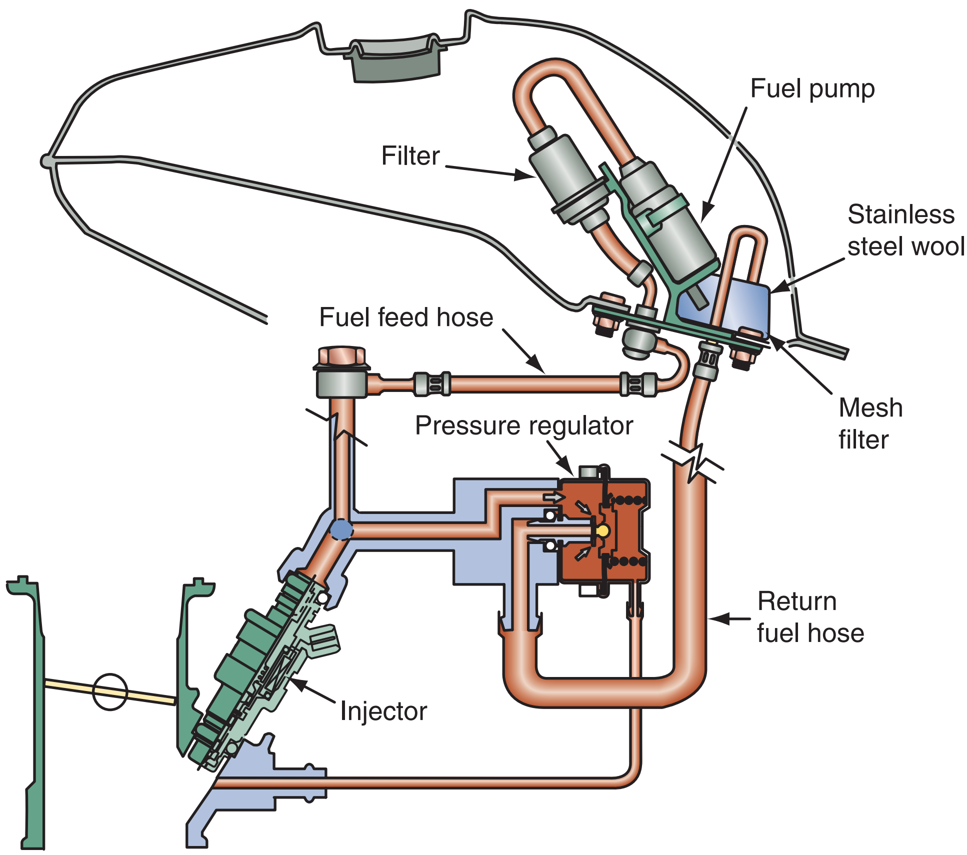

Figure 8-49 A fuel pressure regulator is used to maintain correct fuel pressure and keep it above the pressure of the intake manifold.

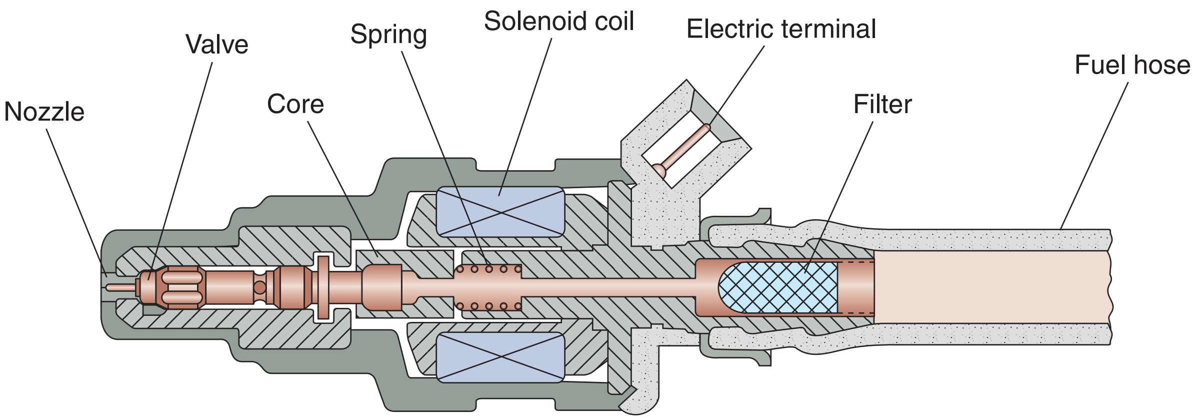

Figure 8-50 The fuel injector is a solenoid that is either on (fuel flows) or off (fuel does not flow).

Some power equipment engines can detect electrical failures while the machine is running. Others can detect a failure only when they're started.

There are two possible mechanical failures for an injector:

- Leaking fuel (partial or complete)
- Blocked fuel discharge (partial or complete)

Possible fuel leakage is indicated by:

- Dark spark plug color
- Fuel fouled spark plugs

Blocked fuel discharge is indicated by:

- A cold exhaust pipe on that cylinder

ECM

The heart of all fuel injection systems is the ECM. The ECM receives signals from all the EFI system sensors, processes them, and transmits programmed electrical pulses to the fuel injectors. Both incoming and outgoing signals are sent through a wiring harness and a multiple-pin connector. The ECM uses a microcomputer to process data and control the operation of the fuel injectors, ignition spark and timing, and the fuel pump. The ECM receives information from basic input sensors and determines what, when, why, and how long the various operation steps need to be controlled. Depending on the manufacturer, an ECM can also be called an electronic control unit (ECU).

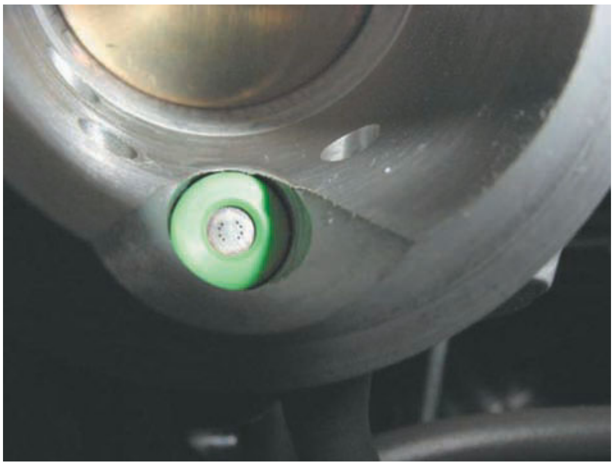

Figure 8-51 Various types of tips can be found on a fuel injector. Decisions on the type of injector to be used can be based on intended use as well as cost.

ECM Inputs and Outputs

The ECM has three types of inputs (Table 8-2):

- Basic
- Correction
- Control

The basic inputs provide information that the ECM needs to select a particular mixture control map (most EFI systems have at least two maps). The ECM then selects the basic fuel

Table 8-2 Typical inputs for an electronic fuel injection
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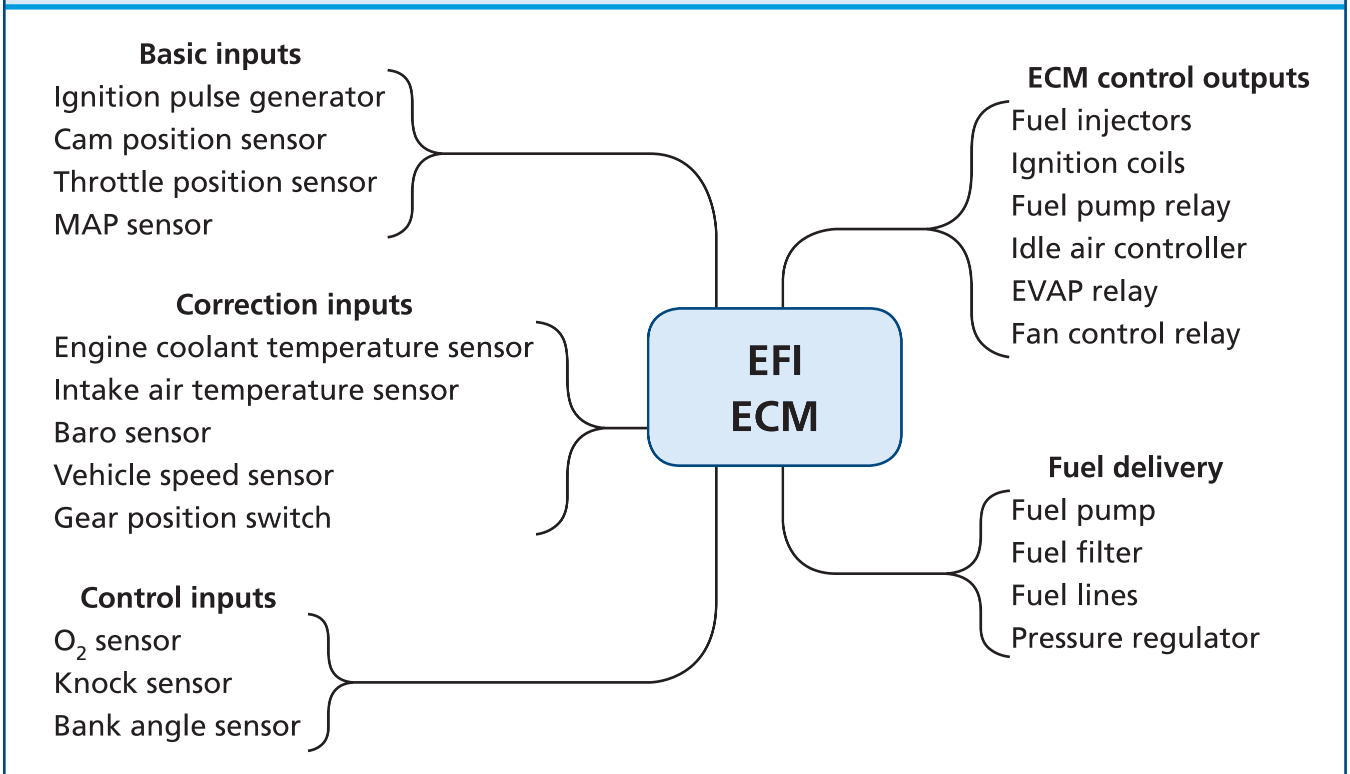


discharge duration from the chosen map. Basic inputs include ignition pulse, camshaft position sensor, throttle position sensor, and the vacuum pressure in the intake manifold [manifold absolute pressure (MAP) sensor].

The correction inputs provide the information that the ECM needs to adjust the basic fuel discharge duration. Typical correction inputs would include engine temperature, intake air temperature, barometric pressure (BARO), and vehicle speed.

The control inputs provide the information that the ECM needs to adjust engine operation. These inputs would be the oxygen sensor and knock sensor. A bank angle sensor is used often in power equipment engines to cut off electrical power to the ECM in the case of the machine tipping over. Bank angle sensors are designed to stop the engine.

ECM outputs include the fuel injection, ignition spark as well as the operation of the fuel pump and cooling fan in liquid-cooled machines.

Sensors

Various sensors monitor the engine and atmospheric conditions such as throttle position, engine revolutions per minute (rpm), engine and intake air temperature, vehicle speed and MAP (which is calculated into air density), coolant temperature, and piston position. These sensors assist in all aspects of EFI and send information to the ECM to allow the engine to run as efficiently as possible.

Throttle Body

Engines with PGM-FI may have one throttle valve for each cylinder. The throttle body contains the injector as well as a butterfly valve (Figure 8-52). Power equipment engines with EFI don't need to depend on the Venturi effect because of the fuel injector delivery of a precise amount of fuel at any given time, unlike a carbureted power equipment engine that will receive the same amount of fuel at all throttle openings.

EFI Self-Diagnostics

Most modern power equipment engines that use EFI have a self-diagnostic system incorporated to assist technicians when problems arise. Various components on EFI are monitored continuously by the self-diagnosis function and if the ECM notices a fault, a light comes on within the dashboard of the machine. This light is sometimes called the "check engine" light or the "FI" light. Some manufacturers call this light by the term officially used in the automotive industry, which is the *malfunction indicator lamp* (MIL) (Figure 8-53), and depending on the severity of the fault, may give a warning to the user. In other cases, the engine may go into a fail-safe operation mode, which allows the engine to continue to run but at a reduced performance level or stop completely, depending on the severity of the fault, such as when

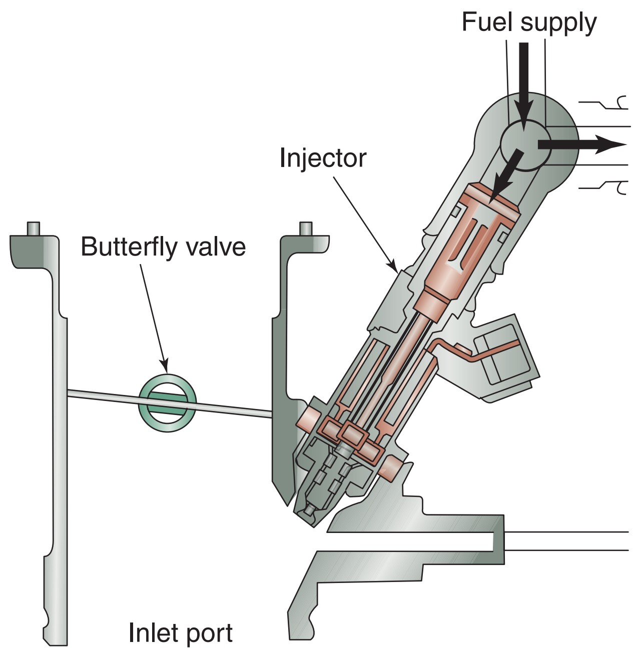


Figure 8-52 A throttle body for an electronic fuel injection (EFI) system along with an illustration of a fuel injector and the inlet port of the throttle body. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

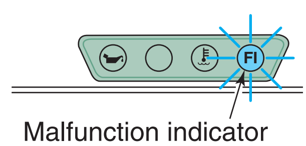


Figure 8-53 The malfunction indicator light (MIL) will let a user know if a failure is detected in the EFI system. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

an electrical-related problem is detected by the system sensors. The MIL is used to detect and assist in diagnosing any EFI-related, electrical failure.

Basic Operation of the Fuel Injection System

In a typical EFI system, the ECM must "know" the amount of air entering the engine so that it can supply the stoichiometric air–fuel ratio. Most EFI systems have a MAP sensor to allow the computer to calculate the amount of air entering the engine from the MAP and engine rpm input signals. The ignition pickup or crankshaft position sensor supplies an rpm signal to the computer. The MAP sensor sends a signal relating to the pressure inside the intake manifold to the ECM. The computer must have accurate signals from these inputs to maintain the stoichiometric air–fuel ratio. Other inputs are used by the computer to fine-tune the air–fuel ratio through electronic feedback. Electronic feedback means the system is self-regulating and the ECM is controlling the injectors on the basis of operating conditions rather than on preprogrammed instructions. As an example of a feedback loop used in many EFI systems, the ECM reads signals from an oxygen sensor, varies the pulse width of the injectors, and again reads the signals from the oxygen sensor. This cycle is repeated until the injectors are pulsed for just the amount of time needed to get the proper amount of oxygen into the exhaust stream. While this interaction is occurring, the system is operating in a closed loop. During the closed-loop mode, sensor inputs are sent to the ECM; the ECM compares the values with those in its programs and then reacts to the information to adjust the air–fuel ratio and other engine systems.

When conditions such as starting or wide-open throttle demand that the signals from the oxygen sensor be ignored, the system operates in an open loop. During open loop, injector pulse length is controlled by set parameters contained in the ECM's memory. Systems with oxygen sensors may also go into the open-loop mode while idling or at any other time that the oxygen sensor cools off enough to stop sending a good signal, and at wide-open throttle.

The basic purpose of these control loops is to create an ideal air–fuel ratio, which allows engines using **catalytic converters** to operate at maximum efficiency while giving the best fuel mileage and performance possible. A catalytic converter is a device used to reduce the toxicity of emissions from an engine.

Summary

- Fuel has different octane ratings and various factors affect these ratings.
- The primary principles of carburetor operation are atomization, the process of combining air and fuel to create a mixture of liquid droplets suspended in air, and the Venturi principle, which states that a gas or liquid that's flowing through a narrowed-down section of a passage will increase in speed and decrease in pressure compared with its speed and pressure in wider sections of the passageway.
- Fuel delivery systems consist of many separate components, and servicing fuel delivery systems involves inspecting and cleaning or replacing many of these components.
- Each type of carburetor has different components that function similarly.
- The purpose of fuel injection is to allow an extremely precise metering of air–fuel mixture ratios at any given engine and atmospheric condition.

Chapter 8 Review Questions

1. Gasoline by itself as a liquid will not burn. (True/False)
2. The air we breathe contains _____, which is used to help ignite the fuel mixture in an engine.
3. The _____ rating is defined as the fuel's ability to resist detonation in an engine.
4. The choke plate cold start system controls the amount of _____ entering the carburetor.
5. Carburetor circuits overlap one another. (True/False)
6. The fuel pump in an electronic fuel injection system is _____ or _____ powered.
7. The amount of time that the fuel injector is open is known as _____.
8. Sensors in a fuel injection system monitor the throttle position, air volume, and other important engine parameters, transmitting this information to the _____ or _____.
9. An electronically operated solenoid in a fuel injection system that turns fuel on and off is called a _____.
10. You should not clean a paper air filter with soap and water as it will damage the paper fibers. (True/False)

CHAPTER

9 Throttle and Governor Control Systems

Learning Objectives

- Understand the operation of a manual throttle control engine
- Explain the purpose of a governor control system
- Identify individual components and explain the operation of an air vane governor system
- Identify individual components and explain the operation of a centrifugal governor system

Key Terms

Air vane governor
Centrifugal governor
Control arm assembly
Governor throttle control system
Manual throttle control system
Throttle control

INTRODUCTION

The speed of an engine is regulated by the throttle valve opening. Many power equipment engines, such as lawnmowers, use a manual **throttle control**, which allows the operator to directly set the engine speed. This control system gives the operator the option of running the engine at a level of performance that best suits the needs of what type of work the engine is being used for.

To ensure that the engine speed remains constant during usage, many outdoor power equipment engines use a governor to control engine speed. This chapter will describe how these two systems work.

MANUAL THROTTLE CONTROL

A **manual throttle control system** is an engine speed control system in which the operator sets the engine speed by positioning the carburetor throttle valve in a particular position. Engines with manual throttle control often use a control linkage, as the throttle may be operated at a distance from the carburetor (Figure 9-1) or the controls may be installed directly on the engine (Figure 9-2). The throttle linkage in most power equipment engines is operated with a hand lever. When used in outdoor power equipment, the controls are found commonly on the handle (such as on a lawnmower) or the dashboard (such as on a lawn tractor) of the machine, depending on the type of equipment. The operator sets the speed by moving the throttle linkage to the desired engine speed. Along with manual control, the engine governor also assists with the control of the engine speed.

A throttle cable is used to transfer movement from the lever to the throttle valve. The throttle cable has a flexible metal housing. The outside housing is solidly mounted. A cable inner wire is free to move back and forth inside the cable housing (Figures 9-3a and 9-3b).

The cable inner wire goes from the throttle lever to the **control arm assembly** (Figure 9-4). The control arm assembly is a plate with levers and screw stops for the engine controls. One end of the cable inner wire is connected to the throttle control arm. The other is connected to the control arm assembly. This linkage connects the carburetor throttle valve to the control lever assembly. As the operator moves the throttle control, the cable inner wire moves the carburetor throttle valve through the control lever assembly.

Figure 9-1 Engines with manual throttle control often use a control linkage as the throttle may be operated at a distance from the carburetor. Shown is a throttle control mechanism on the dashboard for easy access.

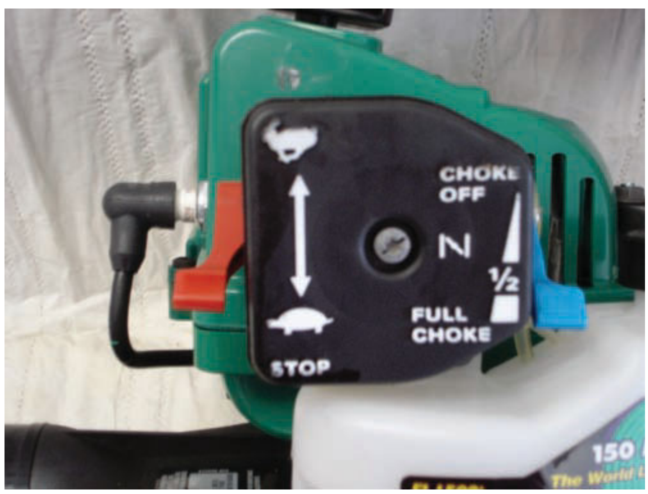
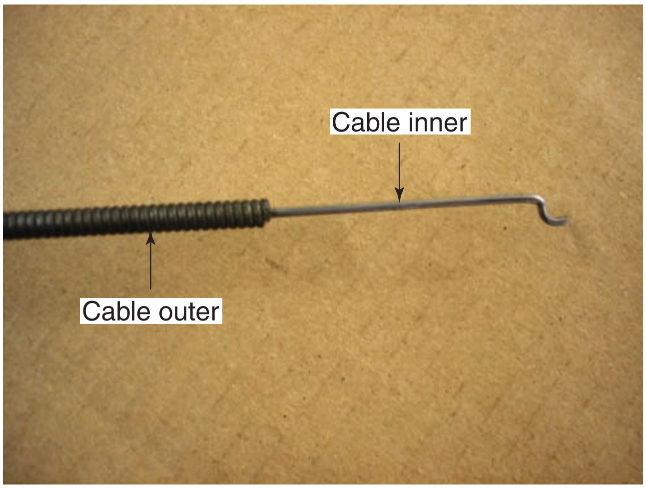


Figure 9-2 Manual throttle control attached directly to the engine.



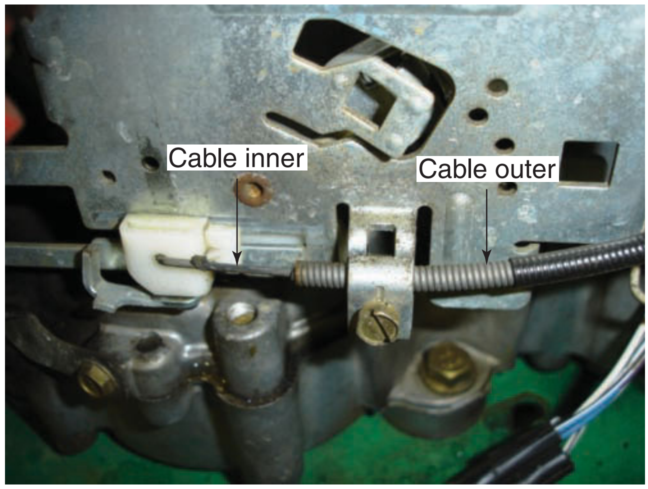


Figure 9-3 A typical throttle cable inner and outer housing.

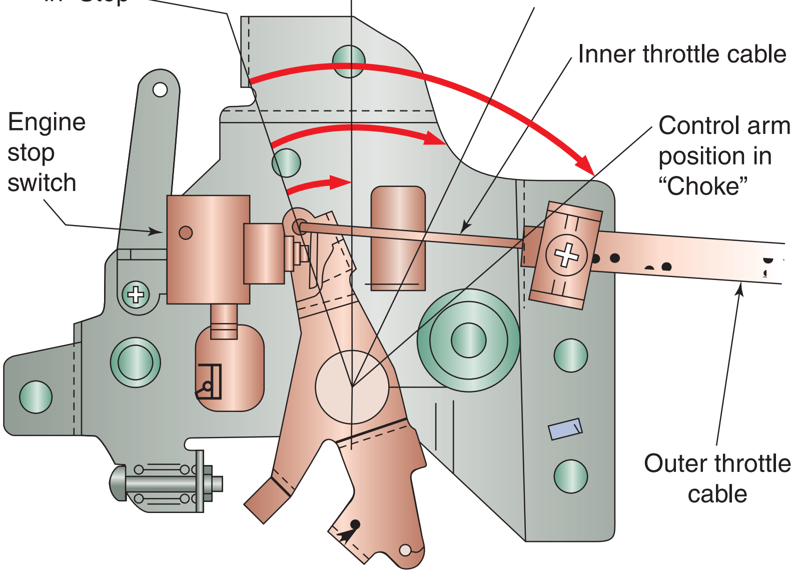


Figure 9-4 A typical control arm assembly and the various throttle positions. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Most power equipment engine carburetors are equipped with a throttle return spring (Figure 9-5). The return spring is connected to the carburetor throttle valve to hold the throttle valve in the closed position. The spring pressure works against (opposes) the throttle valve opening. The spring pressure ensures that the throttle valve closes when the operator shuts down the throttle control.

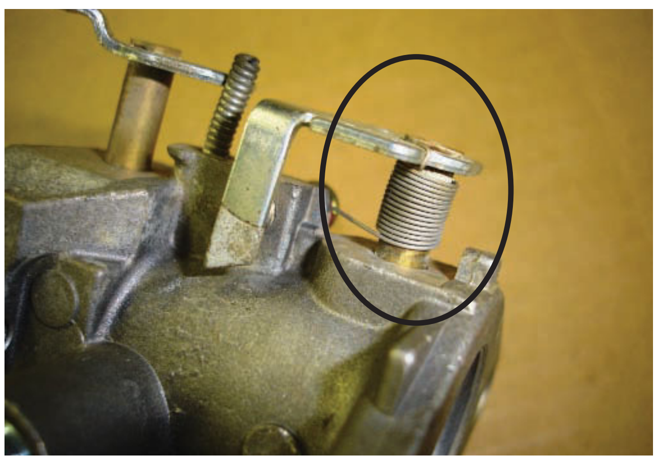


Figure 9-5 A close-up of a throttle return spring.

Choke and Engine Shut-Off Switch Linkage

Manual throttle control systems often have linkages that also operate the choke. The choke is activated when the operator selects the "start" position on the engine's throttle control. A linkage rod is connected to the manual control lever. The linkage rod is connected to the choke lever on the carburetor. The choke plate is located closest to the air filter side of the carburetor. The choke lever moves the choke valve in the carburetor throat into a closed position. After engine start-up, the operator can set the manual control to the "run" position. The linkage rod moves the choke lever from a closed position to an open position.

Many engines have an ignition shut-off switch that is part of the throttle control lever assembly. The shut-off switch has a contact that is activated by the throttle control lever. In the "stop" position, the throttle control lever touches the shut-off switch contact. This provides a path to ground for the primary wire of the ignition coil, which shuts the engine off. When the manual control is set on start or run, the throttle lever is moved out of contact with the shut-off switch. This removes the ground path and enables spark ignition. We will discuss ignition systems in detail in Chapter 15.

GOVERNOR THROTTLE CONTROL

Along with a manual throttle control lever, many power equipment engines use a governor. An engine governor is a throttle control system that senses engine load and automatically adjusts engine speed when required. The **governor throttle control system** has three main functions:

- Protect the engine from over-revving
- Maintain a safe blade or equipment speed
- Match the engine speed to engine load demands

The two most common types of governors used in power equipment engines are the air vane and centrifugal types, although electronic governors are beginning to be used by some manufacturers. Here, we will concentrate on the most common types that you will see.

All engines develop maximum horsepower (hp) at a specific crankshaft revolutions per minute (rpm). For example, an engine's maximum power might be 4 hp at an engine speed of 3,600 rpm (Figure 9-6). Operating the engine below 3,600 rpm will result in less power but longer engine life. Operating the engine above 3,600 rpm will result in a shorter engine life. High engine speeds create more heat, friction, and wear. Operating an engine at too high a speed for too long can break internal components such as a connecting rod or piston. The governor system prevents excessive engine speed.

Engine Speed and Load

The governor is designed to match the engine speed to the engine load. For example, during lawn mowing, you might set engine speed to "fast" and start cutting the grass. As you mow, you may run into some high grass. The engine has to work very hard to cut the high grass. The engine will start to slow down because of the high engine load. As you move the mower over a sidewalk, the blade stops cutting any grass. The engine speeds up because of low engine load. Without a governor, you would have to manually increase and decrease engine speed all the time (Figure 9-7).

The governor keeps the engine running at a steady speed by opening or closing the throttle valve. The governor closes the throttle valve for low engine loads. It opens the throttle for more power for high engine loads. The governor senses these load conditions and makes the throttle adjustments automatically (Figure 9-8). There are two types of governors used in power equipment engines: air vane and centrifugal governor systems.

Governor adjustments vary between engine manufacturers. Adjustment procedures are found in service manuals.

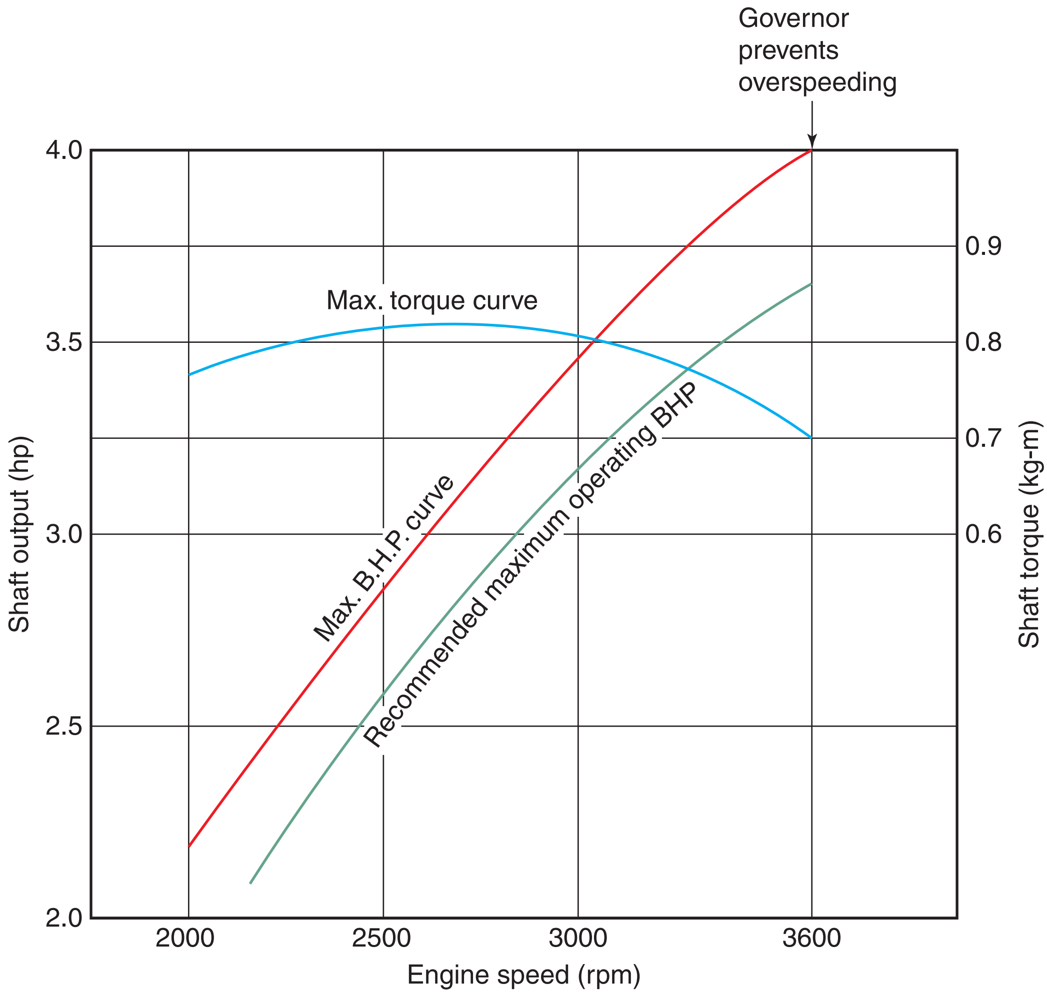


Figure 9-6 A typical engine power curve.

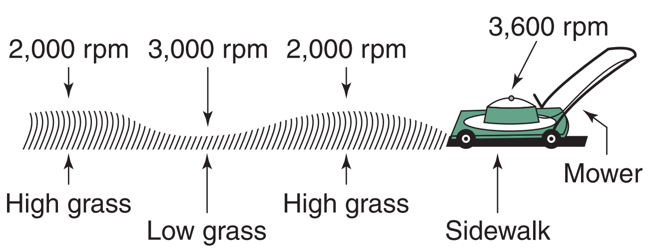


Figure 9-7 A non-governed engine will change engine speed as the engine's load increases and decreases.

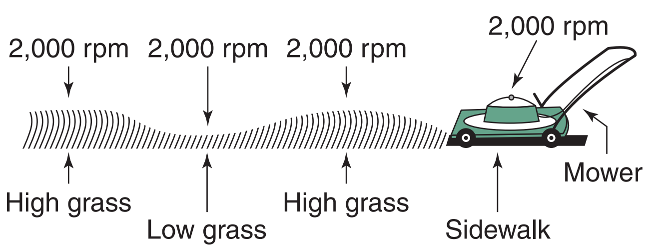


Figure 9-8 A governed engine matches engine speed to engine load.

Air Vane Governors

An **air vane governor** uses air flow coming off the flywheel to regulate throttle opening to control engine load. The air vane governor is also sometimes called a pneumatic governor. These governors are seen commonly in less expensive engines. An advantage of an air vane governor for the manufacturer is its lower cost to produce, whereas its primary disadvantage is that it's not as responsive to the needs of the engine.

An air vane is a flat piece of plastic or steel mounted on a pivot above the flywheel (Figure 9-9). The air vane is connected to the carburetor throttle valve linkage by a small linkage rod. This rod is called a governor link.

The throttle lever is mounted on a pivot. The lever is connected to one end of a spring called the governor spring. The other end of the

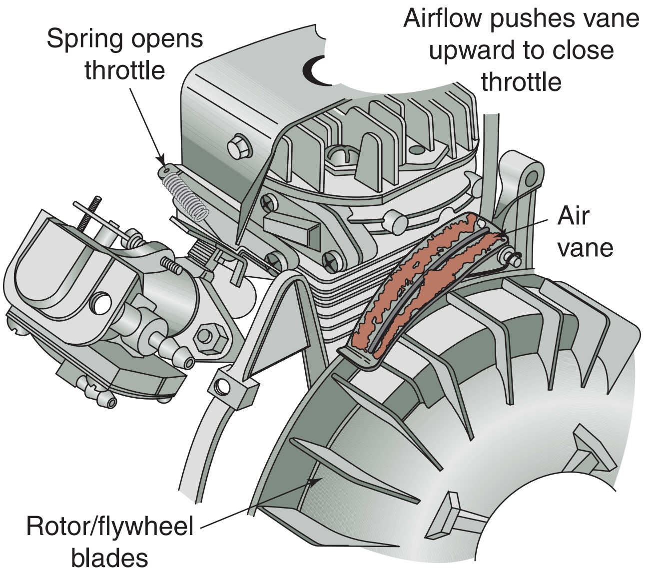


Figure 9-9 An air vane is a flat piece of plastic or steel mounted on a pivot above the flywheel.

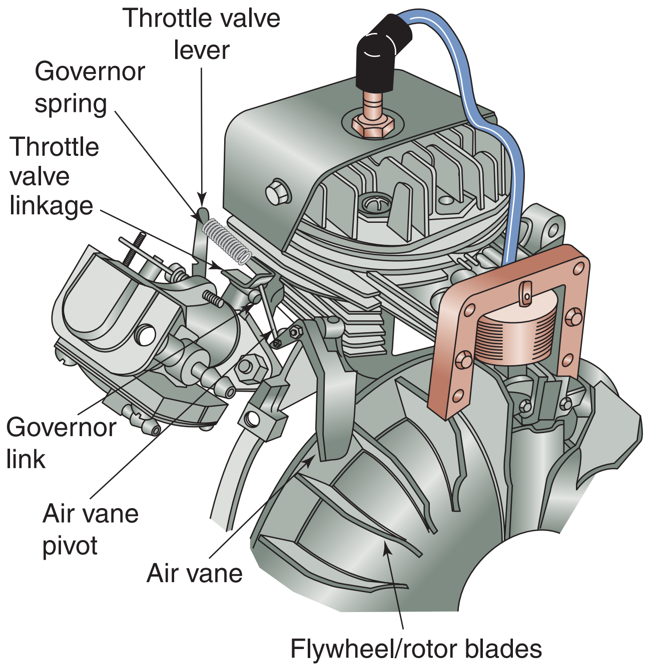


Figure 9-10 Various parts of an air vane governor system.

governor spring is connected to the throttle valve linkage (Figure 9-10).

The air vane governor uses opposing forces to match engine speed to engine load (Figure 9-11). The first force comes from the air flow off the flywheel, which pushes against the air vane. This force goes to the throttle valve through the governor link rod. The air vane movement senses high or low engine load from the speed of the air flowing from the cooling fins on the flywheel. The faster the engine runs (lower the engine load), the higher the flywheel air flow. High air flow against the vane causes the governor link rod to move the throttle valve toward a closed position, which in turn will slow the engine's rpm down.

The opposing force comes from the governor spring. The governor spring is connected to the throttle valve linkage. The spring tension is in a direction to hold the throttle valve open. The spring tension is set to hold a high enough engine speed for high engine load. As the engine load gets lower (such as a lawnmower passing over a sidewalk or a patch of low grass), its speed begins to increase. High air flow on the air valve will overcome the governor spring pressure and slow the engine.

The engine slows down when it comes to a heavy load such as when a mower cuts through high grass. The lower air flow on the air vane

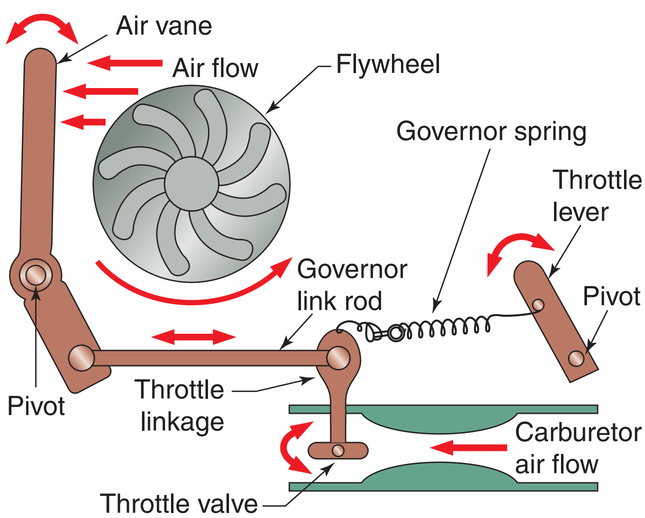


Figure 9-11 The air vane governor uses opposing forces to match engine speed to engine load, as illustrated here.

allows the governor spring tension to open the throttle valve, which increases engine speed. The governor air vane constantly moves back and forth in response to engine load and maintains a constant engine speed.

When engine loads are low, the engine speed increases. When this occurs, the air vane closes the throttle valve by overcoming the governor spring which, as mentioned, is used to open the throttle valve when engine loads are high.

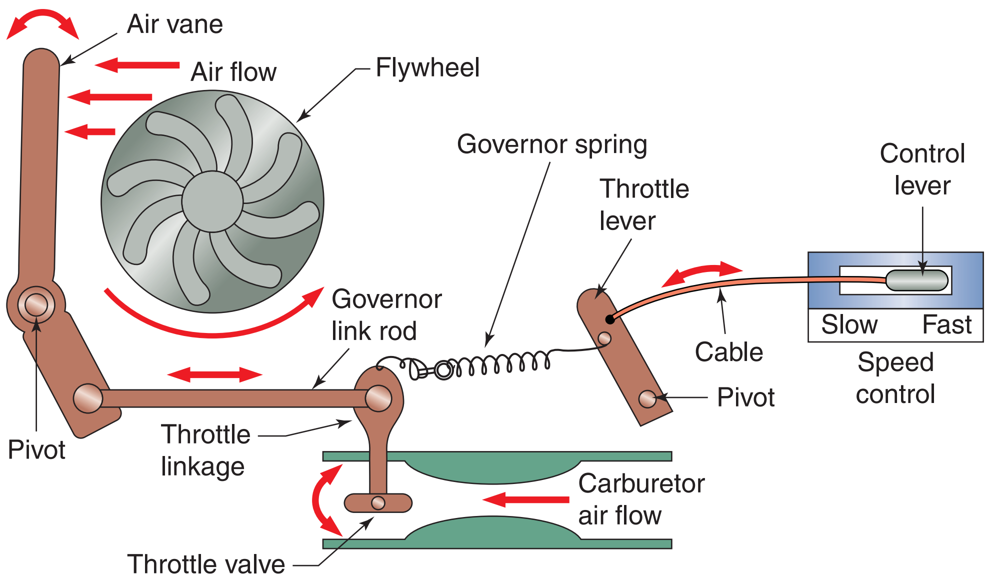


Figure 9-12 The operation of a remote throttle control.

Movement of the throttle control lever from "slow" to "fast" increases governor spring tension (Figure 9-12). The higher governor spring tension holds the throttle valve open with more force. This causes a higher governed engine speed. Moving the lever back to "slow" lowers the governor spring tension. This results in a lower governed engine speed.

Centrifugal Governors

Instead of the air vane type, most of today's power equipment engines use a **centrifugal governor**. A centrifugal governor uses centrifugal force to regulate throttle opening. This type of governor is also called a mechanical governor. The centrifugal force is generated by rotating flyweights inside the engine crankcase. Just as with the air vane governor, a centrifugal governor works to maintain a constant engine rpm as engine load increases or decreases. Although it may cost more to manufacture an engine with a centrifugal governor, it responds to the needs of the engine quickly and effectively, so that most manufacturers are using them in place of the air vane type of governor.

The parts of a centrifugal governor are located inside the engine crankcase (Figure 9-13). The centrifugal governor is housed on a gear and shaft driven by the engine's camshaft gear. The shaft fits into a bearing surface in the crankcase. The teeth on the governor gear mesh with the teeth on the camshaft gear. When the engine is running, the rotating camshaft causes the governor gear to rotate. Two specially shaped weights, called flyweights, fit through a pivot on the governor gear. The flyweights have a specially designed arm formed on the end. The arms make contact to a spool that fits over the governor shaft that moves up and down as the arms flyweights move.

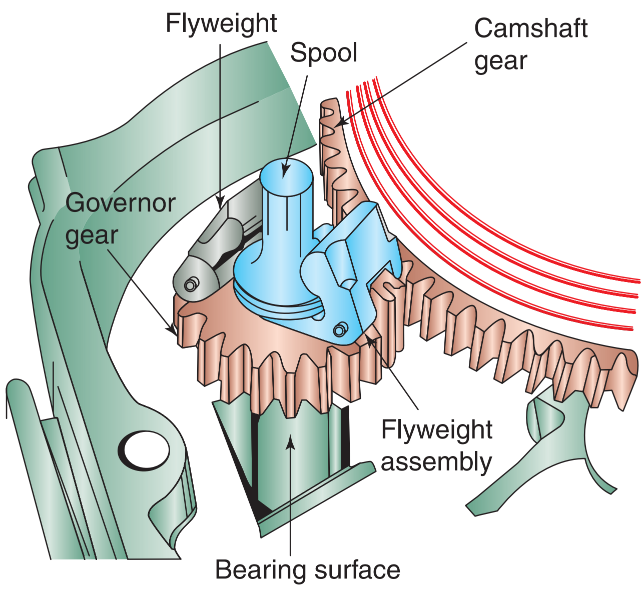


Figure 9-13 The centrifugal (also known as mechanical) governor operated with a gear that meshes with the camshaft gear.

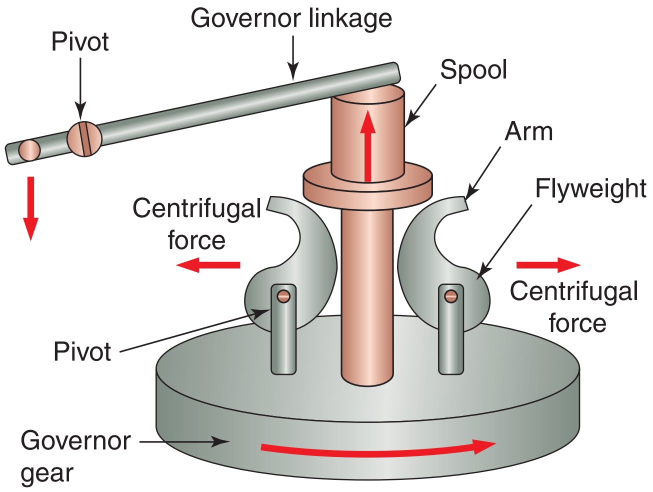


Figure 9-14 The operation of a centrifugal governor.

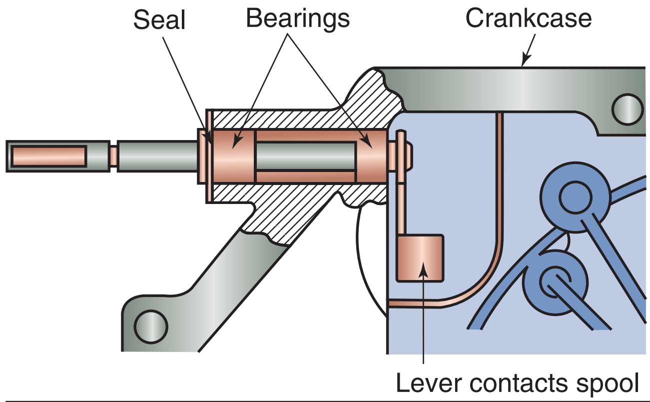


Figure 9-15 The governor rod fits in the crankcase and has a lever that contacts the governor spool. The lever moves as the spool moves.

As the engine runs faster, the camshaft gear rotates the governor gear at a higher speed. The speed of the governor gear creates a centrifugal force, which causes the flyweights to move outward (Figure 9-14). The outward movement, however, is restricted by the mounting pivots. When they move outward, the flyweight arms push the spool up the governor shaft. Linkage in contact with the spool transfers the movement outside the engine. As the engine slows down, spring pressure on the linkage causes the flyweights to retract, which in turn allows the spool to move back down the governor shaft.

The movement of the governor spool is transferred outside the engine by a governor rod (Figure 9-15). The rod goes through the engine crankcase cover. It's supported on bearings so that it can rotate freely in the cover. There is a seal on the end of the rod to prevent engine oil from leaking out of the engine between the rod and the cover. A lever is attached on the inside end of the rod that maintains constant contact with the governor spool.

Movement of the governor spool up and down in response to engine speed causes the governor rod to rotate back and forth (Figure 9-16). The governor rod is connected to a lever on the outside of the engine. A governor spring is connected to the lever. The governor spring opposes the force of the governor weights. The governor spring tension keeps the governor rod in contact with the governor spool.

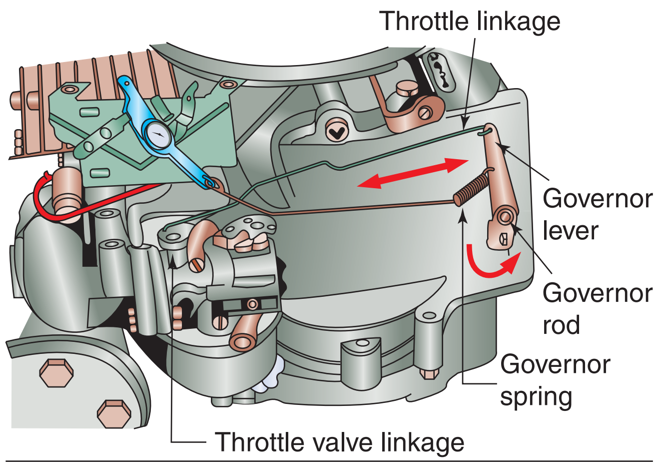


Figure 9-16 Movement of a governor rod.

The governor lever is connected through a throttle linkage rod to the carburetor throttle valve. Movement of the governor rod causes movement to the governor lever. The lever moves the throttle linkage and throttle valve. The governor spring tension opposes the linkage movement and works to hold the throttle open. The governor spring also retracts the flyweights when engine speed and centrifugal force drop.

As with the air vane system, a throttle cable may be connected to the centrifugal governor linkage to provide remote throttle control (Figure 9-17). Movement of a control lever on the equipment handle moves the throttle cable. The cable movement changes the tension of the governor spring. Increasing governor spring tension causes a higher governed speed. Decreasing governor spring tension causes a lower governed speed.

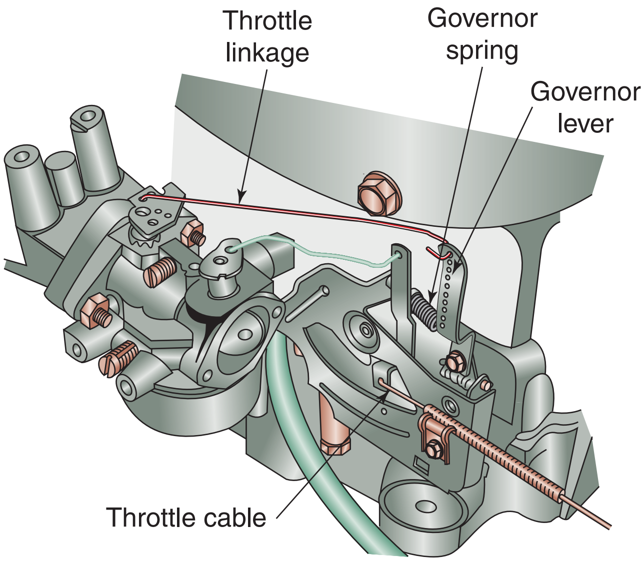


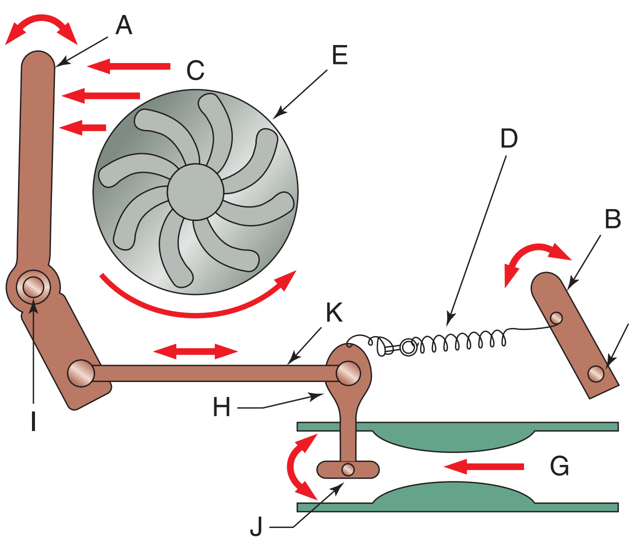
Figure 9-17 A throttle cable can be attached to a centrifugal governor system, as illustrated here.

Summary

- A manual throttle control system is an engine speed control system in which the operator sets the engine speed by positioning the carburetor throttle valve in a particular position.
- An engine governor is a throttle control system that senses engine load and automatically adjusts engine speed when required.
- An air vane governor is a governor that uses air flow coming off the flywheel to regulate throttle opening to engine load.
- A centrifugal governor is a governor that uses centrifugal force to regulate throttle opening.

Chapter 9 Review Questions

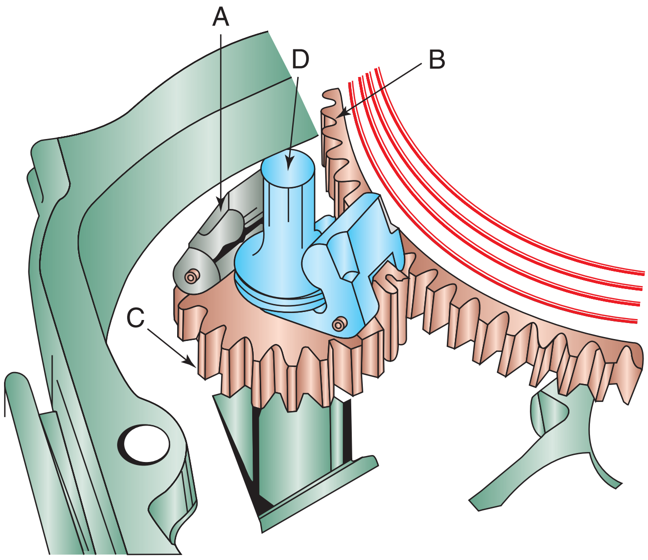
1. The following figure shows an _____ governor system.



2. Match the letters on each component in the figure (see left) to the relevant number provided in the key table.

A	_____
B	_____
C	_____
D	_____
E	_____
F	_____
G	_____
H	_____
I	_____
J	_____
K	_____

3. The following figure shows a ______ governor system.



4. Match the letters on each component in the above figure to the relevant number provided in the key table.

A	____
B	____
C	____
D	____

Key table

1	Flyweight
2	Throttle linkage
3	Governor gear
4	Spool
5	Throttle lever
6	Air flow
7	Pivot
8	Throttle valve
9	Governor link rod
10	Governor spring
11	Air vane
12	Flywheel
13	Carburetor air flow
14	Camshaft gear

CHAPTER

10 Two-Stroke Engine Top End Inspection

Learning Objectives

- Understand the importance of engine problem diagnosis
- Understand the necessity of proper engine component inspection

Key Terms

Compression check
Cylinder taper
Diagnosis
Piston ring side clearance
Piston-to-cylinder clearance
Score marks
Scuff marks
Symptoms
Wrist pin

INTRODUCTION

Although becoming less prominent in the power equipment engine industry because of the advancement of four-stroke engine design and more stringent emission control regulations causing higher costs for production, there are still many two-stroke power equipment engines being manufactured today. Two-stroke engines in today's power equipments are found primarily in small handheld units such as gas-powered blowers (Figure 10-1) and string trimmers. Virtually all are of the single cylinder, air-cooled variety.

Top end engine disassembly is a process in which all the parts of an engine above the engine crankcase are removed. An engine may be disassembled to make repairs, or the disassembly may be the first step in a complete rebuild. During an engine rebuild, an engine's components are replaced to a "like new" condition.

Diagnostics

If the power equipment engine has an engine-related problem, before any components are disassembled, the technician must diagnose the condition. **Diagnosis** is the process of determining what's wrong when something isn't working properly, by checking the symptoms. **Symptoms** are the outward, or visible, signs of a malfunction. For example, a knock is a symptom. The actual cause might be a broken, worn, or malfunctioning part. Of course, this is only one example. To assist with diagnosis, you may need to use other testing equipment to help find the problem.

Often, complete diagnostics can't be confirmed until the engine machine is actually disassembled. For example, if a two-stroke engine develops a rattle in the top end, an experienced technician may recognize the sound and tentatively conclude that the piston is worn out. That would be the diagnosis. The technician wouldn't be able to confirm the diagnosis without disassembling the engine and actually seeing that the piston and cylinder are worn or damaged.

Correctly diagnosing problems is sometimes the most difficult and important part of a technician's job. Diagnosis is difficult because the technician often can't see the defective part before disassembly. Correct diagnosis is important because a technician must not waste time disassembling and inspecting parts that haven't failed.

Problems can also be detected by performing a **compression check** on the engine before it's disassembled (Figure 10-2). A compression check is a simple test that measures the amount of pressure produced in the combustion chamber in the compression stroke. The compression is measured with a compression

Figure 10-1 Two-stroke engines in today's power equipment are found primarily on small handheld units such as gas-powered blowers.

Figure 10-2 A compression check is a simple test that measures the amount of pressure produced in the combustion chamber in the compression stroke.

gauge that's inserted in the spark plug hole. If the piston rings are worn, the compression gauge displays a pressure reading that is lower than the manufacturer's specification. The reading is low because, instead of being compressed, some of the air–fuel mixture is leaking down past the worn rings and into the crankcase. The compression gauge may show an extremely high reading if there is excessive build-up in the combustion chamber area.

To perform a compression test, install the tester in the spark plug hole in the cylinder head, open the throttle wide open, and turn the engine over until the compression gauge no longer rises. It's important to note that the throttle has to be wide open to allow maximum flow of air into the engine.

Another important test that can be performed on a two-stroke engine is a crankcase pressure and vacuum test. Pressure testing is important to locate leaks at seals, gaskets, or cracks in the crankcase or cylinder. Vacuum testing identifies leaks at the seals. It should be noted that some manufacturers require that a vacuum and pressure test be done prior to disassembly of the engine. A crankcase pressure test should be done before and after rebuilding an engine. A crankcase pressure tester consists of a pressure pump, gauge, check valves, hoses, spark plug adapters, and rubber plugs. To perform a pressure test you'll need to plug off the intake and exhaust ports and install the spark plug adaptor. Attach the pump with a hose, pump between 6 and 9 pounds per square inch (psi) of pressure into the engine, and verify if it holds pressure. If it does not hold pressure, use a spray bottle with soapy water to search for leaks.

As this chapter covers the top end of the two-stroke engine, we're going to discuss some engine problems and give the possible diagnoses. In diagnosing, you should have a mental picture of the parts connected with the problem. Table 10-1 lists some common problems you might encounter.

We'll get into troubleshooting in detail in Chapter 17, but as you'll see, you can handle quite a few common engine repairs by disassembling the top end of the two-stroke engine.

Repair Procedures

The procedures in this chapter are general in nature and their purpose is to familiarize you with the types of activities you'll encounter when working on the top end of a two-stroke engine. Always refer to the appropriate power equipment engine service manual for disassembly information. The service manual contains all the information required to perform the job correctly, including detailed instructions regarding the specific model of power equipment engine, special tools, and service tips. Above all, the service manual contains information on safety procedures.

DISASSEMBLY OF THE TWO-STROKE ENGINE TOP END

The components of a typical two-stroke engine are illustrated in Figure 10-3. This exploded view of a typical two-stroke engine is what you would see at the beginning of most manufacturer service and parts manuals. The top end assembly of a typical two-stroke engine consists of the following parts:

- Cylinder and head assembly (26)
- Cylinder base gasket (32)
- Cylinder mounting bolts (25)
- Piston and piston rings (23 and 24)
- Piston wrist pin and retaining clips (31)

We had discussed in Chapter 7 the differences between an air-cooled and a liquid-cooled engine. You may wish to review these differences before working on a two-stroke engine. In this chapter, you'll find a discussion of an air-cooled, single cylinder two-stroke engine, as it's the most common design found in today's power equipment engines. Although they have differences in features, both air- and liquid-cooled two-stroke engines use similar approaches to disassembly and assembly procedures.

As there are many power equipment engine manufacturers building two-stroke engines, it would be impossible to show you how to disassemble the top end of every engine. So we'll discuss the basic procedures using a typical two-stroke

Table 10-1 Diagnosing engine problems

Symptom	Check	Notes
Engine won't start	Fuel flow	Loosen the carburetor drain screw. Fuel should flow as you loosen the screw. If fuel doesn't flow, verify if there's fuel flowing from the fuel tank to the carburetor.
	Ignition	Be sure the spark plug is firing at the correct time.
	Compression	Hold a compression gauge in the spark plug hole while the crankshaft is rotating at cranking speed. Engine compression should be within manufacturer's specification. You'll find the actual specification in the appropriate service manual.
		The most common cause of low compression is excessive piston wear or excessive piston ring wear.
Crankshaft rotates and engine may run but has a loud, heavy knock	For broken piston skirt	If the piston-to-cylinder clearance is too large, the piston rocking in the bore may break the skirt.
	Big-end connecting rod bearing	See Chapter 11 on lower end assembly for connecting rod problems.
Engine runs but has a light, rapid tapping noise	Piston ring	Excessive piston ring-to-cylinder clearance likely means that dirt or other debris has been getting into the engine through the air filter side of the engine.
	Piston pin	Unless a lack of lubrication is found, excessive wear on the piston pin is unusual because the pin is made from high-quality steel.
Crankshaft won't rotate	For piston seizure	Piston seizure means that the piston is stuck in the cylinder. Possible causes of piston seizure are
		Improper fuel–oil mixture
		Improper air–fuel mixture
		Incorrect spark plug or ignition timing
		Insufficient piston-to-cylinder clearance
	Lower end assembly	The crankshaft may not rotate because of failure of the lower end assembly, including clutch or transmission problems. These items are covered in Chapter 11, which relates to the lower end of the motorcycle two-stroke engine.

engine as a guide. It's *strongly* recommended that you use the manufacturer's service manual and follow the procedures indicated therein when disassembling any engine. For the purpose of illustrating the diagnosis methods described in this chapter, we'll be using an air-cooled Weed Eater gas blower, which uses a Poulan power equipment engine (Figure 10-1). Generally speaking, the procedures for the disassembly of most two-stroke engines are the same as required for this engine.

As you disassemble the top end, look closely at all the parts and record your observations. Note any possible sources of damage to any of the parts. Note any marks on the piston and the rings. Your notes will be valuable as you complete your inspection of the individual parts.

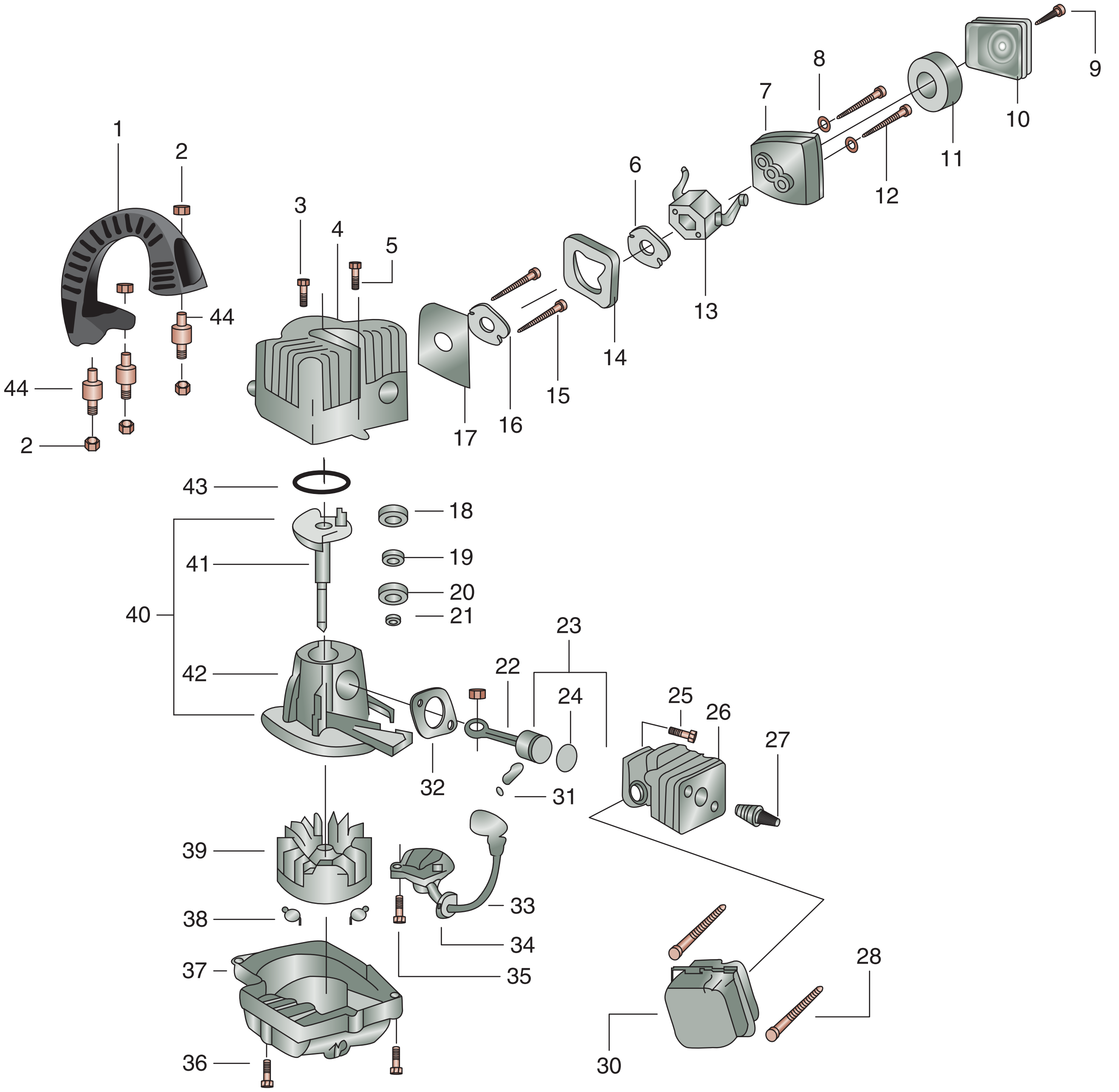


Figure 10-3 The components of a typical two-stroke engine in exploded view format.

CLEANING AND INSPECTION OF THE TWO-STROKE ENGINE TOP END

Removing the engine cover(s) will expose the external components to the two-stroke engine's top end (Figure 10-4).

Repairs on the top end of a two-stroke power equipment engine generally don't require that the engine be removed from the implement. However, once removed, it's important to clean and inspect each component before reassembling. This inspection process, which will be described here, includes

- Inspecting and measuring the cylinder
- Checking for cylinder wear
- Inspecting and measuring the piston
- Fitting new piston rings to the cylinder

Measuring top end components forms part of this inspection. The purpose of these

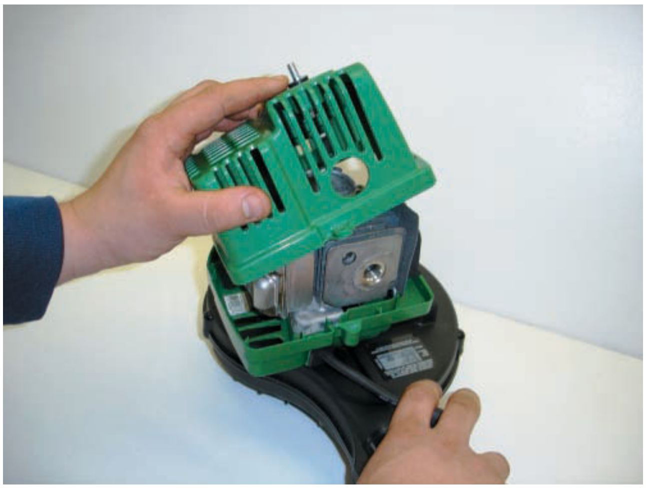


Figure 10-4 Removing the engine cover exposes the external components to the two-stroke engine's top end.

Figure 10-5 Careful cleaning of all the components is an important part of the disassembly process.

measurements is to determine if a part is excessively worn. You should always measure the following top end components:

- Cylinder
- Piston
- Piston rings

Knowledge of certain measuring tools such as micrometers and bore gauges is essential to completing some of these inspections. You may refer to Chapter 3 for a discussion of the function of such tools.

The special measuring tools you'll use to complete the top inspection are

- Dial bore gauge
- Outside micrometer
- Inside micrometer
- Feeler gauge
- Compression gauge

Cleaning Top End Components

Cleaning and visual inspection of all parts and top end components is important (Figure 10-5). In the process of carefully cleaning all the components included in the two-stroke engine top end, you'll prevent potential problems, before they can occur. You'll need degreasing solvents to remove carbon deposits and oil deposits on the piston. Brush gently and use special care not to damage any parts, as many may be fragile. You may need a wire brush and a scraper to remove residual gasket materials from gasket surfaces and excess carbon from the cylinder exhaust port and the cylinder head. Wash all parts in an approved solvent and dry with regulated, compressed air pressure and a lint-free shop rag. Remember that cylinders are made of aluminum, which is a relatively soft metal; so be careful you don't dig into them when cleaning with a scraper or brush. Remove any remaining old gasket material from the cylinder and crankcase joint-mating surfaces. That's where the cylinder joins the crankcase. Warning: Never use gasoline or other highly flammable liquids to wash parts. Uncontrolled fires are easy to start, but hard to stop.

Cylinder and Cylinder Head Inspection

The cylinder and cylinder head in small two-stroke power equipment engines are combined in virtually every case (Figure 10-6). Another word for this combination often used is "jug." The head is the component that seals the upper end of the cylinder. Before inspection of the cylinder and head, be sure that it's clean.

Once the cylinder is thoroughly cleaned, you can check it for any visible signs of damage.

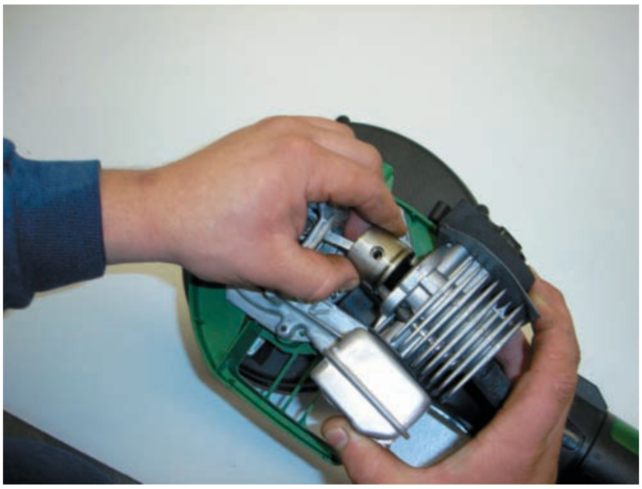


Figure 10-6 The combination of a cylinder and the cylinder head in small two-stroke power equipment engines is also called "jug."

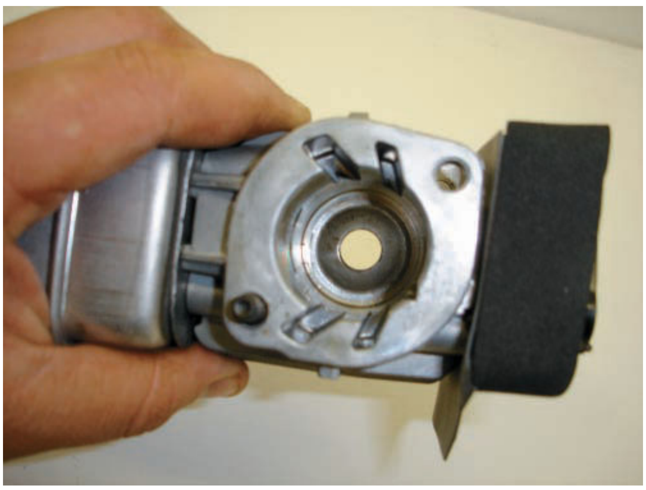


Figure 10-7 Check for small cracks or other damage in the combustion chamber.

Check for small cracks or other damage in the combustion chamber area (Figure 10-7). The most common problem in the cylinder head portion of the cylinder that you'll see is damage to the threads in the spark plug's hole from incorrectly installing the spark plug.

Cylinder Wall Inspection and Measurement

The first check on the cylinder comprises a visual inspection for cracks, scratches, and scoring marks. Once it has been verified that there is no visual damage or wear, measure the bore of the cylinder with a dial bore gauge to check for excessive wear (Figure 10-8). Note that because of the ports used in the two-stroke engine, it's sometimes difficult to measure a point in the middle of the cylinder. Refer to the manufacturer's service manual to ensure that you measure all points of the cylinder as desired by the manufacturer.

Figure 10-8 The measuring of the bore of the cylinder with a dial bore gauge.

This is to determine the extent of wear within the cylinder wall. Movement of the piston and rings within the cylinder causes cylinder wear. The area of greatest wear is the area in which the rings travel. This is because the rings press tightly against the cylinder wall to seal the compression into the cylinder. In the area of ring travel, more heat is generated on the front and backside of the cylinder wall. By front and backside, we mean sides at a 90° angle to the wrist pin.

Insert the dial bore gauge into the cylinder at a point near the top of the ring travel. Take a gauge reading. Move the dial bore gauge to a point near the top of the exhaust port and take another reading, and then to the bottom of the exhaust port. Finally, move the dial bore gauge to a point near the bottom of the cylinder and take one more reading. Note that sometimes it will be difficult to find a good location toward the middle of the cylinder as the ports in two-stroke engines make such a measurement difficult. Be sure to check the manufacturer's service manual to find the recommended locations at which cylinder bore measurements may be made. Compare the readings; the difference indicates the amount of wear. Usually, the higher reading will be from the area of ring travel, that is, at the top. The difference is called **cylinder taper**. The taper must not exceed factory specifications for the power equipment engine model you're repairing. Each model will have different specifications. If the "taper" exceeds allowable limits, the cylinder must be replaced or, if allowable, bored to a new size and fitted with a new, oversized piston and rings. Take the same readings at 90° for the first three readings to determine if the cylinder has become eccentric, that is, it's no more a circle (Figure 10-9).

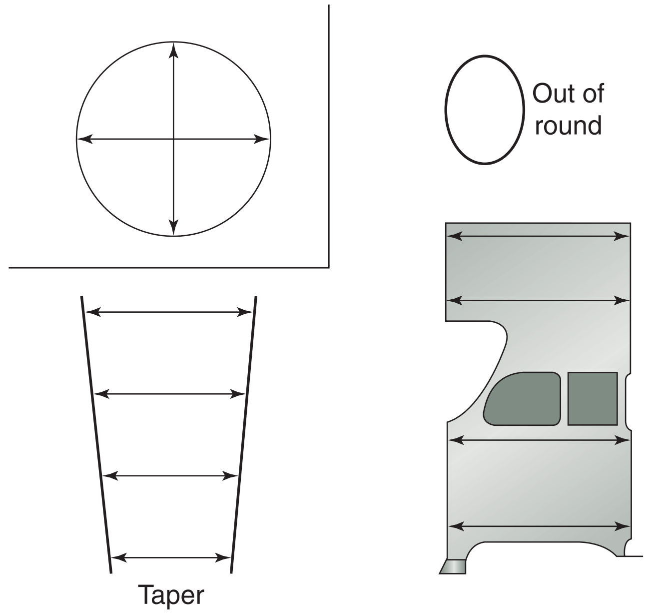


Figure 10-9 A taper and out-of-round cylinder bore.

Boring Cylinders

Many two-stroke cylinders use a plated bore (Figure 10-10) fused to the cylinder wall. This design greatly reduces weight and friction and improves heat transfer. However, in these cases, the cylinder can't be bored and must be replaced if its measurements are outside the manufacturer's specifications or if there is any damage to the cylinder.

Most of the typical power equipment two-stroke engines can't be bored. Boring those cylinders that can be requires special machine tools and is therefore performed by a specialist. Cylinder reboring can be done at some power equipment engine dealerships, but it's generally done at a machine shop that's set up to handle such a job. In many cases, it's more economical to replace the cylinder than to bore it.

If you have determined that you must rebore a cylinder, first obtain a correct oversized piston. Then, bore the cylinder to fit the piston in.

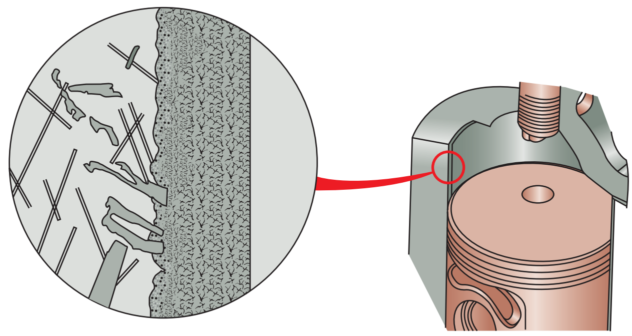


Figure 10-10 Many two-stroke cylinders use a plated bore fused to the cylinder wall and therefore can't be rebored.

Piston Assembly Inspection

As you'll recall, the piston is the cylinder-shaped component that moves up and down the cylinder bore. The piston assembly consists of the piston itself, its wrist pin (or piston pin), clips to hold the wrist pin in place, and the piston ring(s) (Figure 10-11). An engine produces its power by burning the air–fuel mixture in the combustion chamber directly above the piston. Each time the spark plug fires, this air–fuel mixture ignites with an explosive force. The burning process heats the gases, causing them to expand rapidly and forcing the piston down the bore. This piston movement enables the engine to perform useful work. As you can imagine, the piston must withstand a lot of force as well as tremendous heat during an engine's operation. Therefore, as part of the rebuild procedure, you must inspect the entire piston assembly carefully for any damage. Note that the piston wrist pin

Figure 10-11 The piston assembly consists of the piston wrist pin, clips, and the piston ring.

retaining clips must always be replaced after they're removed. It's also recommended that the clips be reinstalled with their open ends facing up or down in relation to movement of the piston. Some theorize that if the clips are installed otherwise, they can compress and fall out under high engine speeds.

Visual Examination

Start the piston assembly inspection with a visual examination of the piston itself (Figure 10-12). Check for cracks or any other signs of surface damage, such as scratches or score marks. Pay particular attention to the front and the backside of the piston. You should examine the piston in areas of both the skirt and the rings; these areas are the most common sites of damage. Look for signs of surface damage on the piston's skirt. One of the most common types of piston damage is scoring on the piston's skirt. **Score marks** are deep, vertical scratches on the skirt. A similar type of damage is scuffing. **Scuff marks** are wide areas of wear on the piston. Scuff marks usually appear as shiny patches. Scuffing may or may not be accompanied by score marks and is generally present on the bottom of the piston as it's installed in the cylinder.

A variety of conditions may cause both scoring and scuffing. In most cases, excessive friction and heat create the marks. Under certain conditions, the temperature in a cylinder can

Figure 10-12 A visual inspection of the piston includes checking for cracks or any other signs of surface damage, such as scratches or score marks.

Figure 10-13 Minor scuffing can be removed by using a fine emery cloth to clean the surface of the piston.

approach the melting point, or weld point, of aluminum. A problem in an engine's cooling system or excess friction between the cylinder wall and the piston rings can cause these high temperatures. Excessive friction is caused often by improper lubrication or from the piston fitting too tightly within the bore. Minor scuffing can be removed using a fine emery cloth to clean the surface of the piston (Figure 10-13).

If you find score marks or scuffing marks on a piston, try to determine the cause so that you can prevent the damage from recurring. This is one of the occasions when you can take advantage of the notes and observations you had made earlier, in the disassembly process. During disassembly, you should have noted defects, if any, on gasket surfaces. If you did note a possible source of damage during disassembly and later found marks on the piston, you already have important clues for use in the troubleshooting process. In such a situation, you may also want to talk to the customer or operator to find out if the engine was overheating during operation.

Engine overheating, in addition to causing scuffing and scoring, usually produces a buildup of oil residue on the piston and the rings. Extreme heat breaks down the viscosity of oil and reduces its lubricating ability. Once oil breaks down, it begins to "bake" onto the engine components, forming a residue that resembles varnish. This residue can coat the piston rings and under extreme conditions can cause the rings to stick firmly to the piston. If this occurs, the rings will no longer be able to seal the combustion chamber properly. Therefore, always check to ensure that the rings are free to move on the piston and that both the piston and the rings are free of any buildup of residue.

Although the skirt is the most frequently damaged site on a piston, you must also carefully examine the piston's crown (Figure 10-14). If you find any damage, try to determine the exact cause so that you can prevent that damage from recurring. Any damage to the crown is usually the result of the fuel mixture burning improperly in the cylinder. If the fuel mixture ignites incorrectly or at the wrong time, a violent explosion can result. The concentrated heat created in such an explosion can burn a hole through the piston's crown. Also, the explosion itself can be powerful enough to knock a hole right through the top of the piston. You may find small fragments lodged in the piston crown. This is an indication of lower end bearing failure, with the fragments being connecting rod bearing particles.

We'll discuss common problems that occur in an engine that cause piston damage in Chapter 17, which is on troubleshooting. As the final stage of your visual inspection of the piston, check the underside of the piston (Figure 10-15). It's in this area that the connecting rod is attached to the piston. Because the interior of the piston isn't directly exposed to the high heat of the combustion chamber and generally remains well lubricated, you'll usually find no signs of damage there. However, you should still check to make sure there are no cracks and that the wrist pin fits properly into the piston.

Piston Measurement

A typical piston appears to have a simple, cylindrical shape, much like a can. However, looks can deceive. Pistons are not perfectly round, and they don't usually have perfectly straight

Figure 10-14 An examination of the piston crown is mandatory to ensure no damage has occurred.

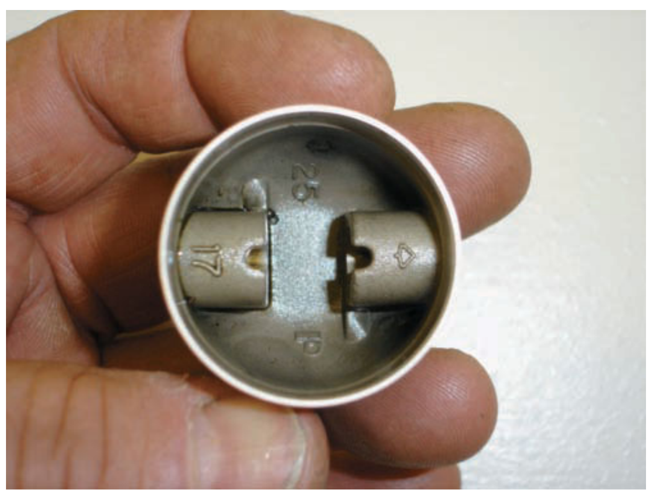


Figure 10-15 Check the underside of the piston for cracks or other damage.

sides when at room temperature. In fact, a typical piston is manufactured with a taper, that is, the diameter at the very bottom of the piston's skirt is larger than the diameter at the piston's head. Why does the piston have this taper? The reason is the variation of heat from one end of the piston to the other. Pistons, as we know, are made of aluminum, and aluminum expands as the temperature rises. A piston, however, gets hot at its head (where the combustion actually occurs) but remains relatively cool at the skirt (which is comparatively far away from the combustion chamber). Because the piston gets hotter at the top and also has more mass at the top than at the bottom, its top expands more than does its bottom. To compensate for this difference in expansion, a piston is made with a built-in taper. As the piston gets hot, it expands and assumes a cylindrical shape. You should also note that almost all two-stroke engine pistons have an arrow or marking that points toward the exhaust port to ensure that the piston is installed correctly.

A piston's shape is designed to compensate not only for the piston's expansion but also for the forces exerted on it. In the typical operation of an engine, the expanding gases force the piston both downward in the cylinder and against the cylinder walls. The piston's wrist pin links the piston to the connecting rod. Therefore, both the piston and the rod move together to rotate the crankshaft. Figure 10-16 shows the way the piston is connected to the crankshaft, causing a force to be directed toward one side of the piston on each upstroke and downstroke. This side of the piston is called the thrust face and is in a plane that's parallel to a line running through the length of the wrist pin. The forces applied during a power stroke are greater at the thrust face than they're elsewhere on the piston's sides. Therefore, a piston is usually made so that the diameter measured at a right angle to the wrist pin is slightly larger than the diameter measured along the wrist pin's length. This means that if you were to look at the head of a piston from above, the piston would appear to be slightly egg shaped. The wrist pin divides the egg shape into its wide and narrow halves. The piston's thrust face would be at the wide half.

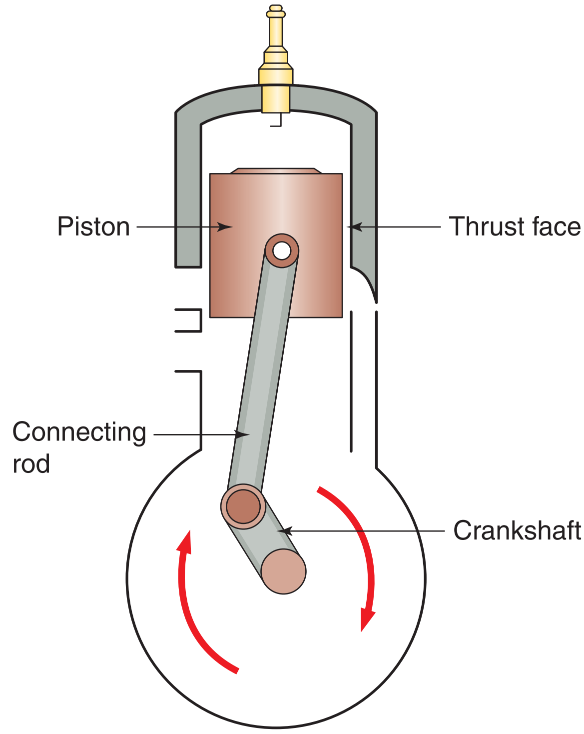


Figure 10-16 Pistons have two thrust surfaces: the back side on the downstroke and the front side on the upstroke.

As we've already discussed, the downward force applied to a piston on the engine's power stroke pushes the piston's thrust face against the cylinder wall. During the application of this force, the shape of a piston will become more round. Note that the egg shape of an actual piston is usually very slight and difficult to see with the eyes alone. However, if you measure the diameter at a right angle to the wrist pin and compare it with a diameter measured along the wrist pin's length, you should be able to note a difference between the two measurements.

Once the piston has been visually inspected, you can prepare the piston for measurement. Before measuring the piston, remove the piston ring(s). To remove a piston ring, you must spread the ring open so that you can slide it out of its ring groove and off the piston. Most technicians spread piston rings open by hand (Figure 10-17).

Measure and record the piston outside diameter at an angle of 90° to the wrist pin bore, as shown in Figure 10-18. Note that the micrometer is placed at the bottom of the piston skirt.

Figure 10-17 When removing the piston ring, be careful not to spread the ring too much or else damage may occur.

Figure 10-18 Measuring the piston with a micrometer.

Some manufacturers will have a specific point at which to measure the piston. Be sure to check the appropriate service manual specifications and procedures when measuring a piston.

Once you've measured the piston's diameter, compare your measurement with the appropriate specification in the manufacturer's approved service manual. If the diameter of your piston is outside of specifications (generally, this measurement would be lesser than the specification), the piston should be replaced. If the piston is within specifications and shows no signs of damage, you can reinstall it in the engine.

Always remember to replace piston rings, even if you reuse the piston. The piston ring grooves, which are cut into the sides of the piston, hold the piston rings in place. The ring lands are the uncut areas between the ring grooves. The ring grooves are actually slightly wider than the piston rings. As a result, the rings can move slightly, or float, within their grooves. Thus, the rings are able to actively conform to the cylinder walls while the engine is operating. The small space between each piston ring and the inner side of its groove is called **piston ring side clearance**.

The combustion gases forcing themselves onto the piston get into the ring grooves and leave behind a residue. Therefore, to inspect the ring grooves for excessive wear, you must first clean the grooves thoroughly. As the piston is made of aluminum, a soft metal, be careful not to dig into the piston while cleaning and inadvertently remove any metal, especially along the inner sides of the ring grooves. The best tool to use is an old piston ring. Made of a very tough material, old piston rings work well because they fit the ring grooves perfectly and therefore won't damage the sides of the grooves. If you want to use an old ring for this purpose, break it in half to produce a scraper-like edge. Then, insert the edge into the groove and scrape the residue out.

Once the ring grooves are cleaned, the piston can be wiped off and the side clearance for the piston rings can be checked. As mentioned before, this dimension is the clearance between the piston ring and the inner side of the ring groove. This small clearance performs an important function. During the power stroke, the pressure produced by combustion pushes the piston down the cylinder bore. Some of the expanding gases also force down along the side of the piston and behind the floating piston ring. The resulting pressure behind the piston ring forces the ring outward hard against the cylinder wall, thus helping to seal the combustion chamber better. By allowing the ring to seal better, the proper ring side clearance helps the engine produce more power.

Because a small clearance should always be present, a piston ring will tip slightly under

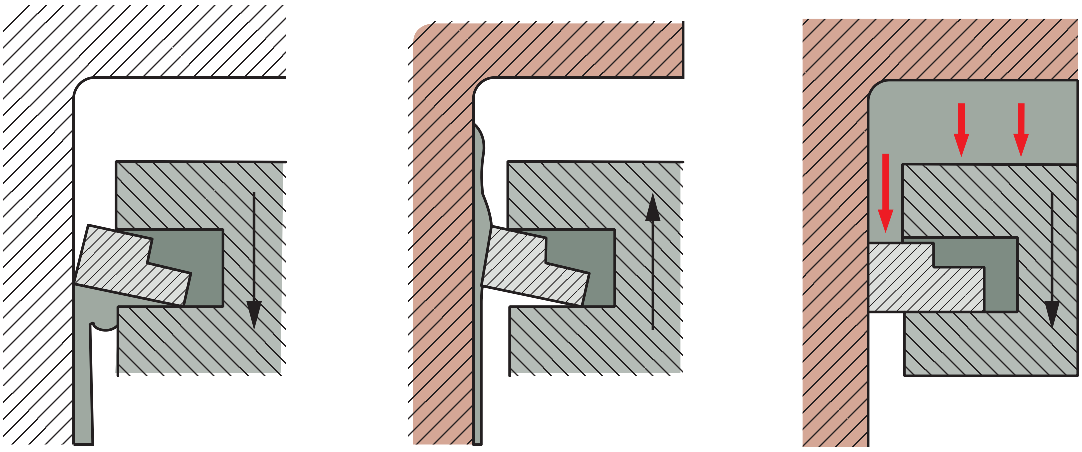


Figure 10-19 Piston rings move around while the engine is running to scrape off extra oil and aid in combustion.

normal operating circumstances, as illustrated in Figure 10-19. As the piston goes down the cylinder during the intake stroke, the ring tips and scrapes excess oil off the cylinder wall. During the compression and exhaust strokes, the piston rises and the tipped ring glides over the oil film remaining on the cylinder wall. During the power stroke, the forces pushing down on the ring cause it to sit squarely, providing a better seal and therefore better power.

A proper ring groove clearance can be critical. If the clearance is too large, the ring will tip excessively as the piston moves up and down, reducing its ability to seal. The excess movement of the ring on the piston may also cause the ring to break. If the clearance is too small, the ring may bind in its groove when the piston heats up and expands.

To measure the ring side clearance, a piston ring can be installed in its groove. A feeler gauge is then inserted between the ring and the bottom of the groove (Figure 10-20). After you've measured the piston ring side clearance, compare your measurement with the manufacturer's specification. Because each ring groove may be worn differently, you should check the side clearance in all of the piston's grooves.

Figure 10-20 Measuring ring side clearance.

Piston Ring Inspection and Measurement

The next step in the inspection process is to carefully check the piston rings for signs of unusual wear. As mentioned earlier, you should not reinstall old piston rings into a cylinder; they should be replaced whenever an engine is taken apart. Generally, rings that are reused won't seat properly, resulting in poor engine performance. However, the condition of old piston rings can provide clues to certain engine problems. For example, small scratches found on the edge of the rings usually mean that dirt or other debris has been getting into the engine. This may likely indicate a faulty air-filtering system. Remember from Chapter 6 that two-stroke pistons have locating pins to prevent the piston ring from moving around on the piston (Figure 10-21).

You may recall that when new piston rings are installed in an engine, they must wear themselves into position against the cylinder walls to form a tight seal. Once this process of seating has occurred, the rings lose the ability to do

Figure 10-21 Locating pins prevent the piston ring from moving into a port and causing damage in a two-stroke engine.

Figure 10-22 Deglazing a cylinder provides the best seal and quick break-in when replacing a piston and/or piston ring.

so again, that is, if old rings are reinstalled in an engine, they won't be able to conform once again to the cylinder walls and make a tight seal. Without a tight seal, the combustion gases can leak past the rings. This reduces the amount of horsepower the engine can produce.

Before reassembly, you'll be required to deglaze the cylinder (Figure 10-22). The importance of cylinder wall deglazing can't be overemphasized. A proper cylinder finish will provide the quickest possible break-in and greatly reduce the possibilities of ring or piston scuffing during break-in. A glazed cylinder wall causes rings to "skate" on the highly polished finish and discourages the minute amount of wear that's necessary to mate the piston rings with the bore of the cylinder.

A deglazed finish contains minute hills and valleys, which carry a film of oil, which will prevent scuffing during break-in as well as produce the type of cylinder finish piston rings can mate to rapidly. The finish produces a crosshatch pattern that intersects at approximately a 45° angle. Probably the most critical part of the deglazing operation is proper cleaning after deglazing. The residue of deglazing—tiny pieces of iron from the cylinder wall—will rapidly destroy all moving parts if left in the engine. It's important to note that cylinders need to be cleaned thoroughly with warm soap and water prior to assembly. Clean until the bore can be wiped with a clean white cloth without soiling the cloth. Many technicians finish the cleaning process by wiping the bore with automatic transmission fluid because of its ability to pick up tiny pieces of metal. After clean up, oil the area lightly with the same oil that will be used to run the engine, to prevent rust formation (Figure 10-23).

Measure the new piston ring(s) to ensure that the ring end gap is correct by placing the ring squarely into the cylinder (use the piston to do this effectively) and measuring the piston ring end gap with a feeler gauge (Figure 10-24). Piston ring end gap is the space at the ring at its opening when it's compressed in the cylinder.

Figure 10-23 It's important that cylinders be cleaned thoroughly before assembly.

Figure 10-24 Measuring piston ring end gap with a feeler gauge.

When checking ring end gap, locate the ring in the top of the cylinder and measure at a point that the engine manufacturer recommends in the appropriate service manual.

Measuring Piston-to-Cylinder Clearance

As explained earlier, a piston expands as its temperature rises. Since the metal of the piston typically expands more than the metal of the cylinder wall, some clearance must be allowed between these components when both are cold. This clearance is called the **piston-to-cylinder clearance** (or just piston clearance for short). The piston-to-cylinder clearance is a critical dimension. If the clearance is too small, the piston fits too tightly in the cylinder whenever the engine heats up, resulting in excessive friction, which may cause the piston to seize in the bore, that is, the piston may actually melt onto the cylinder, thereby being unable to move up and down. Try rubbing your hands together lightly. There is little heat produced because there is very little friction. Now try rubbing together with much more force against each other and quickly. You'll almost immediately feel the heat being produced from the friction created. If this occurs, the engine stops running, and the starter won't be able to rotate the crankshaft at all. You may be able to free a seized piston after the engine cools down again; however, both the piston and the cylinder wall will probably be badly scored and damaged.

If the piston clearance is too large, the piston won't be held in place well and will tend to rock back and forth while the engine is running. This rocking motion creates a knocking noise and may eventually break the piston skirt. In addition, the piston ring's ability to seal the combustion chamber will be greatly reduced. You should always check the manufacturer's specification for the correct piston-to-cylinder measurement listed in the service manual, since all engines are designed slightly differently.

To determine the piston clearance in an engine, you'll need to measure the diameter of both the piston and the cylinder bore. Illustrations of these measurements can be seen in Figures 10-8 and 10-18. Compare your measurements with the manufacturer's specifications. Then, subtract the outside diameter of the piston from the inside diameter of the cylinder bore. The result of your calculation is the actual piston clearance. Compare your calculated clearance with the manufacturer's specification. If the clearance is outside specifications, the piston and cylinder will have to be replaced or resized to make the clearance conform to specifications.

Wrist Pin Measurement

The **wrist pin**, a cylinder-shaped piston assembly component, is used to link the connecting rod to the piston. The connecting rod's bearing surface for the wrist pin allows the end of the rod to rotate freely around the wrist pin as the piston travels up and down. The wrist pin must transfer each power stroke's downward physical force from the piston to the connecting rod. To ensure the wrist pin is strong enough to handle this task, the engine manufacturer usually makes the pin from high-quality steel, which is a very hard metal. For this reason, you won't usually see any wear on the pin itself. However, to guarantee that a wrist pin isn't worn, measure the pin's diameter with an outside micrometer (Figure 10-25). Compare your measurement with the specification given in the service manual.

Figure 10-25 Measuring the wrist pin.

Figure 10-26 The two-stroke engine rod will usually use a bushing or needle bearing at the small end.

Connecting Rod Inspection

The connecting rod in a two-stroke engine is generally a one-piece unit and is attached to the crankshaft. The two-stroke engine rod will usually use a bushing or needle bearing at the small end (Figure 10-26) and a needle or roller bearing at the large end, depending on the size of the engine.

Reed Valve Inspection

Many two-stroke power equipment engines use reed valves on the intake side of the induction system (Figure 10-27). Checking the reed valves is a simple process of inspecting the reed's valves, reed stopper, and the reed valve seat (Figure 10-28) for physical damage.

Figure 10-27 Some power equipment two-stroke engines use a reed-valve-type induction system. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

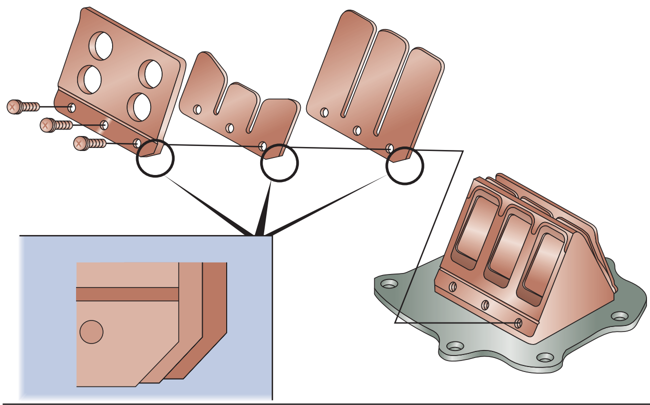


Figure 10-28 The parts of the reed-valve assembly that require inspection. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

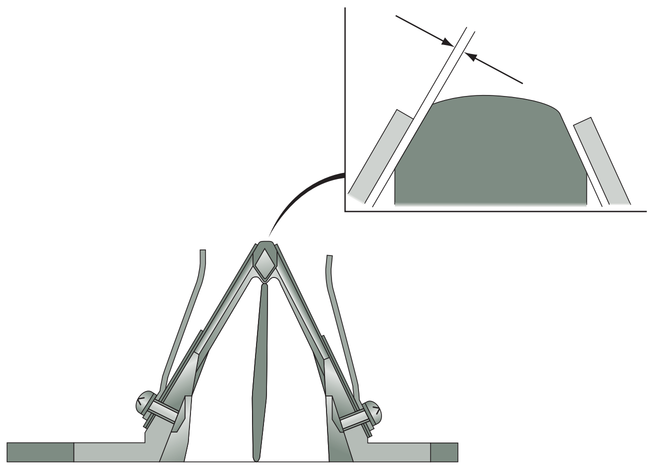


Figure 10-29 There should be little to no air gap between the reed valve and the reed valve seat. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

When looking at the reed valve assembly, there should be little to no air gap between the reed valve and the reed valve seat (Figure 10-29).

STARTING THE REASSEMBLED REBUILT ENGINE

When you're certain that all components have been reassembled and are in place, all fasteners have been properly tightened, and the fluids have been properly added, it's time to start the engine. The engine should start within 5–10 pulls of the starter rope. If it doesn't start at this time, stop and verify that all electrical connectors are attached and then try again. Once started, let the engine idle or keep it as close to idle speed as possible. As the engine is warming up, check for any leaking fluids in and around the engine. Shut the engine off.

Engine Break-In

Most manufacturers recommend that a new (or reconditioned) engine be properly broken in to make sure that all components are sealing well and that all components mesh together properly. During your assembly, use only the best possible materials and use original equipment manufactured parts to assure the highest standards. Even though you're using the highest-quality components, it's still necessary to allow the parts to "break in" before subjecting the engine to maximum stress. The future reliability as well as the performance of the two-stroke engine depends on a proper break-in procedure. This includes extra care and restraint during the early life of the reconditioned engine. Follow the appropriate manufacturer recommendations for the correct break-in procedure.

Summary

- Diagnosis is the process of determining what's wrong when something isn't working properly, by checking the symptoms.
- Symptoms are the outward, or visible, signs of a malfunction.
- It's important to understand fully the necessity for proper engine component inspection, which includes visual inspections as well as measurement of components for wear.

Chapter 10 Review Questions

1. To measure the diameter of a piston, you should use a _____.
2. A piston ring groove clearance can be measured by using a _____.
3. An engine produces its power by burning the air–fuel mixture in the combustion chamber directly above the _____.
4. If the piston clearance is too small, the friction between the piston and the cylinder may cause the piston to _____ in the bore.
5. A _____ between the cylinder and the crankcase helps create an air-tight seal.
6. Wear within the cylinder is caused by the up-and-down motion of the _____ and _____.
7. An indication of worn piston rings can be seen before the engine is disassembled by conducting a _____ test.
8. All two-stroke cylinders can be bored to fit an oversized piston. (True/False)
9. To measure the cylinder bore, you would use a _____.
10. Pistons are perfectly round to fit in the cylinder. (True/False)

CHAPTER

11 Two-Stroke Engine Bottom End Inspection

Learning Objectives

- Recognize common bottom end engine failures in a two-stroke power equipment engine
- Understand the importance of inspecting the various parts of the two-stroke engine bottom end for damage or wear
- Understand the importance of bench testing an engine prior to completing reassembly

Key Terms

Bench testing

Interference fit

Mechanic's stethoscope

INTRODUCTION

The process of disassembling the bottom end engine assembly is a process in which all engine parts located below the cylinder are removed, inspected, and replaced if necessary. As a technician, it's important that you understand how to disassemble the engine right down to its heart: the crankshaft. It's also important that you know how to inspect engine components, do any necessary repair work, and reassemble the engine correctly.

Disassembly of most engines requires that the engine be removed from the implement it's installed in. Therefore, you should first be sure the malfunctioning component is located in the engine and not the implement it's mounted on. After all, you would not want to remove an engine and disassemble it completely, just to find out that the "failed" component didn't require any disassembly in the first place! This is actually quite common, so be sure the engine you're working on really requires disassembly before you start.

Common Bottom End Engine Failures

The following is a brief discussion of some areas in the bottom end assembly where malfunctions commonly occur.

Leaking Seals

Seals are used on transmission shafts and other rotating shafts within a power equipment engine to prevent oil loss, prevent contaminants from entering the engine and bearings, and prevent the crankcase from leaking. Remember a leaking crankcase causes poor transfer of fuel.

A leaking oil seal requires that the engine's bottom end be disassembled, although in many cases, replacement can be done without disassembly. Therefore, before disassembling the bottom end, always confirm by checking the appropriate service manual if replacement of the faulty oil seal requires complete disassembly.

Figure 11-1 A mechanic's stethoscope is often used to listen for internal engine noises.

Worn Crankshaft Bearings

Crankshaft bearings are used to mount the crankshaft assembly into the crankcase. Bearing failure is indicated by a rough, growling sound. You may wish to use a **mechanic's stethoscope** (Figure 11-1) to help you pinpoint the location of the bad bearing. A mechanic's stethoscope is similar to a stethoscope that a doctor uses to listen to your heart and lungs during a physical examination. It picks up very faint sounds and can pinpoint the location of noises in an engine. Worn bearings may cause excessive up-and-down movement of the crankshaft, which can cause seals to leak, which in turn can cause the engine not to start or even prevent the crankshaft from rotating.

Worn Connecting-Rod Bearings

Connecting-rod bearings allow the connecting rod to rotate as the crankshaft assembly turns. The following are some symptoms of worn connecting-rod bearings.

- The engine knocks.
- The engine starts, but won't run freely.

The crankshaft doesn't rotate (it's locked up).

Any of these symptoms will necessitate disassembly and repair of the bottom end of the engine.

Repair Procedures

Being alert to other problems by inspecting when you're performing repairs on an engine will help you become a fully competent power equipment engine technician. In this chapter, we'll list the necessary procedures to inspect and replace worn parts in single cylinder two-stroke air-cooled engines. These procedures apply to all two-stroke engines that you'll work on as a technician.

As mentioned before, be sure that the power equipment engine is clean before you begin any disassembly work. Use a water-soluble degreaser and use it according to the manufacturer's instructions. Remember that dirt or foreign particles can ruin your repairs if allowed to enter the working parts of the engine.

The disassembly of the bottom end of a two-stroke engine requires that the top end be removed first. Therefore, we'll assume that the top end of the engine has been removed, using the procedures found in the appropriate service manual.

The procedures in this chapter are general in nature. Their purpose is to familiarize you with the types of activities you'll encounter when you inspect the components of a typical two-stroke engine bottom end. Always refer to the appropriate power equipment engine service manual for detailed information. The manufacturer's service manual contains all the information to do the job correctly, including detailed instructions for the specific make and model of engine, special tools, and service tips. Above all, the service manual contains appropriate safety information to ensure that your job is completed safely.

TWO-STROKE ENGINE REMOVAL AND DISASSEMBLY

Although two-stroke engines are built by different power equipment engine manufacturers, almost all are disassembled in a similar manner. It's strongly recommended that you use the appropriate manufacturer service manual and follow the procedures therein when disassembling any engine. Incidentally, as in Chapter 10, we would be using an engine from an air-cooled

Figure 11-2 An air-cooled two-stroke engine to power a leaf blower (used in this chapter for illustrative purposes).

Weed Eater gas blower, which uses a Poulan engine, for illustrative purposes (Figure 11-2). Generally speaking, the procedures for the inspection of the bottom end of all two-stroke engines are similar, from the least to the most expensive engines. Although some engines are considered to be non-serviceable because of high replacement costs (as compared with rebuilding costs), any two-stroke engine can be rebuilt if needed.

As we discussed in Chapter 10, in most cases, the two-stroke engine top end can be disassembled and inspected without removing it from the implement it's powering. However, to gain access to the two-stroke engine bottom end components, you must first remove the engine from the implement it's powering (Figure 11-3). When a systematic approach is used, the procedure to remove a two-stroke power equipment engine is quite simple. However, specific instructions provided by the manufacturer for this purpose must be followed. Therefore, the appropriate service manual should always be used as a reference.

TWO-STROKE ENGINE BOTTOM END INSPECTION

In most cases in two-stroke power equipment engines, disassembly is quite simple as there are not many components involved (Figure 11-4).

Figure 11-3 To gain access to the two-stroke engine bottom end components, you must first remove the engine from the implement it's powering.

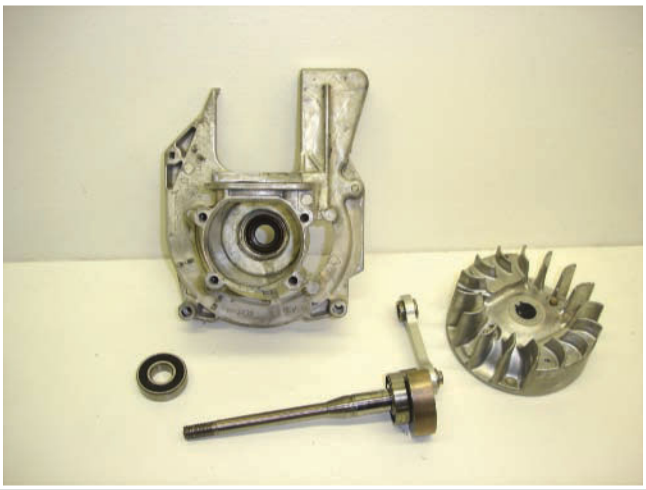


Figure 11-4 In most cases in two-stroke power equipment engines, disassembly is quite simple, as there are not many components, as seen here.

Once the bottom end of the engine has been disassembled, it's time to inspect each component for damage and wear. As heating the crankcase allows for easier disassembly, a heat gun can be used to assist with the disassembly of the two-stroke bottom end. This prevents damage to the crankcase.

Although you may be trying to locate a particular problem, you should carefully inspect all engine components when the engine has been disassembled. Because a complete engine disassembly is a lengthy procedure that isn't done frequently, it's important to make sure that the job is done right and that there are no existing or soon-to-occur problems. We'll learn how to inspect the bottom end of a two-stroke engine, beginning with the engine crankcase.

Inspecting the Engine Crankcase

The engine crankcase (Figure 11-5) should be closely inspected for cracks, loose-fitting bearings, or worn-out fastener anchoring points. If there are stripped bolt holes, they may be repaired using a special thread repair kit that reconditions the hole (Figure 11-6). The Heli-Coil and the Time-Sert are two popular thread repair systems, which should be available from an automotive tool supplier.

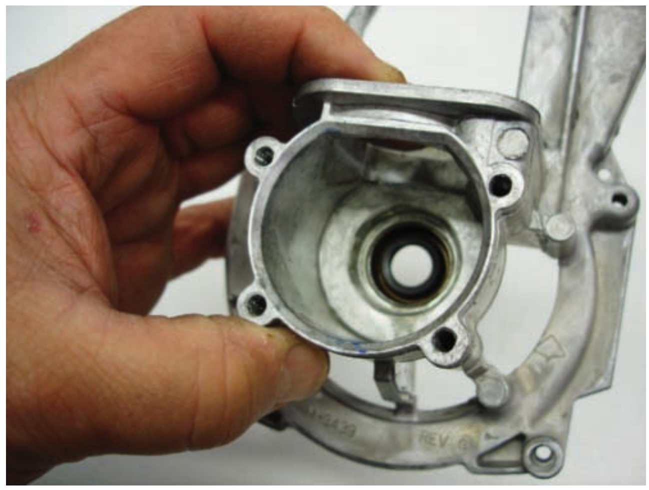


Figure 11-5 When inspecting the crankcase, look closely for cracks, loose-fitting bearings, and worn out fastener anchoring points.

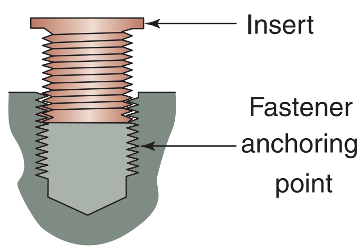


Figure 11-6 An insert that would assist in the repair of a stripped fastener anchoring point.

Inspecting and Replacing Engine Seals

Engine seals are designed to retain oil in the engine compartment and keep air out of the crankcase of a two-stroke engine bottom end. Their most important function is to prevent crankcase pressure from leaking around the crankshaft. Seals are located on all two-stroke engine shafts that rotate, and they're exposed to the outside atmosphere and internal engine oil that must be separated from the engine's crankshaft (Figure 11-7).

Although today's engine seals are durable, it's important to inspect them to verify that they're in good condition. Inspect the oil-seal lip for wear and damage. Depending on its location, damage to the lip of the oil seal may result in leakages of air into the engine, transmission oil into the crankshaft compartment, or transmission oil from inside the engine to the ground. Inspect the seals carefully. If a seal isn't in perfect condition, replace it. The rubber of the seal must be "live," that is, the lip of the seal must be soft and springy. Virtually all engine seals have a small coil spring that fits on the seal lip to apply pressure to the shaft (Figure 11-8). Some seals have two lips, one on each side to seal both pressure and vacuum. Be sure this spring is attached properly. If it's not in place, even a good seal will leak.

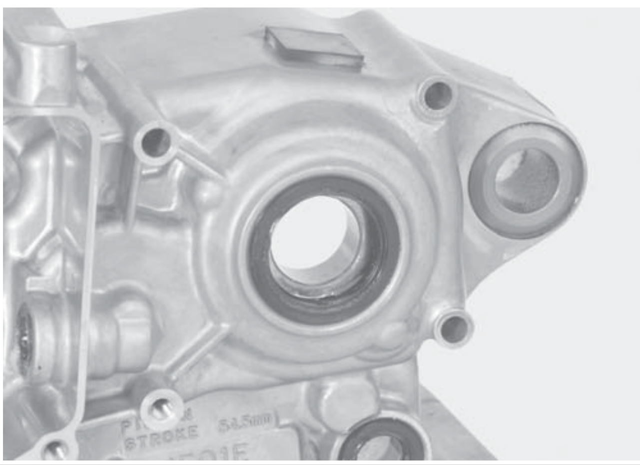


Figure 11-7 Engine seals are located on rotating shafts and are designed to keep oil in, keep oil out, or in certain cases on a two-stroke engine, keep air out of the crankcase. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

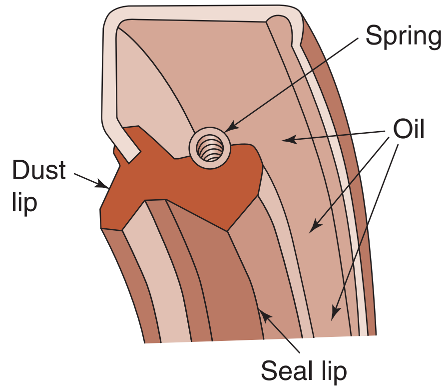


Figure 11-8 The parts of a seal. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Always install a new seal if you have any doubt about the condition of the old one. Also, install new seals whenever you replace any bearings that have a seal next to them.

Before you remove any seal, be sure to note how it's installed, as seals will work correctly only if installed in the proper direction. Once removed, you should never reuse a seal, as it would have suffered damage while being removed. If you remove a seal, replace it with a new one. Because you should never reuse a removed seal, the removal process becomes pretty simple. Seals can be carefully pried out of the cases by using a screwdriver or by using a special seal removal tool (Figure 11-9). When removing seals be sure to be careful not to damage the crankcases.

Figure 11-9 You can purchase special tools to remove seals or, in many cases, just pry it out with a screwdriver. Never reuse a seal once it has been removed.

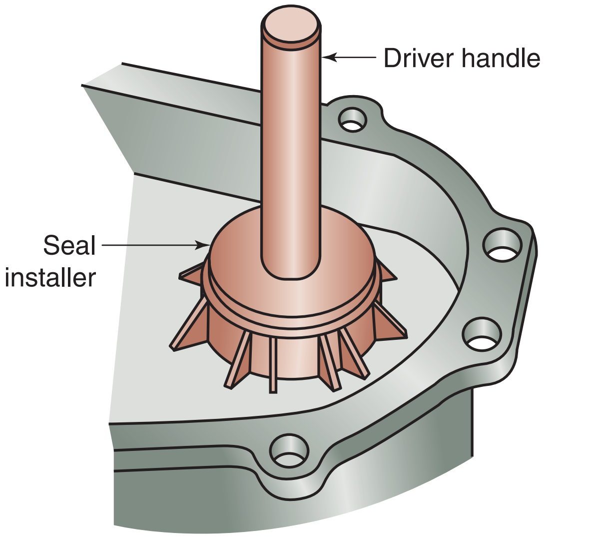


Figure 11-10 Seals need to be installed correctly and evenly by using a special seal installation driver that rests on the outside of the seal.

Figure 11-11 Ball bearings are the most common bearing found in a two-stroke engine and are easy to inspect for wear or damage.

A new seal must be installed evenly in the hole. Use a seal installation tool to assist in placing a new seal correctly (Figure 11-10). Be sure to install the seal into the case properly. Generally, the seal manufacturer's identification number is on the side away from the bearing or shaft to be sealed. Check the appropriate service manual to be certain that you do install the seal correctly. Lubricate the seal with the recommended lubricant before installing the seal. This can be either oil or grease depending on the manufacturer's recommendation.

Some engine seals are located on the inside of the crankcase cavity and can be replaced only when the crankcase halves are separated. It's always a good idea to replace this type of seal.

Inspecting and Replacing Engine Bearings

The most common bearing that you'll find in a power equipment two-stroke engine is the ball bearing. Remember that bearings usually make a low growling sound when they're failing. You can inspect a bearing by hand while it's still mounted in the crankcase or on its shaft (Figure 11-11) by rotating the bearing inner race (or outer race if the bearing is outside of the crankcase) and feeling for smooth operation. If a bearing has a rough feel or makes a noise when you rotate it, the bearing should be replaced.

Also, visually inspect the inner and outer races, balls, and ball cage of the bearing (Figure 11-12). If there is any sign of wear, chips, cracks, or damage, the bearing must be replaced.

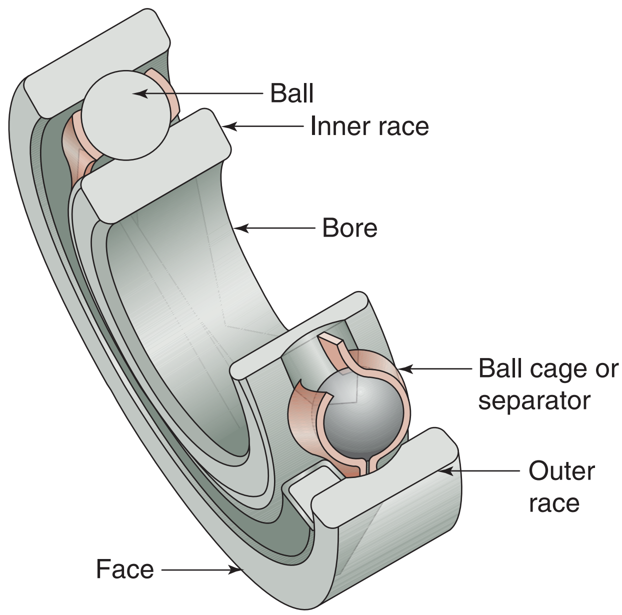


Figure 11-12 A cutaway illustration of a ball bearing.

Figure 11-13 Ball bearings must be driven out of the crankcase or pulled off the shaft it's installed on.

Figure 11-14 A bearing being driven into the crankcase.

To replace any two-stroke engine bearing, you must first remove the old bearing by driving it out of the crankcase or pulling it off the shaft (Figure 11-13).

Ball bearings are held in the case by a tight fit, which is called an **interference fit**. Before installing new bearings, you may want to put them in a freezer. When bearings are placed in a cold environment, they will shrink slightly, which will make their installation easy. You can also heat the crankcases on a hot plate or by using a heat gun to expand the case metal before installing the bearings. However, doing so may allow any other bearing in the cases to fall out.

As just mentioned, placing cool bearings into a warm case makes for easy installation, while also ensuring a tight fit when both the bearing and case have returned to room temperature. This is because the cooled bearings expand as they warm up, and the warmed case shrinks as it cools down. When installing bearings, be sure to strike the bearing only on its outer cage (Figure 11-14), or else you'll risk damaging the bearing inner cage. Pre-lubing the engine parts will provide assurance that there hasn't been a lack of lubrication when first starting the engine after assembly. Use a small amount of two-stroke oil on all bearing and surfaces when reassembling.

Figure 11-15 Crankshafts in small two-stroke power equipment engines are often single-piece units that look like one half is missing.

Inspecting the Crankshaft

Crankshafts in many home-owner quality, small two-stroke power equipment engines are often single-piece units that look like one half is missing (Figure 11-15). This is due to the fact that many two-stroke engines are very small in size and a full size crankshaft isn't needed because of the relatively low power being developed. Inspecting this type of crankshaft consists of ensuring that there are no signs of wear on the bearing surfaces.

Inspecting the Multi-Piece Crankshaft

While many smaller home-owner quality, two-stroke power equipment engines use a single-piece crankshaft, most high-end units use a multi-piece crankshaft. You'll find that two-stroke engines that use multi-piece crankshafts can in most cases be rebuilt if worn or damaged. The most commonly replaced part of a two-stroke engine crankshaft is the connecting rod and its bearing (Figure 11-16). The crankshaft connecting-rod lower bearings are usually of the roller type and are often replaced as a set with the lower crank pin and connecting rod.

Figure 11-16 A multi-piece crankshaft is often rebuildable.

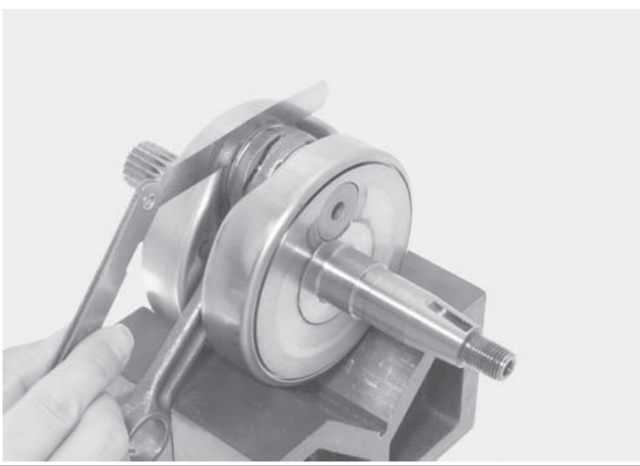


Figure 11-17 Measuring crankshaft side clearance with a feeler gauge. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Replacement of the connecting-rod lower-bearing unit requires separation of the flywheels and is in most cases the type of job that is sent to a machine shop that specializes in such repair. Typically, a technician visually inspects a crankshaft and makes three measurements.

- Side clearance is required to ensure that there is enough space between the connecting rod and the crankshaft flywheels. This is a measurement that is done using a feeler gauge (Figure 11-17). The specification for this measurement can be found in the appropriate service manual.
- Radial clearance is a measurement of the up-and-down motion of the connecting rod at the lower bearing. To check this clearance, the crankshaft will need to be placed on a pair of V-blocks, which will hold it above the bench, and then checked with a dial indicator (Figure 11-18).

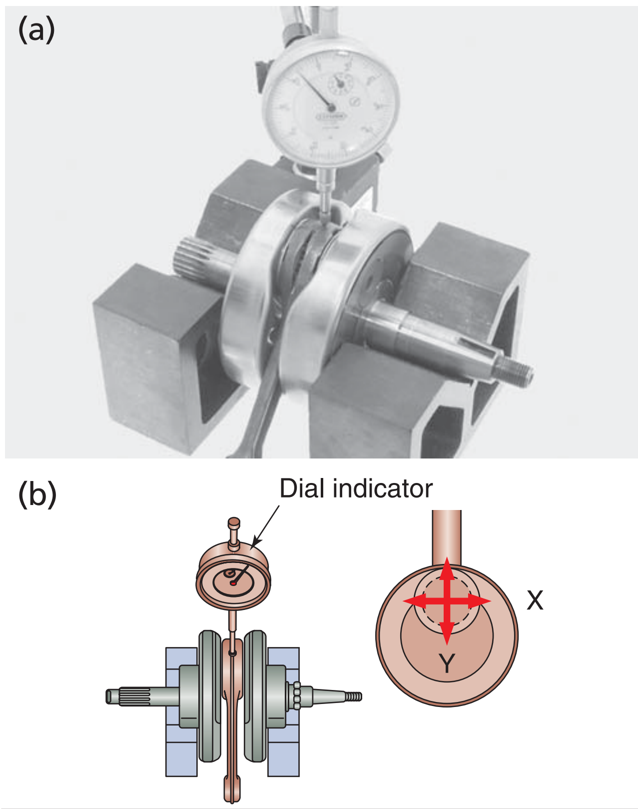


Figure 11-18 (a) Measurement of radial clearance with a dial indicator. Copyright by American Honda Motor Co., Inc. and reprinted with permission. (b) Measurement along the *x* and *y* axes. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

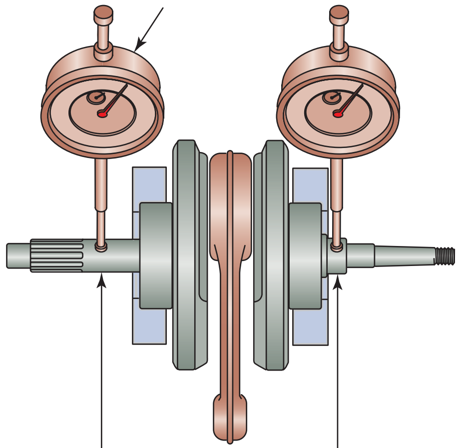


Figure 11-19 Measuring a crankshaft for trueness requires V-blocks to set the crankshaft on and two dial indicators. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

- Runout is checked with the use of two dial indicators (Figure 11-19) and includes checks on the trueness of the crankshaft. This measurement is also done on V-blocks and assures the technician that the crankshaft is straight and not twisted, which makes the engine vibrate excessively.

Bench Testing

After you've completed the reassembly of the bottom end of the engine, it's good practice to verify if all components are moving freely and properly. You wouldn't want to discover that there is a problem after you've completely reassembled the engine and installed it into the chassis.

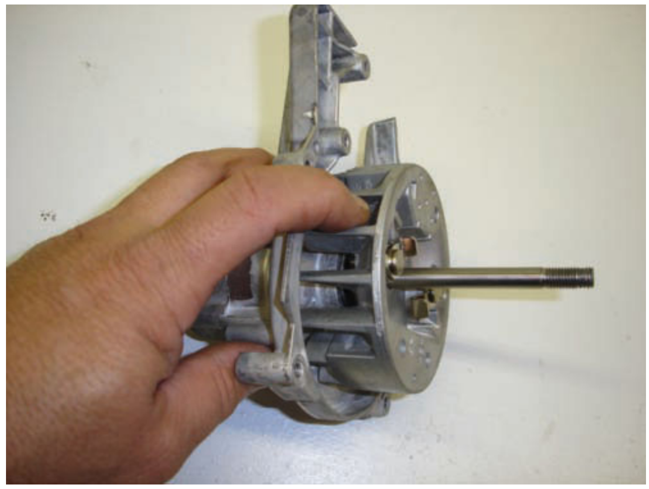


Figure 11-20 Before completing reassembly, always check to ensure that the bottom end components turn freely.

Bench testing refers to the process of verifying the correctness of reassembly. To ensure that the bottom end assembly is operating satisfactorily, turn the crankshaft to make sure it moves freely (Figure 11-20). When you're satisfied that all components have been assembled correctly and turn freely, you're ready to reinstall the top end onto the crankcase and complete the installation of the engine into the implement it powers. Remember always to use the appropriate service manual when reassembling the engine.

Summary

- It's important to understand how to recognize common bottom end engine failures in a two-stroke power equipment engine.
- It's important to inspect all of the components of the bottom end of a two stroke lower end while the crankcases are apart for any reason to ensure that there will be no cause to have to disassemble the engine again after the initial repairs have been made.
- By bench testing an engine prior to completing reassembly, you'll know that all internal parts of the engine are working properly.

Chapter 11 Review Questions

1. An engine _____ should always be replaced with a new one if it's removed.
2. Ball bearings are held in the engine cases by an _____ fit.
3. The _____ bearing is the most popular bearing used to support the crankshaft of a two-stroke engine.
4. The two-stroke engine crankshaft connecting rod is generally of a single-piece design. (True/False)
5. After you've completed the reassembly of the bottom end of the engine, it's good practice to verify that all components move freely and properly. (True/False)

CHAPTER

12 Four-Stroke Engine Inspection

Learning Objectives

- Understand the importance of engine problem diagnosis.
- Know the differences between the two types of top ends in four-stroke power equipment engines
- Identify the various components in a four-stroke power equipment engine
- Understand the importance of inspecting the various components of the four-stroke power equipment engine for damage or wear
- Understand the proper procedures to measure the various components of a four-stroke power equipment engine
- Recognize common bottom end engine failures in a four-stroke power equipment engine
- Recognize the importance of bench testing a power equipment engine prior to completing reassembly
- Understand the importance of properly breaking in a power equipment engine

Key Terms

Detonation
Engine break-in
Leak-down test
Plastigage
Preignition
Prussian blue
Reamer
Stellite
Valve refacing

INTRODUCTION

The vast majority of modern power equipment engines are of the four-stroke design. The inspection of the components in a four-stroke power equipment engine top end and bottom end is a process by which the parts of the engine are removed, cleaned, inspected, and measured. The disassembly and inspection of four-stroke engines are tasks you'll perform often in your job as a power equipment engine technician. An engine may be disassembled to make needed repairs or to complete the first step in a complete engine rebuild.

It's important to understand how to disassemble the engine right down to the crankshaft. It's also important to know how to inspect the various engine components, do any necessary repair work, and reassemble the engine correctly.

During a typical rebuild, the engine is restored to a like-new condition. This chapter introduces you to the procedures used to inspect the four-stroke engine components. The procedures that we'll discuss apply to almost all four-stroke engines (regardless of model or manufacturer). We'll explain how to visually inspect and measure the components of the typical power equipment engine. We'll also discuss the tools used in the process and the function of certain engine components. You may wish to review Chapters 5–7 to refresh your memory on each of the individual components of the engine.

Repairs to the four-stroke power equipment engine often require that the engine be removed from the implement that it's attached to. The service manual for the particular machine you're working on will inform you if the engine can remain in the chassis or if it needs to be removed.

In this chapter, we'll discuss two types of engine designs: the L-head, which is attached to a typical lawn mower (Figure 12-1), and the overhead valve (OHV) engine, which, in our illustrative example, is attached to a gas-powered pressure washer (Figure 12-2). Most of the components of these engines are similar, with the primary difference being in the arrangement and location of the valves.

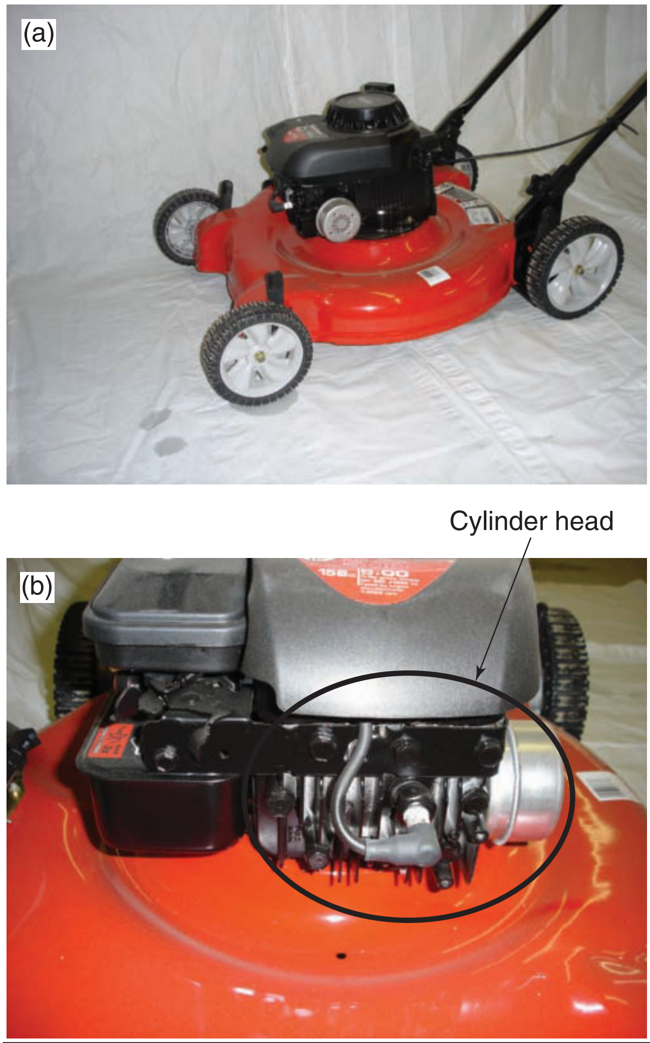


Figure 12-1 A typical push-type lawnmower that uses an L-head. Note the shape of the cylinder head in (b); it can be distinguished by the fact that it has only fins across its top.

DIAGNOSIS

If there is an engine-related problem, before any components are disassembled, the technician must diagnose the condition. Diagnosis, as we know, is the process of determining what's wrong when something isn't working properly, by checking the symptoms. Symptoms are the outward, or visible, signs of a malfunction. For example, a knock is a symptom. The actual cause might be a broken, worn, or malfunctioning part. Of course, this is only an example. To assist with diagnosing a problem, you may need to use other testing equipment to help find the problem.

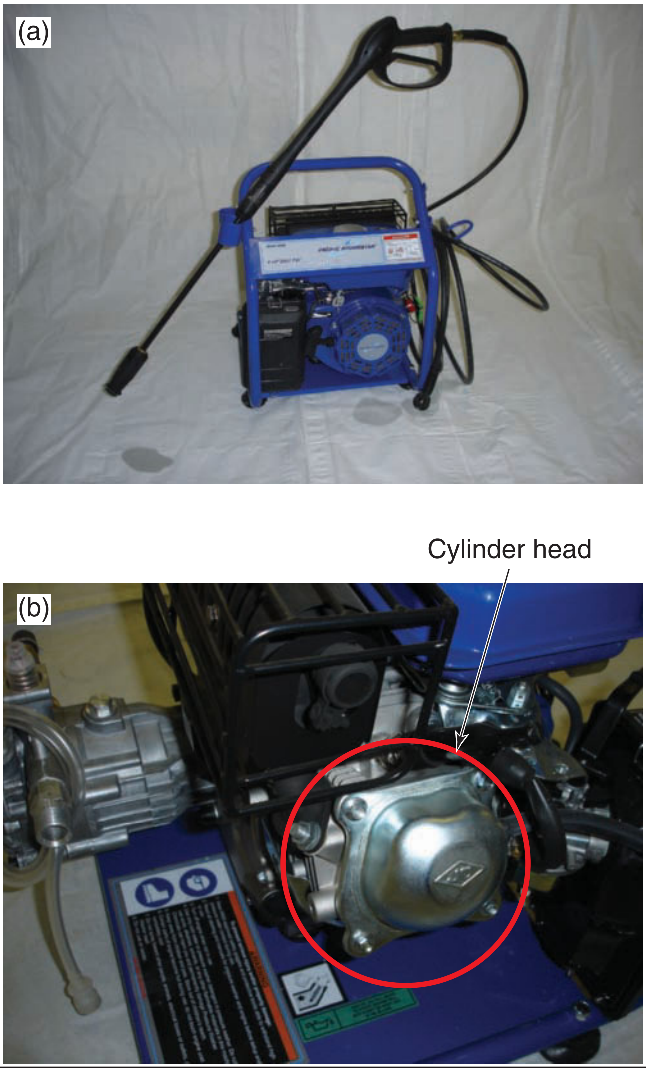


Figure 12-2 A gas-powered pressure washer that uses an overhead valve (OHV). Note the shape of the cylinder head in (b); it has a cover over the valves, which are built onto the head.

Often, complete diagnosis can't be confirmed until the engine is actually disassembled. For example, if a four-stroke engine develops a loud noise in the top end (the symptom), an experienced technician may recognize the sound and tentatively conclude that the piston rings are worn out. That would be the diagnosis. The technician wouldn't be able to confirm the diagnosis without disassembling the engine and actually seeing that the rings and related parts are worn or damaged. A compression and leak-down test would help to confirm the diagnosis in this particular case.

Correct diagnosis of problems is the most difficult and important part of a technician's job. Diagnosis is difficult because the technician often can't see the faulty part before disassembly. Nevertheless, correct diagnosis is important, as the technician must not waste time disassembling and searching for parts that have not failed.

To diagnose problems, experienced technicians mentally divide a power equipment engine into sections. Suppose the engine produces a tapping sound. The technician first listens to hear precisely where the tapping sound is coming from. By working in this manner, the technician inspects each part that's connected to the problem following a logical order of possible malfunctions. We'll get into troubleshooting in more detail in Chapter 17.

Before beginning any type of engine repair, be sure the power equipment engine is clean. Dirt or other foreign particles cause damage to internal working mechanisms. Also, always use the manufacturer's service manual during repairs on an engine.

REPAIR PROCEDURES

The procedures in this chapter, as in Chapter 11, are general in nature and their purpose is to familiarize you with the types of activities you'll encounter when working on a four-stroke power equipment engine. Always refer to the appropriate service manual for complete disassembly information. The service manual contains all the information to do the job correctly, including detailed instructions for the specific model of power equipment engine, special tools, and service tips. Above all, the service manual contains the appropriate safety information. As mentioned previously, to allow for a broad understanding of the four-stroke power equipment engine, we'll refer to the two most common types of engines throughout this chapter: L-head and OHV engines.

Although we'll discuss the process of complete disassembly of engines, be careful not to remove parts that don't need to be removed.

Close inspection of the power equipment engine, or reference to a service manual, can save time spent removing and replacing parts unnecessarily.

When rebuilding any engine, you need to be both patient and precise. Before you begin any repair job, take time to assemble the proper tools and the materials you'll need (e.g., micrometers, valve-related tools, and cleaning solvents). If an engine is to work properly, the measurements involving its piston and valves must fall within the manufacturer's specifications. Be patient and careful as you make the required measurements. Use proper measuring instruments and record all your measurements accurately on paper to look them over after taking them.

When you disassemble and rebuild an engine, examine the condition of each component. Check the parts before you clean them. For the most part, this should be a preliminary examination. The as-is condition of the parts can reveal a lot about the operation of an engine. After you've examined the parts and recorded your observations, clean the parts thoroughly and proceed with the rebuild by measuring and determining which parts need to be replaced and which can be reused.

Figure 12-3 The components found in a typical L-head power equipment engine.

Figure 12-4 The components found in a typical OHV power equipment engine.

FOUR-STROKE ENGINE TOP END DISASSEMBLY AND INSPECTION

The components of a typical L-head power equipment engine and OHV power equipment engine are shown in Figures 12-3 and 12-4, respectively. Removal of the engine from an implement follows a pattern, that is, certain parts must be removed in a particular order. Although we'll not cover the removal of an engine from its implement here, this pattern is similar for most machines. To ensure that the correct pattern is followed, be sure to use always the manufacturer's service manual when removing the engine from the implement. It's advisable to use an assistant when taking the engine out of the implement, whenever possible, as some engines can be quite heavy or cumbersome to move around.

As there are different power equipment engine manufacturers building four-stroke engines, we'll not discuss *how* to disassemble the top end of a four-stroke engine. As mentioned in preceding text, the pattern of disassembly procedures is similar for most four-stroke engines. It's strongly recommended that you use the appropriate manufacturer's service manual and follow the procedures therein when disassembling an engine. The purpose of this chapter is to show you common procedures that you'll see as you work on a four-stroke power equipment engine.

Figure 12-5 The oil drain bolt in an OHV power equipment engine.

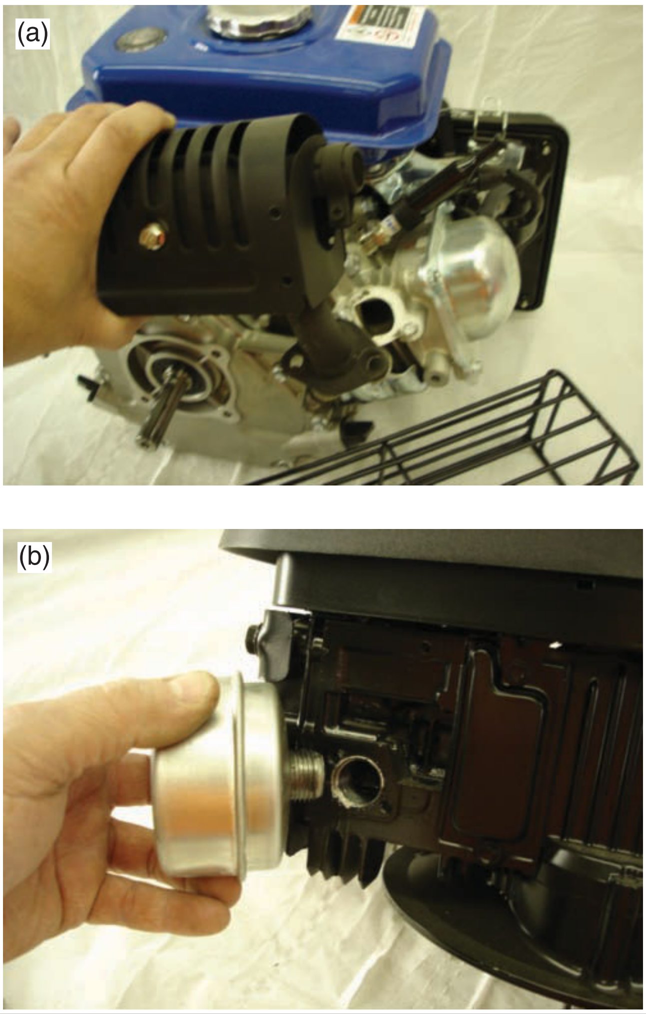


Figure 12-6 Removing the mufflers on the engine helps gain access to covers that will need to be removed. Note that the OHV engine (a) has a bolt on the muffler, whereas our L-head engine (b) has a muffler that screws on.

Draining Fluids and Removing External Components

Before disassembly of the engine, you should remove the engine oil by draining it out of the engine through the drain bolt provided at the bottom of the engine (Figure 12-5). Keep in mind that some engines do not have a drain bolt; in such engines, the oil is drained out of the engine filler by tipping the engine on its side. Removal of the exhaust system (Figure 12-6) and carburetor (Figure 12-7), including all the linkages, should also be done at this time.

Now that the external components have been taken off, you can remove all engine covers to get at the internal engine components that you intend to disassemble and inspect (Figure 12-8).

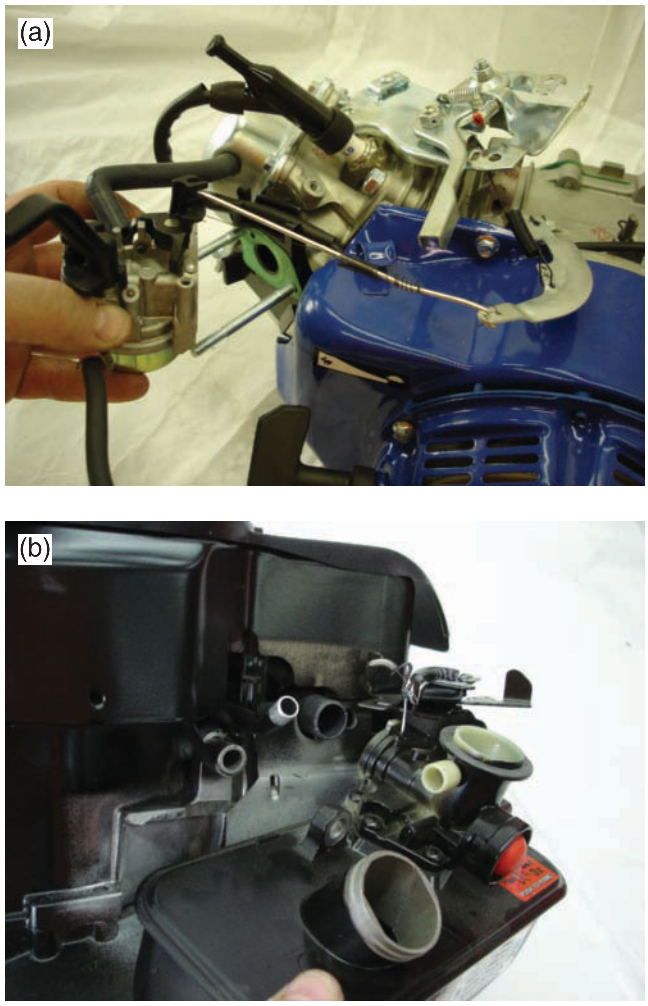


Figure 12-7 Carburetor removal in an OHV engine (a) and an L-head engine (b).

Figure 12-8 After the covers have been removed, it's easy to get at the engine's internal components.

Figure 12-10 A close-up of the L-head attached to the engine.

Figure 12-9 The L-head engine has no moving parts attached to it. Shown is the underside of the head.

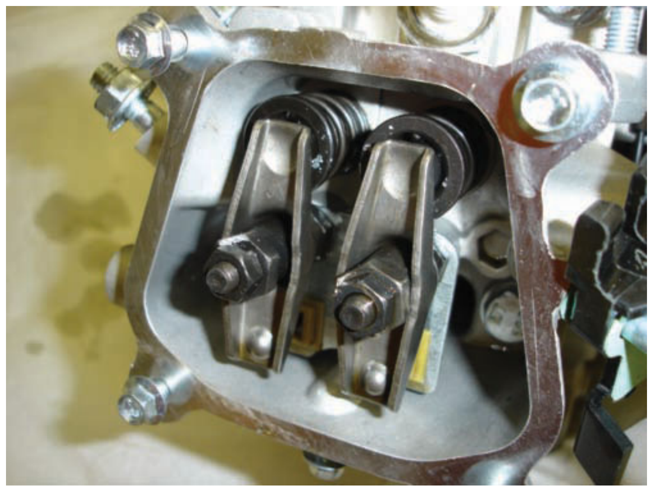


Figure 12-11 The top of a typical OHV power equipment engine. Note the valves, rocker arms, and nuts for adjustment.

Cylinder Head Removal

As we have mentioned, there are two types of engines discussed in this chapter, the primary difference between them being the design of their heads.

Cylinder Heads in the L-Head Engine Design

The L-head design is quite simple as it acts as a top cover to the engine piston, has no moving parts (Figure 12-9), and consists of the combustion chamber. It simply bolts on to the top of the engine cylinder (Figure 12-10).

Cylinder Heads in the OHV Head Engine Design

With the OHV design, the cylinder head contains the engine valves as well as the valve-opening device, in most cases rocker arms (Figure 12-11). It also houses ports to allow the fuel mixture into the combustion chamber as well as to allow the exhaust gases to escape. You can see the difference between these two cylinder heads in Figures 12-12a and 12-12b. OHV engines are more efficient than L-head engines, giving as much as 25% more power.

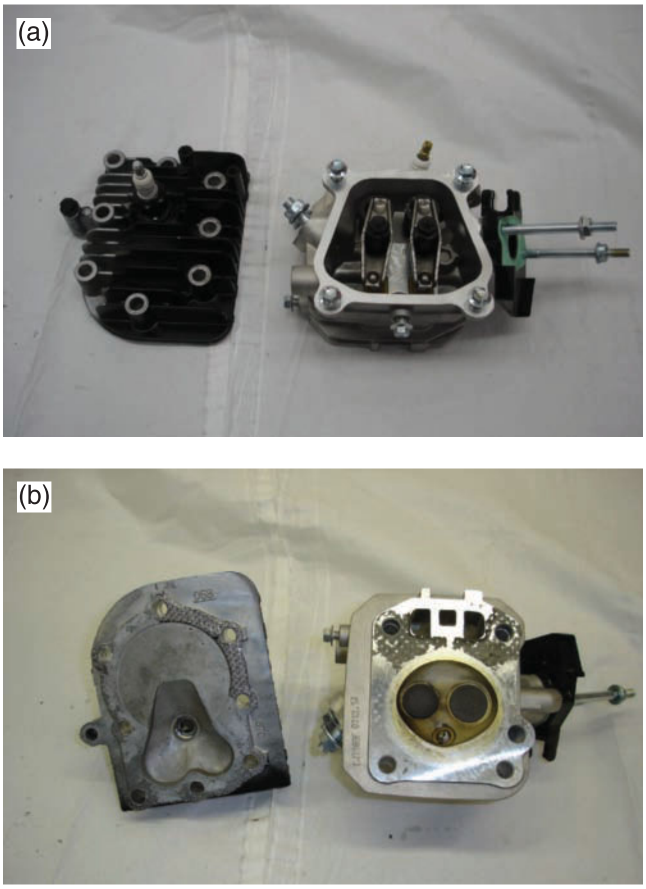


Figure 12-12 A comparison of (a) the tops and (b) the underneaths of the L-type and OHV engine heads.

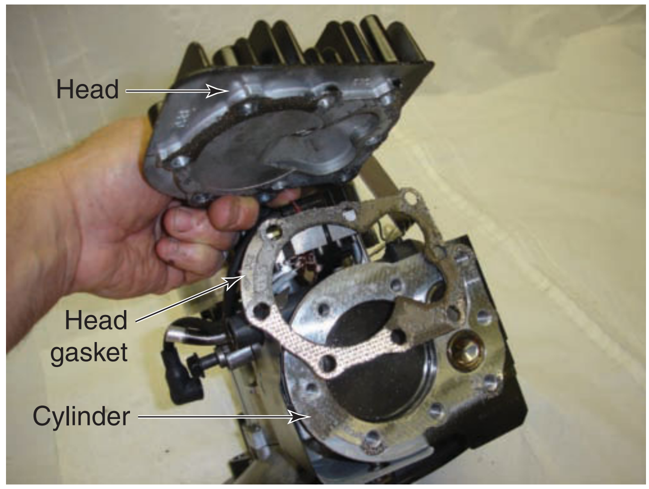


Figure 12-13 The head gasket seals between the head and the cylinder.

Figure 12-14 Carbon buildup is a hard residue that's found often on surfaces exposed to the burned air–fuel mixture, as seen in this combustion chamber.

Cylinder Head Inspection

The cylinder head, in addition to housing the valves on the OHV engine design, is the component that seals the top end of the cylinder. The head is attached to the top of the cylinder by numerous fasteners. A gasket between the head and the block (Figure 12-13) helps create an airtight seal. Because the cylinder head must seal off the cylinder, the head must be in good condition and free of cracks and warpage. Before you can accurately determine the condition of a cylinder head, you should thoroughly clean it with a cleaning solvent.

Removing Carbon and Gasket Material Buildup

The combustion area of the head may require some special attention when you're cleaning the head. Carbon buildup, from the combustion process will almost certainly be present on the surface (Figure 12-14). Carbon buildup is a hard residue that's often found on surfaces exposed to the burned air–fuel mixture. Because the residue tends to be quite stubborn, you'll probably need a wire or fiber wheel brush to remove the buildup from the cylinder head (Figure 12-15). In addition, although most manufacturers use steel gaskets in today's engines, there may be some gasket material left behind when the cylinder head is removed from the cylinder. This leftover material can be removed in the same way you would remove carbon buildup. Remember

Figure 12-15 The combustion chamber after it's been cleaned of the carbon residue.

Figure 12-16 The most common problem found on cylinder heads is a stripped spark plug hole. This is something that can be easily repaired when proper tools are used.

that power equipment engine cylinder heads are made generally of aluminum, which is a relatively soft metal. Be careful that you don't dig into the cylinder head with a scraper or brush when cleaning it. After the carbon residue and gasket surfaces have been scraped off, the head can be cleaned with cleaning solvent.

Checking the Cylinder Head for Damage

After the cylinder head has been cleaned, it can be thoroughly checked for any visible signs of damage. Check for small cracks or other damage in the area of the combustion chamber. Also, if cooling fins are broken on air-cooled engines, the head may need to be replaced. When working on liquid-cooled engines, check all the water jackets to ensure there are no obstructions. Cylinder heads generally prove to be reliable.

The most common cylinder head problem you'll see is damage to the threads in the spark plug hole (Figure 12-16). On all four-stroke power equipment engines, the spark plug is threaded through a hole in the cylinder head. After the head is removed from the engine, you can easily clean and check the condition of the threads in the spark plug hole. Because most cylinder heads are made of aluminum, the threads in the head can be easily damaged by cross-threading the spark plug. If the threads appear to be damaged, repair them by running a thread tap through the hole or by installing a new threaded insert.

Checking for Cylinder and Cylinder Head Warpage

Having inspected the cylinder head, you can now move on to check for warping of the surface where the new head gasket will be installed. Remember that the cylinder head must seal tightly to the top of the cylinder. The gasket between the head and the cylinder can compensate for some variation in the surface, but not much—the surface of the head must be quite flat. The manufacturer's service manual would tell you the maximum amount up to which the surface of a usable cylinder and head can be warped. The most common method recommended to verify the flatness of the cylinder and head surface uses a straightedge, which is a precision ruler-type tool that is machined flat on its edges. To check a cylinder for warpage, place the straightedge on the cylinder surface on which the gasket will be installed, as shown in Figure 12-17. If you notice clearance anywhere between the straightedge and the cylinder surface, insert the blades of a feeler gauge to measure the amount of warp at that point. The thickness of the blade that fits the clearance is the amount of warp at that particular point. Because the straightedge is narrow, it should be moved about the surface of the cylinder to check several locations. Measure the flatness in

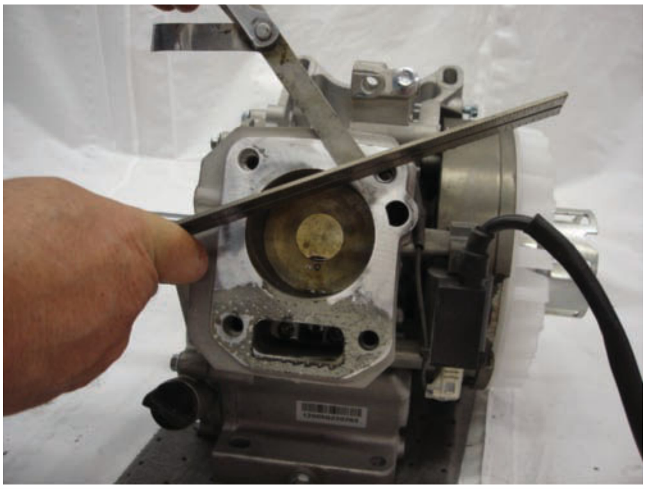


Figure 12-17 Checking the cylinder for warpage using a feeler gauge and straightedge.

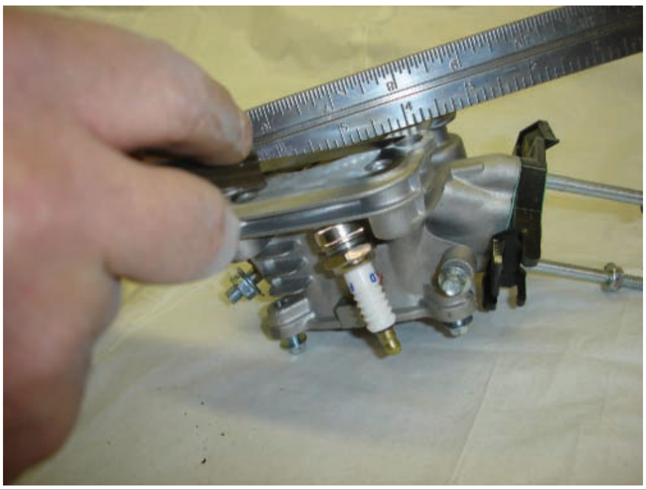


Figure 12-18 Checking the cylinder head for warpage using a feeler gauge and straightedge.

several directions across the cylinder surface. In most cases, the best indication of the cylinder's flatness is found when the straightedge is placed diagonally across the surface. Generally, the measurement you should use to compare against the manufacturer's specification is the maximum warp measured at any point on the surface. You should also check the cylinder head to verify that it's not warped, by using the same method as discussed for the cylinder (Figure 12-18). Generally, cylinder heads warp more than cylinders.

Four-Stroke Engine Valves

The valves in a four-stroke power equipment engine, as we know, perform two vital functions during engine operation. The intake valve allows the air–fuel mixture to enter the combustion chamber so that the mixture can be burned to produce power. The exhaust valve allows exhaust gases to exit the combustion chamber so that a fresh supply of air–fuel mixture can enter. The valves must seal tightly when they're closed, so that the mixture in the cylinder doesn't escape during the compression and power strokes (Figure 12-19). Therefore, for an engine to operate properly, its valves must be in good condition.

To help the valves to seal, valve springs are used to keep the valves closed (Figure 12-20). Valve springs are held in place by retainers (Figure 12-21). There are three types of retainers found on power equipment engines: pin-type retainers are found in older engines, whereas collar-type and washer-type retainers are found more commonly in today's engines. Also, it's common to find a valve seal under the valve spring, which is used to keep oil from entering the combustion chamber. Valve seals can be found on intake or exhaust valves or both.

The basic purpose of a valve spring is to close the valve and ensure that the valve train

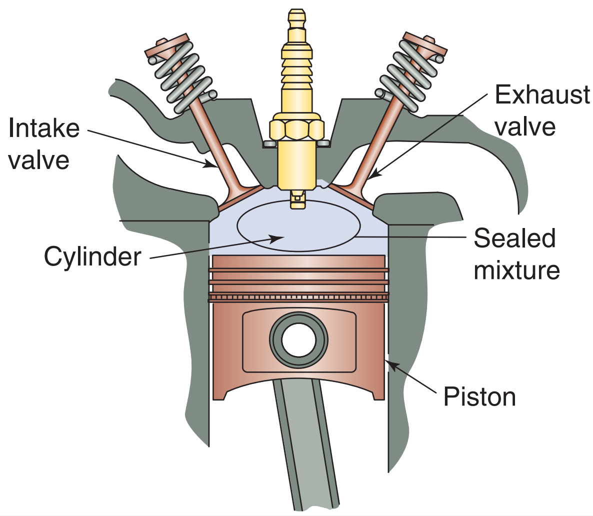


Figure 12-19 The intake and exhaust valves must seal tightly to prevent unwanted flow of gases.

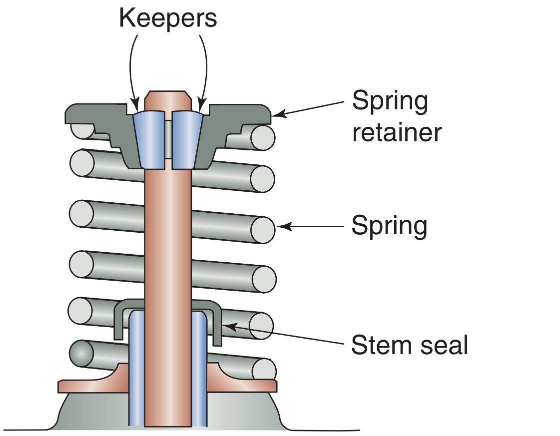


Figure 12-20 A typical valve spring and retaining device.

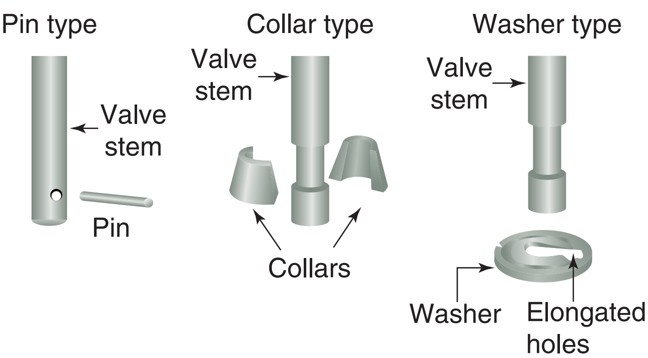


Figure 12-21 The three most common retaining devices found on power equipment engines. Pin-type retainers are found in older engines, whereas collar-type and washer-type retainers are more commonly found in today's engines.

stays in contact with the cam lobe. Also, it must perform this function under grueling conditions that vary tremendously numerous times every minute. The expected rpm range, camshaft profile, and cylinder-head design are just some of the criteria that engineers use when choosing the right valve spring for an engine.

Generally speaking, manufacturers of power equipment engines use 2-valve designs (one intake and one exhaust valve, as seen in Figure 12-22), but you may also see 3-valve engines (two intake and one exhaust) and 4-valve engines (two intake and two exhaust). Such valve arrangements are used to obtain optimal flow of intake and exhaust gases for the application intended.

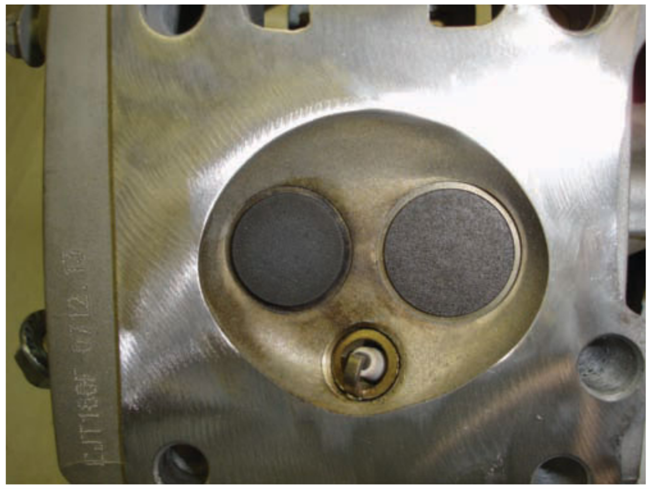


Figure 12-22 Power equipment engines are generally of the 2-valve design, which includes one intake valve and one exhaust valve.

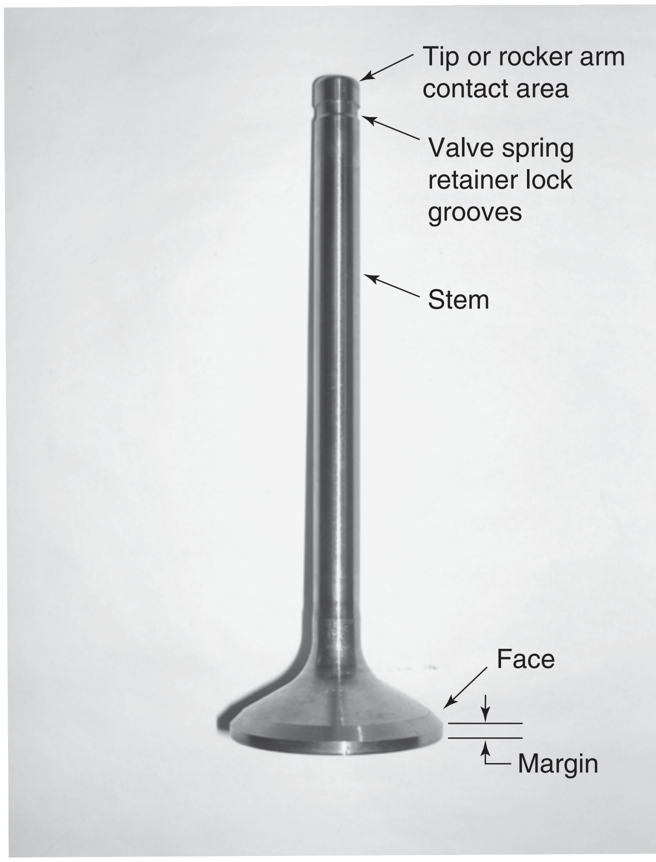


Figure 12-23 The five critical areas to look at on a valve.

There are five critical areas of the typical four-stroke engine valve. The valve areas you'll need to pay close attention to are shown in Figure 12-23.

Valves must operate under a variety of extreme conditions. As a result, certain areas of the valve assembly often show signs of wear or physical damage. Because they're located in the combustion chamber, valves can be exposed to temperatures of well over 1,000° Fahrenheit (F) under normal operating conditions. Heat tends to wear away the exposed surfaces, particularly the valve face. Heat, however, isn't the only problem valves face. Friction between the valve stems and the valve guides produces wear. Keep in mind that each valve must open and close for every power stroke in a four-stroke engine. Because many power equipment engines operate at speeds of 5,000 rpm or more, valves must open and close over 2,500 times per minute. When a valve opens and closes this fast, friction builds up between the valve stem and the valve guide. This eventually leads to wear in the stem, the guide, or both. The rapid movement of the valve also tends to hammer on the valve seat. This hammering action distorts the valve face and the cylinder head valve seat, eventually allowing combustion gases to leak past the valve, even when the valve is closed. For these reasons, all components of the valve assembly must be thoroughly inspected and sometimes replaced or reconditioned as part of any top end engine inspection or rebuild.

Valve Inspection

Before a thorough visual inspection can be performed, the valves must be removed and cleaned. Although many valve springs can be removed without special tools, some require the use of a valve spring compressor to compress the valve spring to allow you to remove the valve spring holding device (Figure 12-24). Be sure to wear safety glasses whenever working on an engine.

Anything that comes in contact with a valve (such as oil, gas, or carbon) tends to get baked onto the valve surface. This can sometimes build up to create large carbon deposits on the valves (Figure 12-25). Ordinary cleaning solvents may not have the ability to remove all the carbon on the valves. In most cases, the best way to clean a valve is to use a wire wheel brush. This ensures the removal of all buildup to allow for a good inspection. An ordinary handheld wire brush could be used, but a wire brush on a bench grinder will make the job much easier. After you've cleaned the valves with the wire brush, wash them in cleaning solvent to remove any leftover dirt particles.

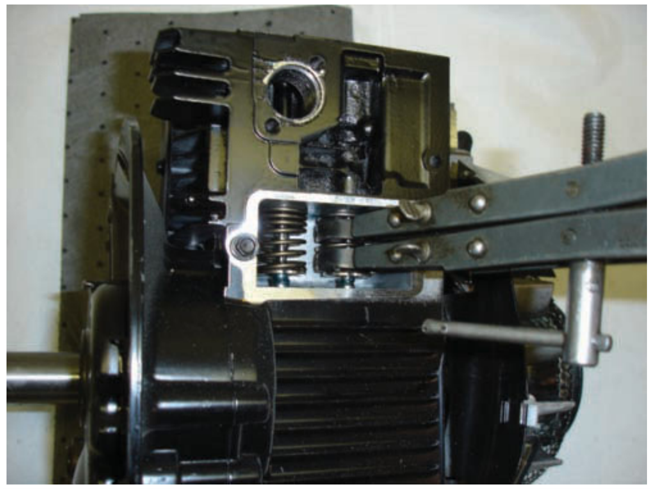


Figure 12-24 Many valve springs are removable without special tools, but some require the use of a valve spring compressor to compress the valve spring to enable valve removal.

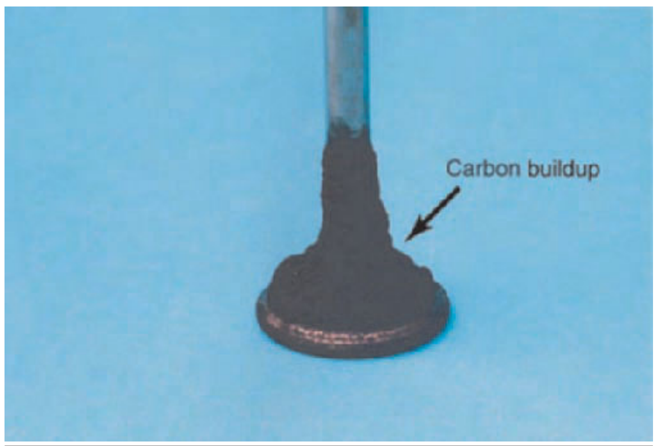


Figure 12-25 A valve with excessive carbon buildup.

Now you can begin the actual visual inspection of the valve. Visually inspect the intake and exhaust valves. This includes inspecting for signs of physical damage and determining if the size of each valve is within specifications. Valves can be damaged because of several conditions. Most often, though, valves are damaged by excessive heat (Figure 12-26).

If a valve becomes overheated to an extreme, its edges can melt or its head can crack. If the damage is severe enough, pieces of the valve can actually break off. Common types of valve damage are shown in Figure 12-27. If you notice any of these types of damage, you must replace the valve.

The valve face makes direct contact with the valve seat. The face generally shows uniform wear around the valve and parallel to the margin. Carbon can build up on the face and cause the valve not to seat correctly.

Inspect the valve margin for signs of distortion (Figure 12-28). The valve margin is the area between the valve's head and the line where the valve face begins. The valve margin is important as it helps the valve withstand the heat in the combustion chamber. If the valve margin is too small, the valve will possibly crack or burn through. It's usually measured using a small ruler or a vernier caliper. When you're checking valve margins, always remember to verify the manufacturer's specifications for the power equipment engine on which you're working.

In addition to measuring the valve margin, you should measure the valve stem, which is the part extending down from the valve's head (Figure 12-29). An outside micrometer is used to measure the valve stem's diameter. It's a good idea to measure the valve stem at the top, middle, and bottom. The diameters at all three locations should match the manufacturer's specification.

The valve springs must also be measured for their free length to ensure there's enough seat pressure placed on the valve itself. This measurement is done using a vernier caliper (Figure 12-30).

Figure 12-26 A common cause of burned valves is excessive heat.

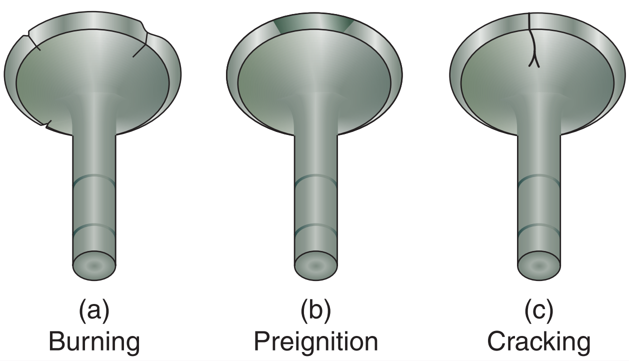


Figure 12-27 Common types of valve wear.

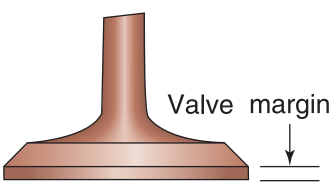


Figure 12-28 The valve margin is a critical part of a valve.

Figure 12-29 A micrometer is used to measure the valve stem. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

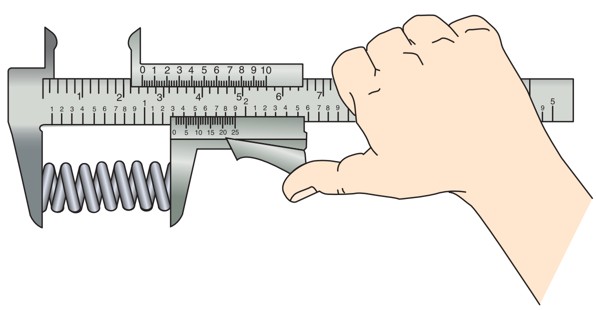


Figure 12-30 A vernier caliper is used to measure a valve spring.

Figure 12-31 The valve spring should be installed with the compressed coils facing the nonmoving part of the engine. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Pay close attention to the valve spring coils. In many cases, they're wound in a progressive fashion, meaning that the coils are closer together at one end than at the other (Figure 12-31). This allows for a lower rate of pressure being required to initiate the opening of the valve while increasing the pressure as the valve is moved to its fully open position. In most cases, valve spring coils are installed such that the ends with coils closer together are on the surface of the cylinder head or engine block.

Refacing Valves

If you inspect valves and find that they're in good condition, they can be reused in the engine. However, all valves will eventually experience wear and distortion from use. However, **valve refacing** isn't common in power equipment engines. This is because exhaust valves and many intake valves in almost all modern power equipment engines have a coating on the valve face that is used to harden them and increase their longevity. This coating is made of an alloy called **stellite**. Stellite alloys have astounding hardness and toughness, and are also resistant to corrosion. Stellite alloys are so hard that they're difficult to machine. Therefore, valves that use it are expensive. Typically, a valve using stellite alloy has only a very thin coating of the alloy on its face and often on its tip. Stellite alloys also tend to have extremely high melting points, because of the cobalt and chromium that make the material useful for exhaust valves in today's high-performance engines. Because of the use of stellite, refacing a valve should be carefully considered. A valve that has the hard stellite

Figure 12-32 Valve-refacing machines are not used often now.

coating ground off will wear considerably faster than simply replacing the valve.

The process of reconditioning the face of the valve is commonly called valve grinding, or refacing. A machine like the one in Figure 12-32 is used for this process.

Most modern engines come with stellite-coated valves and, therefore, shouldn't be refaced. If these valves show excess wear, they should be replaced. The appropriate service manual will inform you if the valve may be refaced. It's generally less expensive to simply replace a valve than to reface it.

Inspecting Valve Guides

Now that valves have been inspected and found acceptable, we can move on to valve guides. These components of the valve assembly are used to position the valves properly in the engine and to guide the valves as they move up and down. The valve guide's job is difficult. Not only must it keep the valve in position but also it must allow the valve to move freely up and down, and dissipate extreme heat (Figure 12-33). The extreme heat around the valve guide makes it difficult for oil to properly lubricate the guide. If insufficient oil is available for lubrication, excessive friction rapidly wears down the guide. If more oil is present than is needed, the excess oil becomes baked onto the valve stem. The baked-on oil can build up and block the valve openings.

Valve guide wear is a phrase that refers to the amount of clearance between the valve stem and the valve guide. Keep in mind that the valve opens and closes thousands of times each minute. This leads to wear in the valve guide. As the valve guide wears, the valve begins to move slightly side-to-side as it opens and

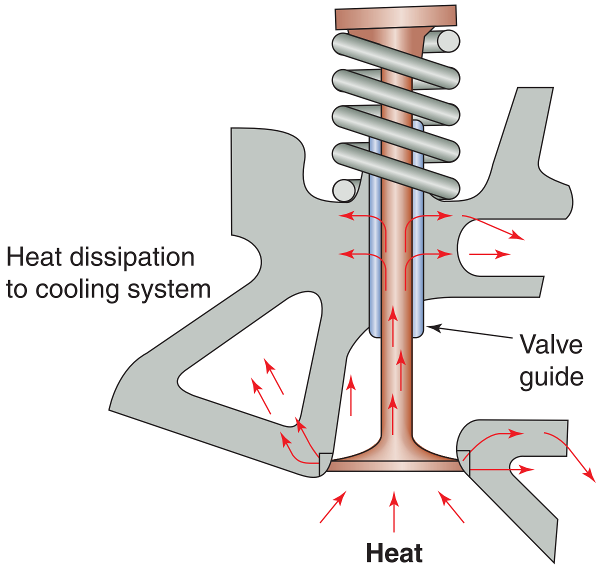


Figure 12-33 The valve guide helps to dissipate heat from the valve.

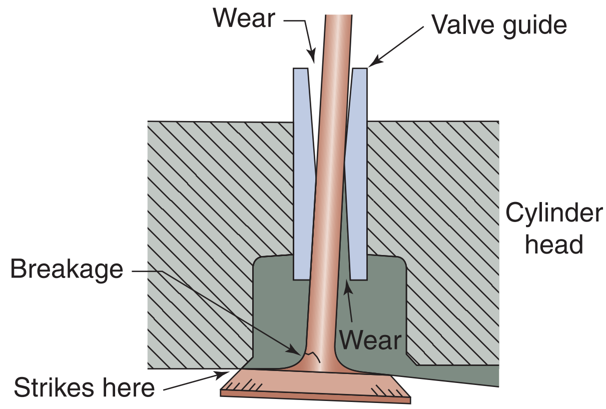


Figure 12-34 An illustration of a worn valve guide.

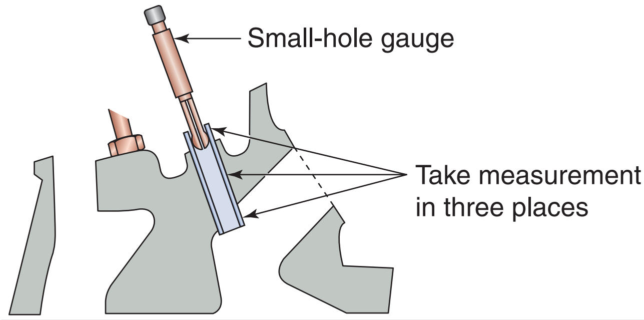


Figure 12-35 Measure the guide inside diameter at three locations using a small-hole gauge.

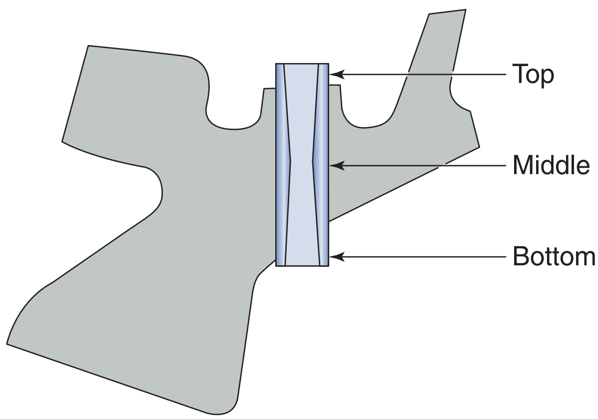


Figure 12-36 Most of the wear on a valve guide occurs at the top and the bottom of the guide.

closes. This side-to-side movement, if excessive, can cause the valve to seat improperly and thus fail to completely seal the cylinder. In extreme cases, the side-to-side movement can break a valve (Figure 12-34). For this reason, the guides must be checked, and they must be replaced if found to be worn beyond the manufacturer's specifications.

Valve guide wear is determined by comparing the inside diameter of the guide with the outside diameter of the valve stem. Because the inside diameter of the guide is quite small, a small-hole gauge is required to measure that dimension (Figure 12-35). As discussed earlier, a typical outside micrometer can be used to measure the valve stem's diameter. The stem diameter is then subtracted from the guide diameter to find the clearance between the stem and guide. Check the guide inside diameter at three locations, top, middle, and bottom of the guide, as the guide will tend to wear more at the top and bottom (Figure 12-36). Finally, the calculated clearance is compared with the manufacturer's specifications given in the service manual.

Replacing Valve Guides

Generally, valve guides are made of soft metals, such as bronze or cast iron, to reduce the amount of friction created by the moving valve stem. Worn valve guides can be removed with a driver and a ball peen hammer and a special driver tool (Figure 12-37). These tools are available from the power equipment engine manufacturer or a specialty tool maker. When driving out the old valve guide, be sure that the cylinder head is supported so that it won't move. A few small blocks of wood under the cylinder head provide proper support. After you've obtained a

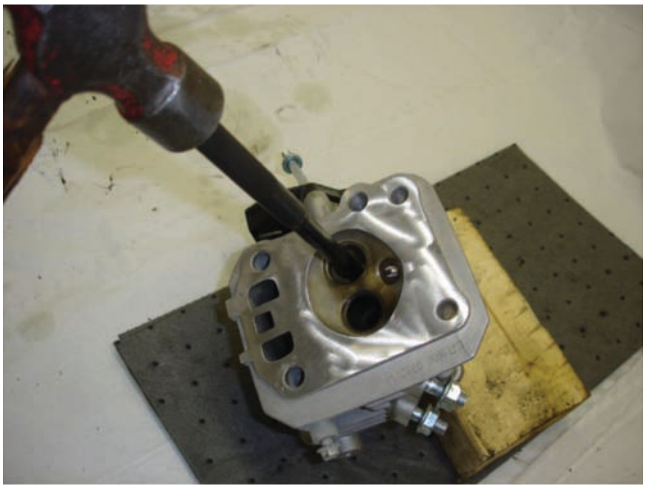


Figure 12-37 Driving the guide out from the combustion chamber side of the cylinder head.

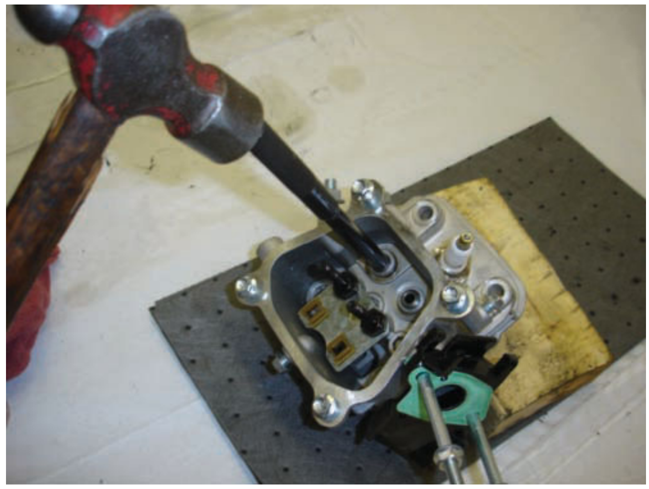


Figure 12-38 Installing a new guide from the valve spring side of the cylinder head.

driver of proper size, place it on the valve guide from the combustion side of the cylinder head. Then, use a ball peen hammer or press to knock or push out the guide.

The new valve guide must fit very tightly in the guide bore. Remember that when metals are chilled, they contract (get smaller), and when heated, they expand (get larger). Therefore, to make the task of inserting the valve guide easier, place the guide in a freezer for about an hour, which causes the valve guide to shrink. Also, you may want to heat the cylinder head on a hot plate to allow the head to expand. When the guide has cooled off and the head has heated up, insert the guide into the cylinder head. A special driver is used, again with a ball peen hammer, to install the new guide into the cylinder head (Figure 12-38), only this time from the top of the cylinder head instead of from the combustion chamber side, as when the guide is removed. Because the cold guide has shrunk and the cylinder head has expanded, the guide should fit into the guide bore relatively easily. Be sure to follow the manufacturer's instructions when installing a new valve guide, as procedures vary from one manufacturer to the other.

After you've replaced the guides, you'll need to ream out the newly inserted valve guide, per specifications. A new guide has a slightly smaller inside diameter than is necessary. After the guide has been installed, its inside diameter must be increased to be slightly more than that of the

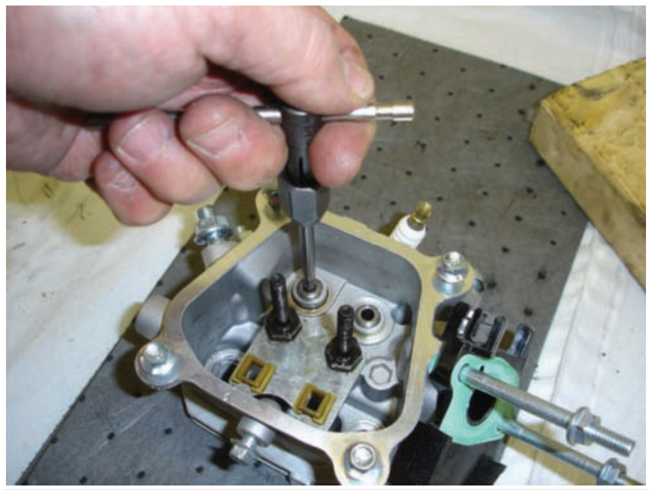


Figure 12-39 Using a valve guide reamer is necessary after installing a new guide.

valve stem. The hole in the guide is enlarged using a **reamer**. A reamer is a long, round cutting tool with cutting edges along its length. The tool operates much like a drill bit. Unlike a drill bit, however, a reamer doesn't cut on its end; it can't be used to actually drill a hole in a piece of metal. The cutting surfaces of a reamer are along its sides. The tool is used to remove material only along the inside surface of an already existing hole.

To ream out a valve guide, the reamer is inserted into the hole and turned clockwise until it has penetrated the entire length of the guide (Figure 12-39). Because of the typical design of the reamer's cutting edges, the tool should always be turned in the clockwise direction (turning it in the opposite direction will dull the edges). Even when you're backing the reamer out of the valve guide, you should continue turning it in the clockwise direction.

The appropriate inside diameter of a valve guide depends on the size of the valve stem. The service manual for the engine specifies the proper diameter. This allows sufficient clearance for the stem to move through the guide as the valve opens and closes. After a valve guide has been reamed, any metal particles remaining should be removed with compressed air. Then the area should be washed clean with solvent. Now that you have replaced the valve guide, you must recut or recondition the valve seats.

Reconditioning Valve Seats

A valve seat is the part of the cylinder head that mates with the valve face. In most cases (especially in OHV engines), a worn valve seat can be reconditioned to get it back into shape (Figure 12-40). The seal formed by the valve seat's precise fit with the valve face prevents leakage from the cylinder when a valve is closed. Due to it's proximity to the combustion chamber, a valve seat, like the valve itself, must be able to withstand high temperatures. A valve seat must also be able to conduct the heat from the closed valve and dissipate it to the engine's cooling system. If a valve seat doesn't help dissipate the valve's heat, the valve would get so hot it could actually begin to melt.

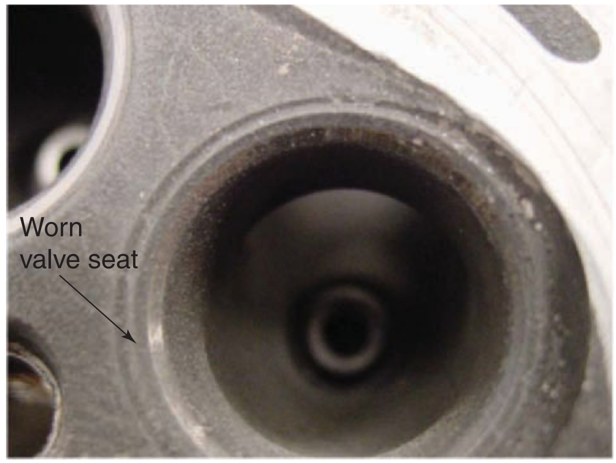


Figure 12-40 A worn valve seat will not seal the combustion chamber properly.

Melting of a valve is often referred to as burning (see Figure 12-26). Most often, the exhaust valves are the valves that burn. Exhaust valves get very hot from passing exhaust gases. An intake valve doesn't get quite as hot because the incoming air–fuel mixture tends to slightly cool it. When a valve closes, the valve face fits closely into the valve seat. As a result, the heat from the valve head is passed onto the valve seat. From there, the heat can be dissipated to the engine's cooling system to the air (in an air-cooled engine) or to the coolant (in a water-cooled engine). The valve seat's ability to dissipate heat is just as important as its ability to provide a proper seal.

In most engines, valve seats are made of a very hard steel alloy. In an aluminum cylinder head, valve seats are usually in the form of inserts pressed into place by the manufacturer. Because of the extreme heat under which the valve seats operate, the seats, like the valves, become distorted and worn out over time. When the valve face or the valve seat becomes distorted, the sealing surfaces no longer match up; therefore, the valve doesn't seal completely when it's closed. For this reason, valve seats normally need to be refinished during the rebuilding process. The refinishing process, called valve seat refacing, restores the valve seat to a perfectly round shape with a smooth sealing surface. Also, the valve seat is beveled to match the angle of the valve face. By refinishing the valve seat, you ensure that the valve forms a proper seal when closed.

Generally, valve seats are refinished using cutting tools of the type shown in Figure 12-41. The appropriate angle for a valve seat is found in the service manual for the engine. The equipment for valve seat cutting is available generally from specialty tool manufacturers.

The valve seat reconditioning tool uses a pilot to position the cutting device and to ensure that the tool remains centered properly. The pilot is simply a round piece of metal that fits tightly into the valve guide. The cutting device has a hole in its center that fits over the end of

Figure 12-41 A typical valve seat cutting tool with its various components.

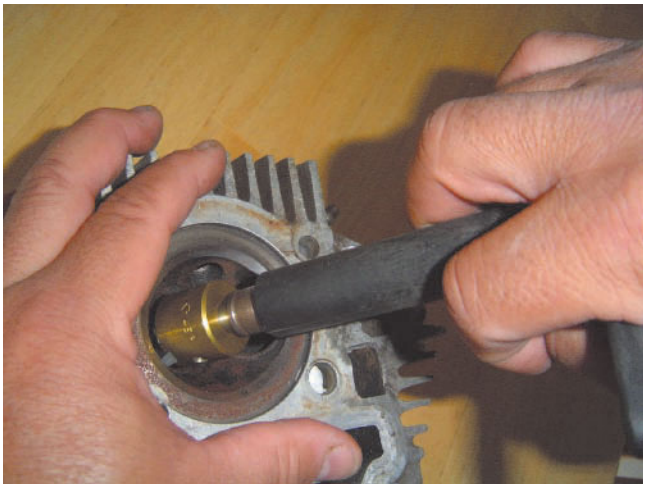


Figure 12-42 A valve seat cutting tool in use.

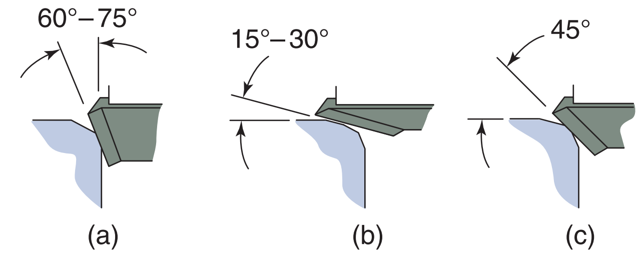


Figure 12-43 Typically, three cuts are made to a valve seat: (a) 60°–75° for below the seat, (b) 15°–30° for above the seat, and (c) 45° for the valve seat itself. The angle of the valve seat cut is predetermined by the engine manufacturer.

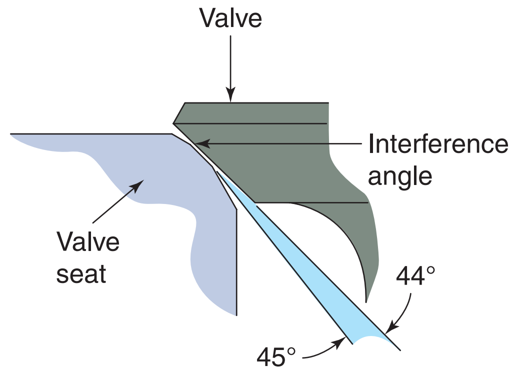


Figure 12-44 An interference fit is made when reconditioning valve seats to allow for better sealing of the valve and valve seat.

the pilot. The pilot can thus hold the tool centered in the valve guide. Because a pilot must be inserted into the valve guide to refinish the seat, the valve guide must be in proper condition before the seat is refinished.

After the pilot has been inserted into the valve guide, the cutting device is placed gently over the pilot and in contact with the valve seat (Figure 12-42). Note that any sudden impact can damage the edges of the cutter inserts. The cutting tool is then rotated. The rotation of the tool removes metal from the valve seat and refinishes its surface.

There are generally three cuts made when reconditioning a valve seat (Figure 12-43). Many consider the angle of the first cut to be a matter of personal preference. The first cut cleans and reconditions actual valve seat area and this cut is generally at an angle of 45°. The second and third cuts are for the area below the valve seat (generally at an angle of 60°–75°) and for the area above (generally at angle of 15°–30°). Some machinists prefer to cut the 45°-angle cut last, instead of first. You should note that the angle of the valve seat is usually about 1° different than that of the valve. This causes an interference, which allows for correct mating of the surfaces once the engine is reassembled and started (Figure 12-44).

Thereafter, metal is removed from the valve seat until a smooth, uniform surface appears. At first, the tool may cut in only a few spots because of the distortion of the valve seat, but as the tool continues rotating, metal continues to be removed until the tool cuts evenly at all points all the way around the valve seat.

Figure 12-45 shows a finished valve seat. Note the different angles at the three different locations in the figure. The middle bevel (45°) is the actual seat that makes contact with the valve face. The width of the valve seat must now be measured and checked against specifications. A seat width scale (Figure 12-46), machinist's ruler, or a vernier caliper can be used to measure this dimension. Making the seat too narrow prevents the valve from sealing properly. Check the manufacturer's service manual for exact specifications.

Figure 12-47 shows the ways in which a valve seat can be cut incorrectly. After cutting the seat and measuring its width, you may find that the valve seat is too wide, too narrow, too high, or too low. The width can be decreased by partially recutting the seat with either the top cutter or the bottom cutter.

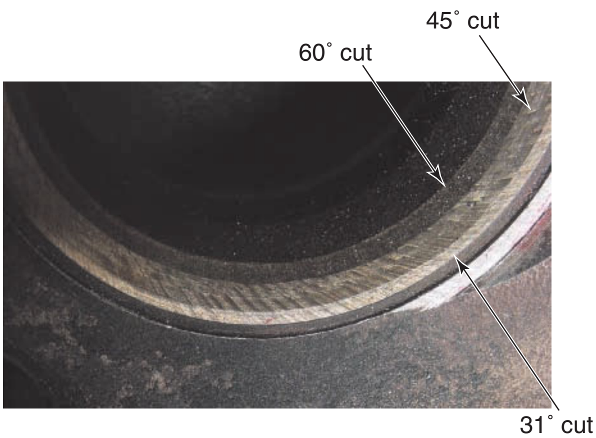


Figure 12-45 The three cuts made to the valve seat.

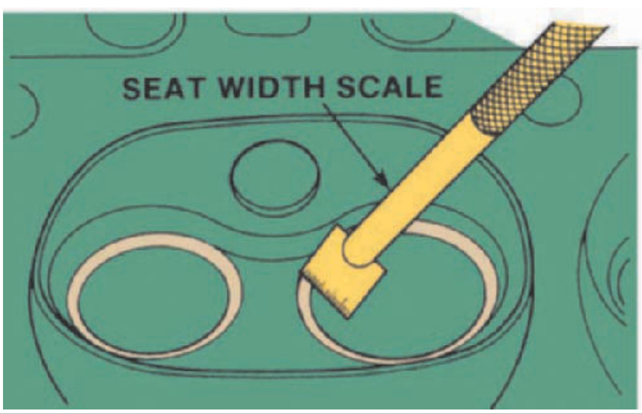


Figure 12-46 A seat width scale.

So, how do we know if we should cut material off the top or bottom of the seat? You can decide on the basis of where the valve face makes contact with its seat, as the seat should be centered on the valve face (Figure 12-48). At the same time, you can check on whether the valve face makes contact all the way around its seat. It's important that you finish the job with a proper and complete seal between the face and the seat.

To decide which end of the seat's width you should cut, you can use a technique that involves the application of a blue dye called **Prussian blue**. This is a special blue dye that can be purchased from most automotive supply stores. First, remove the cutting tool and pilot from the valve guide. Then, place a coating of the blue dye on the valve face using a small brush or cotton swab. Insert the valve into the guide and press it in until it firmly contacts the valve seat. When the face is in contact, apply slight pressure and rotate the valve to a one-quarter turn in the seat. Then, remove the valve and look carefully at the valve face. The dye mark left on the valve seat indicates exactly where the valve face contacts the seat. It should be noted that Prussian blue can be messy! Always keep a rag nearby for cleanup; just a little goes a long way.

If the contact area appears to be closer to the bottom of the valve seat, you should narrow the seat from the top, thus helping to center the contact area. Likewise, if the contact area is closer to the top of the valve seat, you can center the contact area by narrowing the seat from the bottom.

Figure 12-47 Incorrect cuts to the valve seat can cause the valve not to seat correctly, as illustrated here.

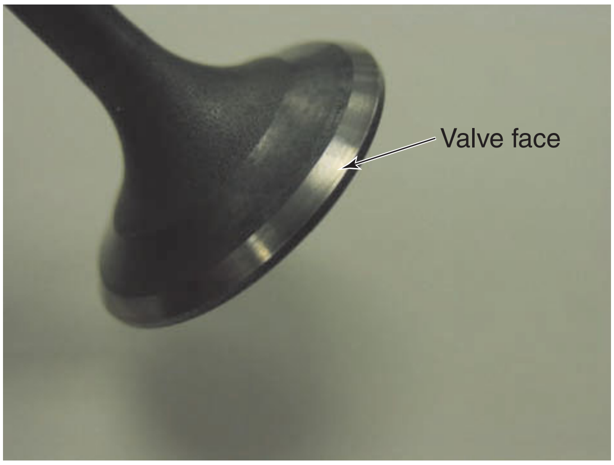


Figure 12-48 The valve seat should be centered with the face of the valve.

Valve Lapping

Valve lapping is the process of mating the valve and the valve seat together to ensure a complete fit between the valve and the valve seat. Valve lapping produces the closest possible fit between the valve face and the valve seat. As a general rule, valves should be lapped to the seats any time the valves have been removed from the engine, even if they appear to be in good shape and you don't plan on reconditioning the seats. Most manufacturers recommend that brand-new valves should be lapped before installing them into an engine to ensure a perfect seal.

Valves are lapped using a grinding paste or a lapping compound, a substance that feels a lot like ordinary toothpaste, but contains fine, abrasive grains. When the compound is rubbed onto metal, the abrasive grains smooth the metal's surface. The paste is used with all four-stroke engines. Lapping compound is a common product that can usually be purchased from a local automotive parts store. The compound is available in versions with grains of varying abrasives. Usually, a fine-grain compound is used in power equipment engines.

To begin lapping the valves, apply a thin coating of lapping compound to the face of a valve. When you've covered the contact area, insert the valve into the valve guide and push it down until it makes contact with the valve seat. When installed, each valve rotates within its own seat. Remember that the abrasive lapping compound is between the valve face and the valve seat. Therefore, when the valve is rotated, the abrasives in the compound wear away the surfaces slightly, thereby mating them to one another.

A valve-lapping stick is a tool sometimes used to rotate the valves. The lapping stick consists simply of a round wooden or plastic shaft with a suction cup on the end. The suction cup is attached to the head of the valve. To help the suction cup stick better, many technicians moisten the cup slightly before attaching it. After you've attached the lapping stick, you can rotate the valve back and forth by spinning the shaft of the tool between the palms of your hands. While rolling the shaft back and forth, apply a moderate downward pressure. This helps the lapping compound to mate the valve and the seat together. Many power equipment engines use valves that are too small in diameter to use a lapping stick. In these cases, install a small piece of rubber hose over the valve stem on the valve spring side of the engine. Then rub the hose between the palms your hands like with the lapping stick while gently lifting the valve into the cylinder head (Figure 12-49).

To check the valve seating, remove the valve from the engine and clean away the lapping compound using solvent and a clean cloth. When the valve is clean, apply a thin coat of Prussian blue dye to the valve face. Then, insert the valve back into the valve guide. Apply a slight downward pressure with your thumb, and rotate the valve

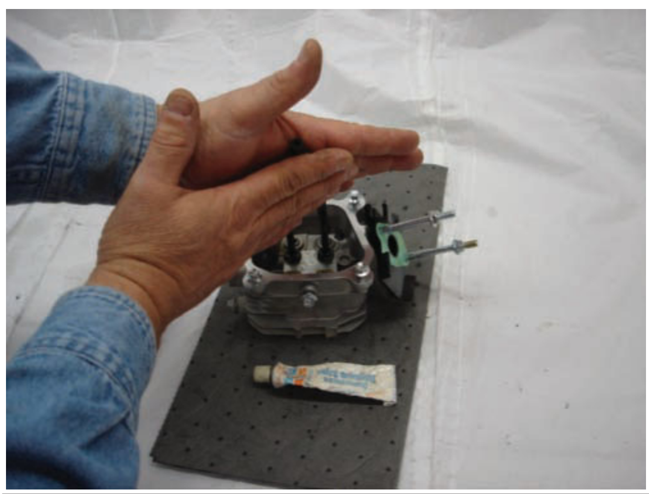


Figure 12-49 Using a small hose on the end of the valve makes for a handy valve lapping tool.

slightly. Remove the valve and observe the valve seat. If the blue dye is evenly distributed around the seat, it means that the valve has been properly lapped. If the dye is distributed unevenly around the seat, more lapping compound should be applied and the valve should be relapped or you should consider reconditioning the valve seat.

After all the valves have been appropriately lapped, the valves and their seats should be thoroughly cleaned with solvent and then with soap and water. This removes any leftover lapping compound. Remember that lapping compound is abrasive; if it's allowed to get into the working engine, it may do serious harm to the bearings and other vital engine parts. You can test the seal of the valves by inserting them and pouring a liquid (like cleaning solvent) into the port to verify if there is leakage past the valve.

Removal and Inspection of Piston and Rings

Before we reassemble the valves of the engine, we'll discuss the removal and inspection of the piston and rings in a four-stroke power equipment engine. To remove the piston, the engine side cover must be removed, as the piston will come out of the top of the engine. To do this, the connecting rod must be separated (Figure 12-50). The piston is removed by taking the piston pin retaining clip out using a pair of

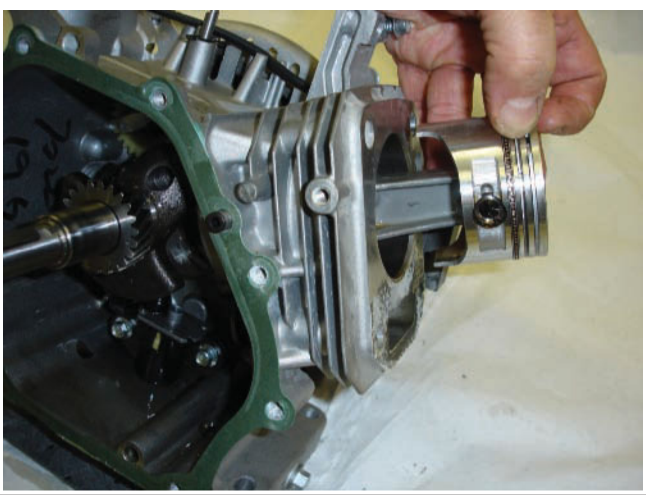


Figure 12-50 In a four-stroke power equipment engine, the piston generally is removed from the top of the cylinder.

Figure 12-51 The piston pin connects the piston to the connecting rod and is held in place by piston pin clips.

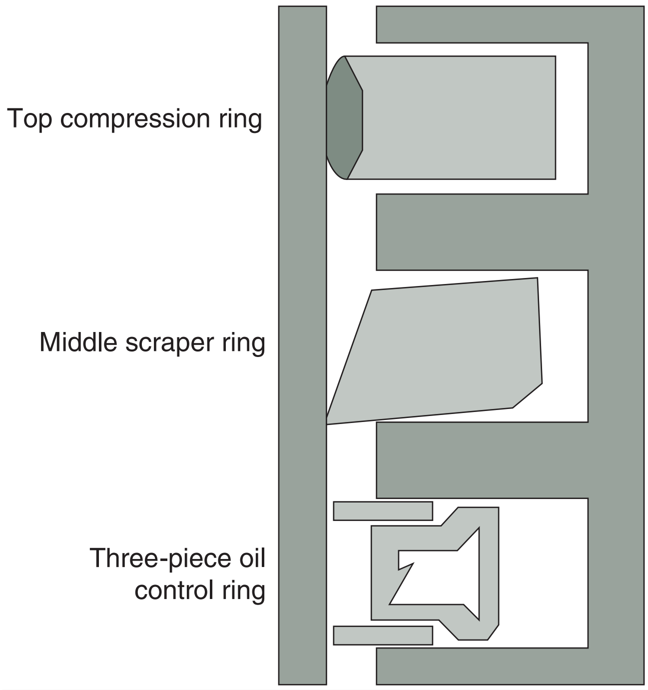


Figure 12-52 The three rings found in a typical four-stroke power equipment engine.

needle nose pliers, and then by sliding the piston pin out of the piston (Figure 12-51).

You'll notice that the typical four-stroke engine generally uses three piston rings (Figure 12-52): an oil ring on the bottom, a scraper ring in the middle, and a compression ring on the top.

Why three rings? The top ring is designed to seal most of the combustion pressure in the top of the piston. The middle ring is used as a compression ring as well but more as a scraper to assist in removing excess oil from the cylinder wall when the piston is moving downward (Figure 12-53).

The bottom ring, also known as the oil control ring (Figure 12-54), is used to remove most of the oil from the cylinder walls through drain slots in the piston as it's moving downward.

The middle and bottom rings are designed to prevent oil from reaching the combustion chamber. If oil does get to the combustion chamber, the engine will smoke when running.

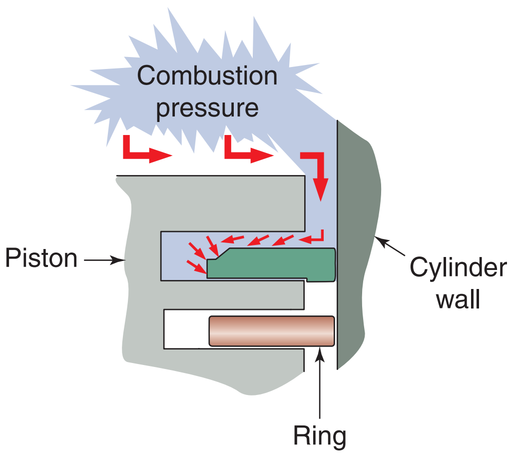


Figure 12-53 The top compression piston ring is used to hold compression gases above the piston, and the scraper ring is used to scrap oil from the cylinder on its way down the cylinder.

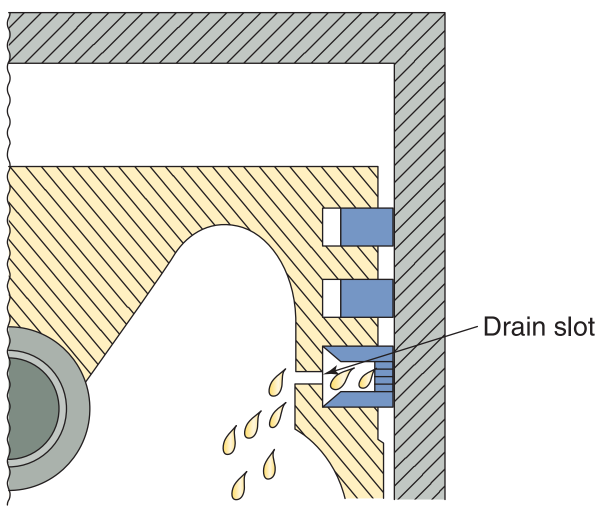


Figure 12-54 The oil control ring allows oil to flow back into the inside of the piston through drain slots.

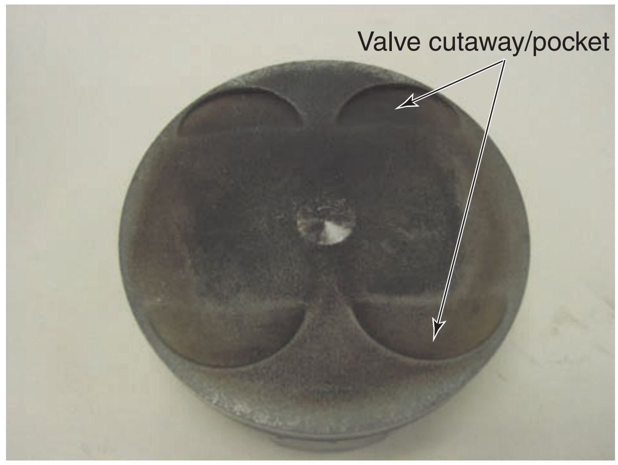


Figure 12-55 Cutaways are used to prevent piston-to-valve contact under normal engine use.

Remember, unlike a two-stroke engine, fuel in the four-stroke engine cylinder is burned without oil; lubrication to the cylinder is supplied by a separate oil supply system.

Some four-stroke engine pistons have cutaways that are provided for valve head clearance (Figure 12-55). These cutaways, or pockets, are designed to allow clearance to prevent the piston from hitting and bending a valve as it opens and closes as the piston goes up and down while the valves are opening and closing.

Piston Inspection

As you'll recall, the piston is the cylinder-shaped component that moves up and down the cylinder bore. The piston assembly consists of the piston itself, its wrist pin (or piston pin), and the piston rings (Figure 12-56). As you're now aware, an engine produces its power by burning the air–fuel mixture in the combustion chamber directly above the piston. Each time the spark plug fires, the air–fuel mixture ignites with tremendous force. The burning process heats the gases, causing them to expand rapidly and forcing the piston down the bore. The piston movement is what allows the engine to perform useful work. During engine operation, the piston has to withstand tremendous force as well as extremely high temperatures. Therefore, as part of the rebuild procedure, you must carefully inspect the entire piston assembly for damage. Be sure

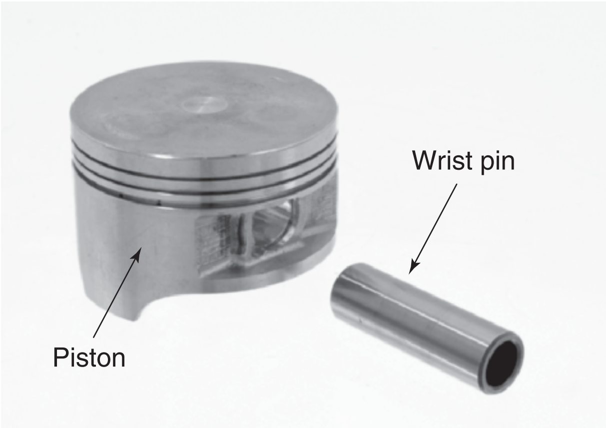


Figure 12-56 The piston pin, also known as the wrist pin, connects the piston to the connecting rod. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

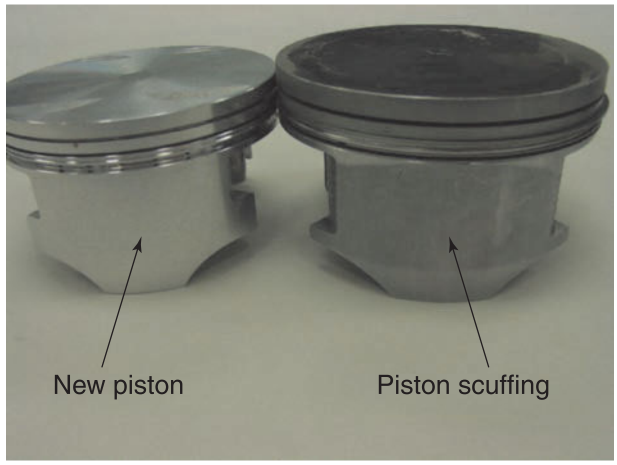


Figure 12-57 The piston on the left is new, whereas the piston on the right has signs of scuffing caused by dirt ingestion through the air-filtering system.

to note any markings on the top of the piston that indicate direction of installation.

Checking the Piston for Damage Start your inspection of the assembly with a visual examination of the piston itself. Check the piston for cracks or any other signs of surface damage. Look closely in the areas of both the piston skirt and the rings; these areas are the most common sites of damage. Look for scuffing or scoring (see Chapter 10) on the piston skirt (Figure 12-57). Scuff markings are wide areas of wear on the piston that usually appear as shiny patches. In most cases, scuffing is caused by inadequate filtering of the air, allowing dirt to be ingested into the cylinder. Score marks are deep, vertical scratches that usually are caused by inadequate lubrication or overheating. Scuffing may or may not be accompanied by score marks.

Scoring and scuffing can be the result of a variety of conditions. In most cases, the marks are created by inadequate filtering (scuffing), excessive friction and heat due to lack of lubrication (scoring), or overloading of the engine. Under certain extreme conditions, the temperature in a cylinder can approach the melting point, or weld point, of aluminum. These very high temperatures can be caused by a problem in the engine's cooling system or excess friction between the cylinder wall and the piston rings. Excessive friction is often due to improper lubrication.

If you find score marks or scuff marks on a piston, try to determine the cause so you can prevent the damage from reoccurring. This is one of the occasions when you can take advantage of the notes and observations you had made earlier in the disassembly process. During the disassembly, you should have checked to determine if the proper amount of oil was present in the engine or if the air filter was clean and installed correctly. As mentioned in Chapter 10, notes and observations made at the time of disassembly can help in the troubleshooting process.

Oil Residue

Engine overheating, in addition to causing scuffing and scoring, usually produces a buildup of oil residue on the piston and the rings. You would know that extreme heat breaks down the viscosity of oil and reduces its lubricating ability. When oil breaks down, it starts to bake onto the engine components, forming a residue that creates oil buildup that after sometime resembles varnish (Figure 12-58). This residue can coat the piston rings and eventually cause the rings to stick firmly to the piston. If this occurs, the rings would no longer be able to seal the combustion chamber properly. Therefore, always check to ensure that the rings are free to move on the piston and that both the piston and rings are free of any buildup. The most common way to clean ring grooves is to break the piston ring and use it to clean out the groove.

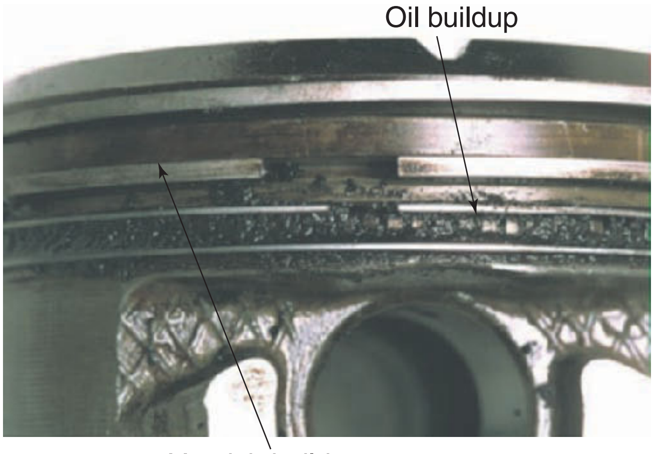


Figure 12-58 Oil buildup on a piston can cause the rings to stick.

Examining the Piston Crown

Although the piston skirt is the most frequent site of wear on a piston, you must also carefully examine the piston crown. If you find any damage, try to determine the exact cause so you can prevent the damage from recurring. Damage to the crown is usually the result of the fuel mixture burning improperly in the cylinder. If the fuel mixture ignites incorrectly, a violent explosion can result. The concentrated heat created in such an explosion can burn a hole right through the piston crown. Also, the explosion itself can be powerful enough to break right through the top of the piston. The following two terms describe different conditions that cause the fuel mixture to burn improperly.

- **Preignition**. When **preignition** occurs, the air–fuel mixture in the combustion chamber ignites before the spark plug actually fires. This may sound strange. How can the mixture ignite before there is spark? The explanation is based on the fact that the burning air–fuel mixture produces a lot of heat. The lingering high temperature in the combustion chamber can cause small carbon deposits to continue to burn, thereby causing the mixture to ignite without a spark (Figure 12-59). Preignition can also be caused by excessive compression of the air–fuel mixture. The carbon that sometimes builds up on the cylinder head and piston crown reduces the overall volume of the combustion chamber. The chamber's reduced volume results in an increase in the compression force exerted on the air–fuel mixture. This causes excess heat buildup.
- **Detonation**. In the engine condition known as **detonation**, the air–fuel mixture fails to burn smoothly. Instead, the mixture begins to burn normally in one area of the combustion chamber and, as the pressure and heat in the combustion chamber increase, it ignites a second time in another area of the combustion chamber (this is also sometimes called "post-spark"). Thus, two separate flames burn at the same time in the chamber (Figure 12-60), even though they were initiated at different times (these events occur within a split second of each other). This should not be confused with the use of two spark plugs in an engine, which would create normal combustion because of the fact that the combustion process was initiated when it was supposed to. When the two flames collide, a shock wave is created. The shock wave of detonation effectively hammers the top of the piston and the piston rings. Eventually, this hammering, or detonating, damages the piston and rings. The key point to understand is that detonation occurs *after* the initiation of normal combustion.

The most common cause of detonation is the use of gasoline with an octane rating that's too low for the engine. The recommended octane rating for the fuel in a particular engine can be found in the owner's manual and in the manufacturer's service manual for that engine. Detonation may also be caused by incorrect ignition timing. If the ignition timing is too far advanced, the spark occurs earlier than it should. In this case, the fuel mixture ignites and starts to burn when the piston is still rising on the compression stroke. This disruption of the normal burning pattern results in detonation.

Piston Ring Inspection

In most cases, piston rings should be replaced when an engine is taken apart. Normally, rings that are reused won't seat in properly, resulting in poor engine performance. You may recall that when new piston rings are installed in an engine, they must wear themselves into position against the cylinder walls to form a tight seal. Once this process of seating-in has occurred, the

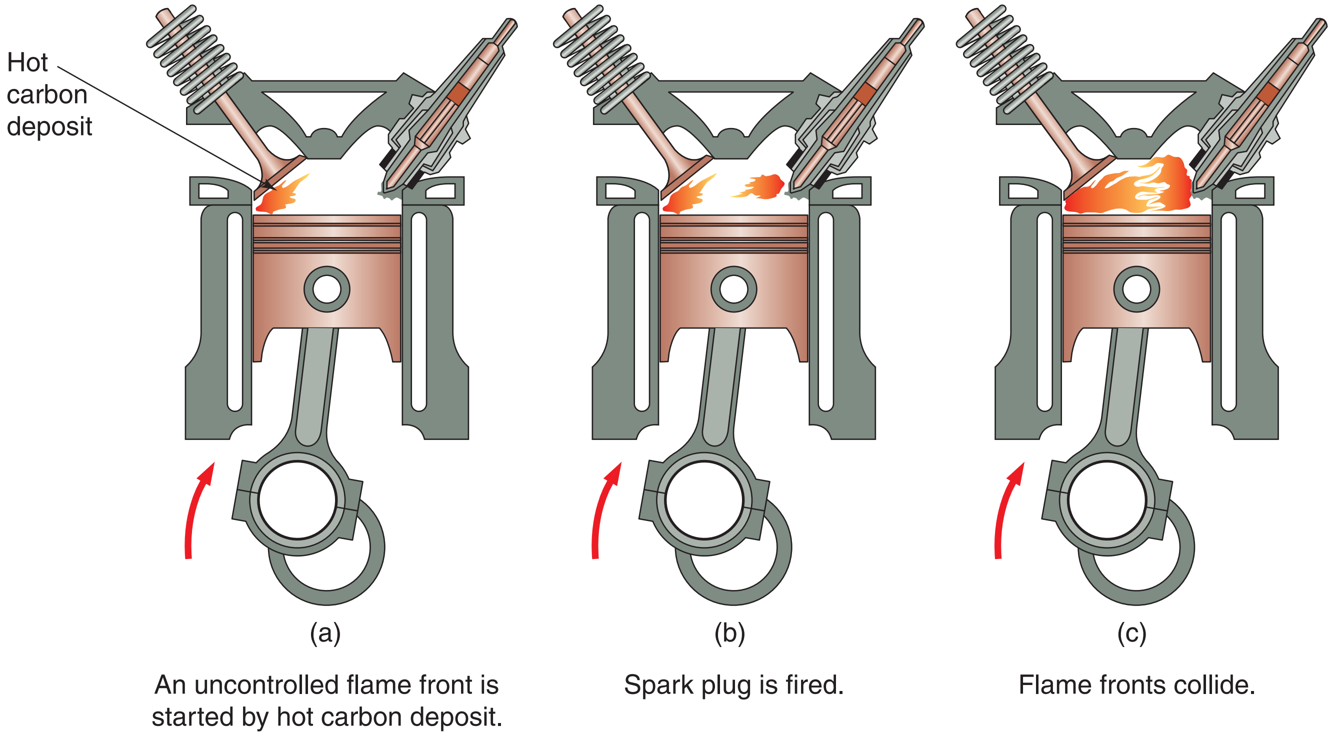


Figure 12-59 The phases of preignition.

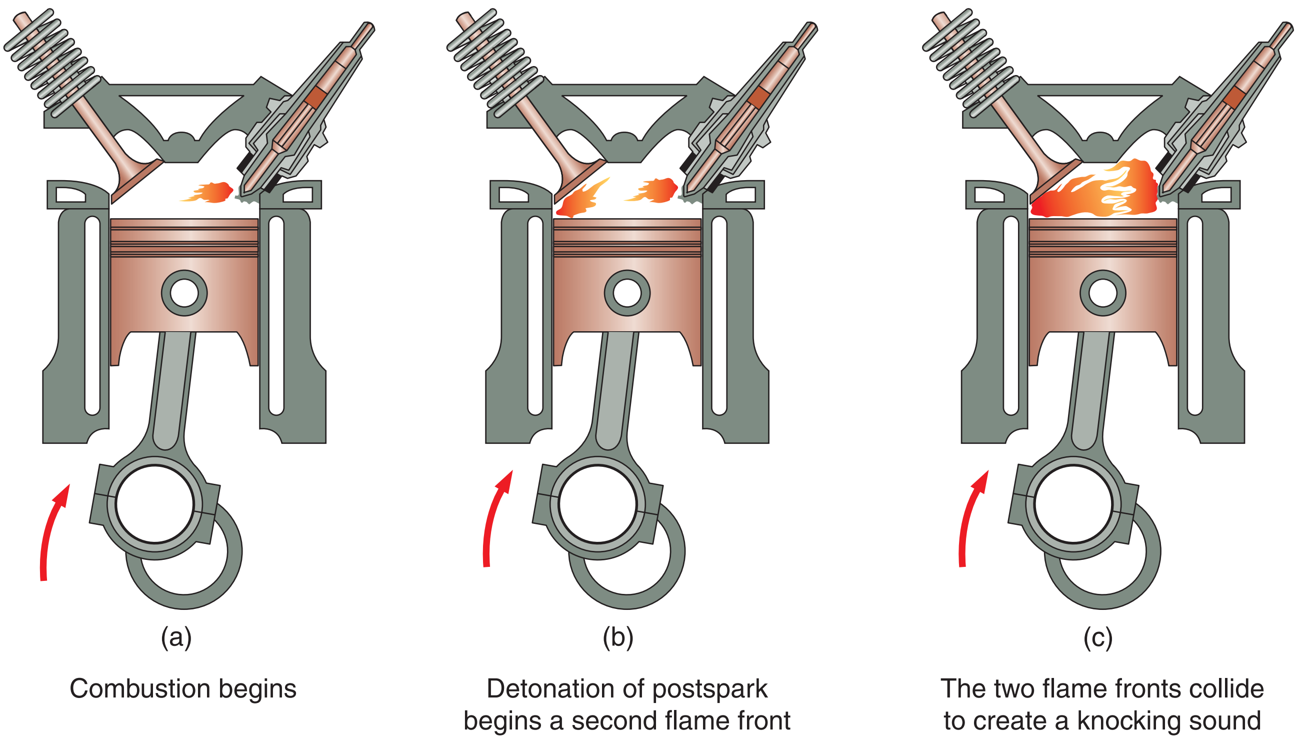


Figure 12-60 The phases of detonation.

rings lose the ability to do so again, that is, if old rings are reinstalled in an engine, they won't be able to conform once again to the cylinder walls and make a tight seal. Without a tight seal, the combustion gases can leak past the rings. This reduces the amount of power the engine can produce. In addition, oil from the crankcase seeps past the rings and into the combustion chamber. The engine thus consumes larger amounts of oil. Oil that enters the combustion chamber burns along with the air–fuel mixture. Any oil burning in the combustion chamber is revealed by excessive exhaust smoke as the engine runs.

Worn piston rings are usually bright and shiny at the point where the edge contacts the cylinder wall. Worn rings can also be detected by performing a compression check and an engine **leak-down test** on the engine *before it's disassembled*. A compression check is a simple test that measures the amount of pressure produced in the combustion chamber in the compression stroke (Figure 12-61a). As discussed in Chapter 10, the compression is measured with a special gauge inserted in the spark plug hole. If the piston rings are worn, the gauge displays a pressure reading that's much lower than the manufacturer's specification. The reading is low because, instead of being compressed, some of the air–fuel mixture is leaking past the worn rings and into the crankcase. To ensure a correct compression reading, be sure to hold the throttle open fully while turning the engine over. This allows the maximum available amount of air into the combustion chamber, which in turn gives the highest possible reading on the compression gauge. Note that some engines have a compression release that will need to be disabled or have a different specification for testing with the compression release attached. Check the manufacturer's service manual for the specifications.

An engine leak-down test (Figure 12-61b) is a more comprehensive engine diagnosis test than a compression test as this type of test allows you to measure the percentage of air that leaks past the piston rings and valves. Engine leak-down testers are available from general tool sources.

The leak-down test provides a clear indication of whether or not the combustion chamber is sealing properly. The test involves pressurizing the combustion chamber and measuring the rate at which the air is lost past the rings and valves (or head gasket).

For instance, if the supply of air pressure is 100 pounds per square inch (psi) and the cylinder is able to maintain a pressure of 90 psi, the cylinder is said to have 10% leakage, based on the supply flow rate. But more important than a determination of whether the engine needs

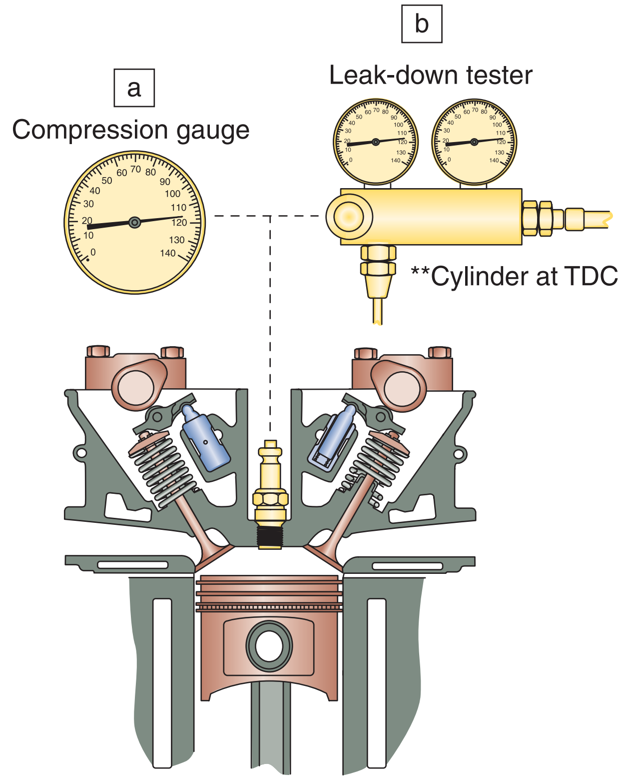


Figure 12-61 (a) A compression test can help diagnose a problem before disassembling a four-stroke engine. (b) An engine leak-down tester gives a better understanding of where the problem is in a four-stroke engine.

repair is to find out more precisely where the problem actually lies. The directions for performing this type of test will be provided by the tool manufacturer.

Once installed, simply listen to the air-filter, exhaust pipe end, and crankcase filler cap to determine if the intake valve(s), exhaust valve(s), or piston rings are leaking.

Squirting a little soapy water around the cylinder and head mating area will tell you if the head gasket is leaking to the outside atmosphere.

Measuring the Piston Rings

Although replacing the piston rings after an engine has been taken apart is good practice, you may wish to measure the piston rings that are already in the engine that you're disassembling. Before you can measure the rings, you must take them off the piston. To remove a ring, spread the ring open so you can slide it out of its ring groove and off the piston (Figure 12-62).

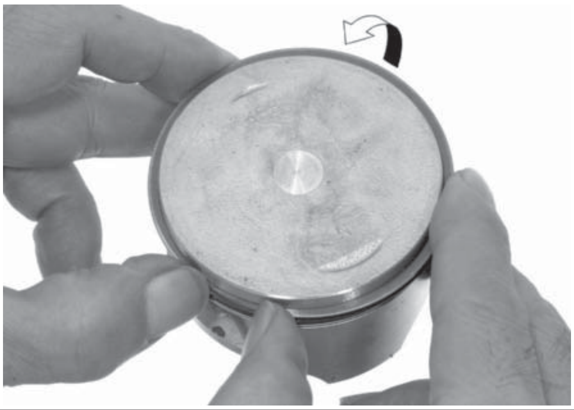


Figure 12-62 A technician properly removing a piston ring. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

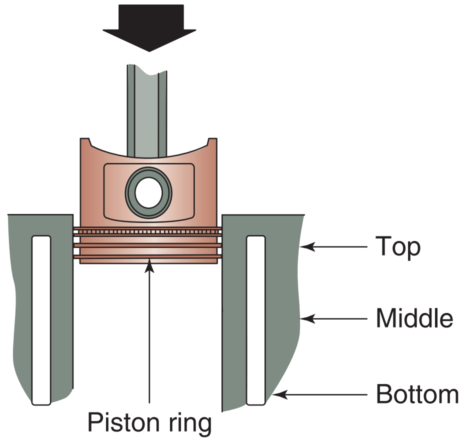


Figure 12-63 Use the piston to place the rings correctly into the cylinder prior to measuring the ring end gap.

Piston rings are measured by fitting them into the cylinder and then checking the end gap with a feeler gauge. This is done by inserting a piston ring into the cylinder squarely, using the piston as a guide (Figure 12-63). After the piston ring is inserted, you can then check for the end gap (Figure 12-64) using a feeler gauge. Each piston ring should be measured at the top, middle, and bottom positions of the cylinder. If the readings are different, it's an indication of cylinder taper or out-of-round. The specification for the proper ring end gap is given in the appropriate service manual.

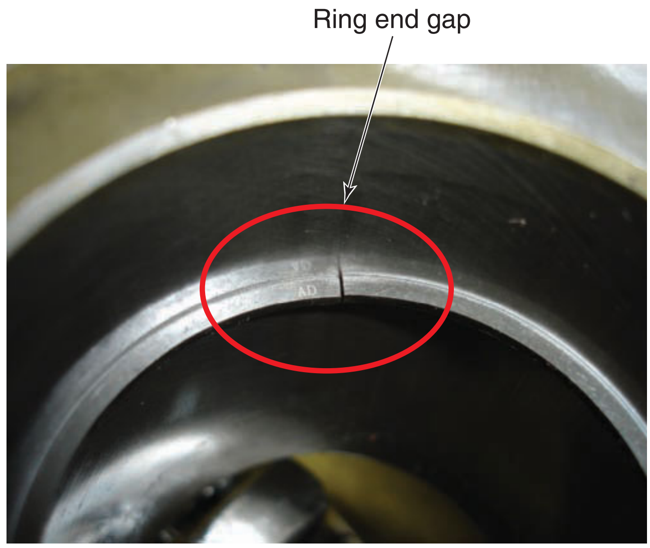


Figure 12-64 A close-up of piston ring end gap, which is measured with a feeler gauge.

Inspecting Piston Ring Grooves

The ring grooves, cut into the sides of the piston, hold the piston rings in place. The ring lands are the uncut areas between the ring grooves. The ring grooves are actually slightly wider than the piston rings. As a result, the rings can move slightly, or float, within their grooves. The rings are able to actively conform to the cylinder walls while the engine is operating. As we know, the small space between each piston ring and the bottom side of its groove is called the piston ring side clearance.

The combustion gases forcing themselves onto the piston get down into the ring grooves and leave behind a residue. Therefore, to inspect the ring grooves for excessive wear, you must first clean the grooves thoroughly. When cleaning the grooves, remember that the piston is made of aluminum, a soft metal. Be careful not to dig into the piston and remove any metal, especially along the inner sides of the ring grooves. The most common tool used to clean the piston ring grooves is an old piston ring. Made of a very tough material, old piston rings work well because they fit the ring grooves perfectly and, therefore, won't damage the sides of the grooves. If you use an old ring for this purpose, break it in half to produce a scraper like edge. Then, insert the edge into the groove and scrape the residue out.

After the ring grooves are cleaned, the piston can be wiped off and the side clearance for the piston rings can be checked. As mentioned earlier, this dimension is the clearance between the piston ring and the inner side of the ring groove

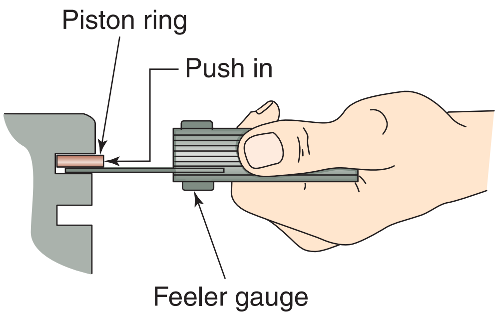


Figure 12-65 Checking piston ring groove clearance with a feeler gauge.

(Figure 12-65). This small amount of clearance performs an important function. During the power stroke, the pressure produced by combustion pushes the piston down the bore. Some of the expanding gases are also forced down the side of the piston and behind the floating piston ring. The resulting pressure behind the pist on ring forces the ring outward, hard against the cylinder wall, thus helping to better seal the combustion chamber. By allowing the ring to seal better, the proper ring side clearance helps the engine produce more power.

Note that because a small clearance should always be present, a ring tips slightly under normal operating conditions. As the piston goes down the cylinder during the intake stroke, the ring tips and scrapes excess oil off the cylinder wall.

During the compression and exhaust strokes, the piston rises and the tipped ring glides over the oil film remaining on the cylinder wall.

During the power stroke, forces pushing down on the ring cause it to sit squarely, providing a better seal and, therefore, better power. Proper clearance between the piston ring groove and the piston ring can be critical. If the clearance is too large, the ring tips excessively as the piston moves up and down, reducing its ability to seal. The excess movement of the ring on the piston may also cause the ring to break. If the clearance is too small, the ring binds in its groove when the piston heats up and expands.

After you've measured the piston ring side clearance, compare your measurement with the manufacturer's specification. Also, because each ring groove may be worn differently, you should check the side clearance in all of the piston's ring grooves.

Measuring the Piston

After the piston and rings have been visually inspected, you can prepare the piston for measurement.

A typical piston appears to have a simple shape, like a can. However, looks can be deceiving. As mentioned previously, pistons are manufactured with a taper, that is, the diameter at the bottom of the piston's skirt is more than the diameter at the piston's crown. This is due to the varying amounts of material and the different rates of expansion of the material with heat. Once up to operating temperature, a piston's diameter becomes uniform from top to bottom.

The appropriate manufacturer's service manual shows where to measure the diameter of the piston. Figure 12-66 provides an example.

The piston must be measured with a micrometer. It's a good idea to keep track of the piston's actual diameter because you can use that measurement when calculating the clearance

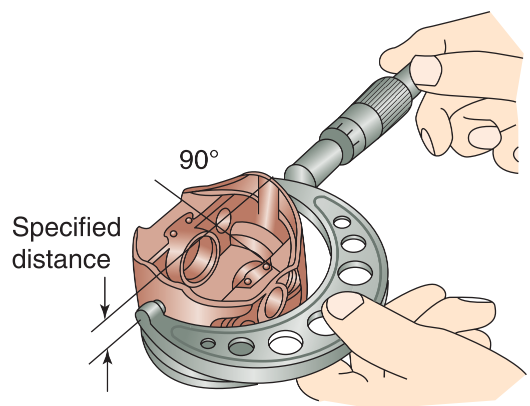


Figure 12-66 Engine manufacturers specify where to take piston measurements. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

between the piston and the cylinder walls. Once you've measured the diameter of the piston, compare your measurement with the appropriate specification or specification range. If the diameter of the piston is outside the specification given by the manufacturer, the piston should be replaced. If the piston is within specifications and shows no signs of damage, you can reinstall it in the engine.

Measuring the Cylinder

Now we'll measure the cylinder to determine the amount of wear that has occurred on the cylinder walls. Movement of the piston and rings within the cylinder contributes to cylinder wear. The areas of wear are the areas in which the rings travel as well as the areas in which the piston skirt contacts the cylinder walls. Cylinder wear is also caused by the piston rocking on the wrist pin, because of the piston tipping slightly during its travel. Piston rocking can create a noise known as piston slap. Under these conditions, the cylinder wears more on the front and back than on the sides. By front and back, we mean at a 90° angle to the wrist pin.

Cylinder measurements are taken from front to back and side to side. These areas are called the *x* and *y* axes of measurement. To measure the cylinder, a cylinder bore gauge (or a telescoping gauge along with an outside micrometer) is used (Figure 12-67).

Insert the cylinder bore gauge at a point near the top of the cylinder and rock it back and forth slightly to find the smallest diameter. Move the dial gauge to "0" and use this as your baseline reading. The gauge is then moved to a point near the center of the cylinder and a reading is taken there as well. Finally, the gauge is positioned at the bottom of the cylinder and another reading is taken. This is done for both the *x* and *y* axes measurements to determine the cylinder's trueness (Figure 12-68). The readings are compared and the difference indicates the amount of wear.

The difference between measurements taken on the same axis (top to bottom) is known as cylinder taper. The difference between the two axes (side to side) is called out-of-round. The taper and out-of-round must not exceed factory specifications for the engine on which you're working. Each model has its own specifications. If the measurements exceed allowable limits, in many cases, the cylinder may be bored or recut to a new size and fitted with a new and larger piston and ring set. Not all cylinders can be bored; check the appropriate service manual to determine if the cylinder is capable of being bored. Boring a cylinder is a job that requires

Figure 12-67 Using a cylinder bore gauge to measure the inside diameter of the cylinder.

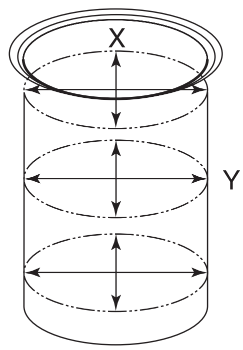


Figure 12-68 Points where a cylinder should be measured to determine wear. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

use of special machine tools and is done generally by a specialist. Boring can be done at most machine shops. Some dealerships do their own boring of cylinders. Cylinder and piston resizing information will be provided in the appropriate manufacturer's service manual.

Measuring Piston-to-Cylinder Clearance

A piston expands as its temperature rises. Because the metal of the piston typically expands more than the metal of the cylinder wall, some clearance must be allowed between these components when both are cold. This clearance is called the piston-to-cylinder clearance, or piston clearance, for short. The proper piston clearance for an engine is given in the appropriate service manual.

If the piston clearance is too small, the piston fits too tightly in the cylinder when the engine heats up, resulting in excessive friction. Friction between the piston and the cylinder can be so great that the piston seizes in the bore. That is, the piston may wedge itself so tightly into the cylinder that it can't move up or down.

You may be able to free a seized piston after the engine cools down again; however, both the piston and the cylinder wall will probably be badly scored and damaged. If the piston clearance is too large, the piston isn't held in place and tends to rock back and forth while the engine is running. This rocking motion can create a knocking noise and may eventually break the piston skirt. In addition, the ability of the piston rings to seal the combustion chamber is greatly reduced.

Determining Piston Clearance To determine the piston clearance in an engine, you'll need to measure the diameter of both the piston and the cylinder bore. Compare your measurements with the manufacturer's specifications. Then, subtract the outside diameter of the piston from the inside diameter of the cylinder bore. The result of your calculation is the actual piston clearance. Finally, compare your calculated clearance with the manufacturer's specification. If the clearance is outside specifications, the piston and cylinder must be resized to make the clearance conform to specification. This method is the most accurate way to measure the piston-to-cylinder clearance.

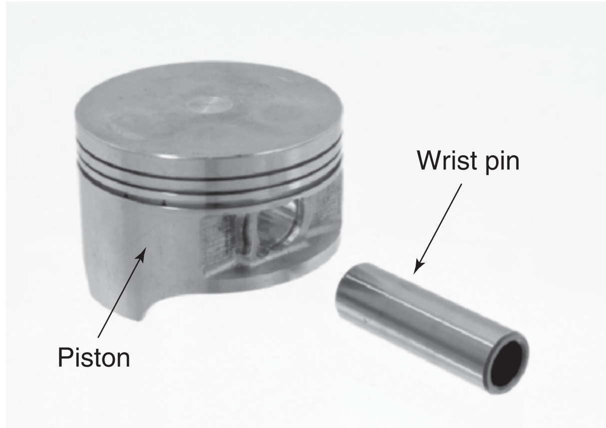


Figure 12-69 The piston wrist pin is used to link the piston to the connecting rod and is also a bearing surface that requires inspection and measurement. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Inspecting the Wrist Pin

The wrist pin is a cylinder-shaped component of the piston assembly (Figure 12-69). It's used to link the connecting rod to the piston. The connecting rod's bearing surface for the wrist pin allows the end of the rod to rotate freely around the pin as the piston travels up and down. The wrist pin must transfer each power stroke's downward physical force from the piston to the connecting rod.

To ensure the wrist pin is strong enough to handle the task, the engine manufacturer makes the pin of very high-quality steel. For this reason, you normally won't see much wear on the pin itself unless there is a lack of lubrication in which case you'll be able to feel and see scoring marks on the pin. To verify that a wrist pin isn't worn, measure the pin's diameter with an outside micrometer and compare your measurement with the specification given in the service manual (Figure 12-70). If there has been a lack of lubrication to the wrist pin, you may need to tap out the pin with a punch and/or apply heat to the piston to expand it. If there is any damage to the piston from lack of lubrication, it should be replaced.

Piston Ring Installation

When installing rings in a four-stroke engine piston, it's important that they be installed with ring markings—if any are placed on the rings—

Figure 12-70 Measuring a piston pin with an outside micrometer. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

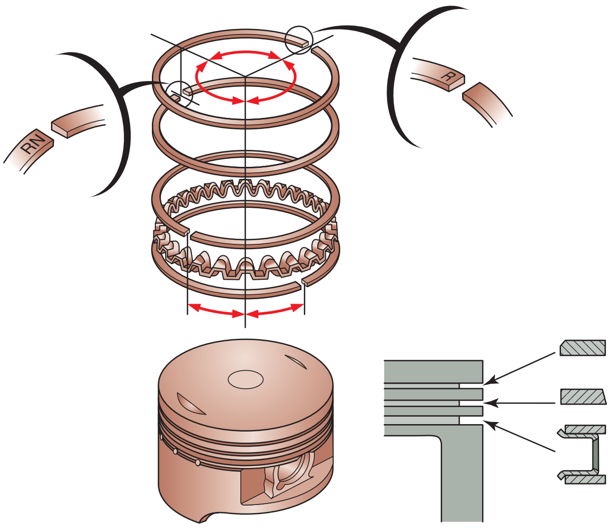


Figure 12-71 Piston ring markings should always face toward the piston crown, and the rings should be placed at angles to one another to prevent compression gas blow-by. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

facing upward (toward the piston crown) and their end gaps set at the manufacturer's recommended angle apart from each other (generally 120°) (Figure 12-71). If not properly angled, compression gas blow-by may occur.

COMMON BOTTOM END ENGINE FAILURES

When discussing the bottom end of the engine, we refer to all components located below the piston (Figure 12-72). In bottom end engine

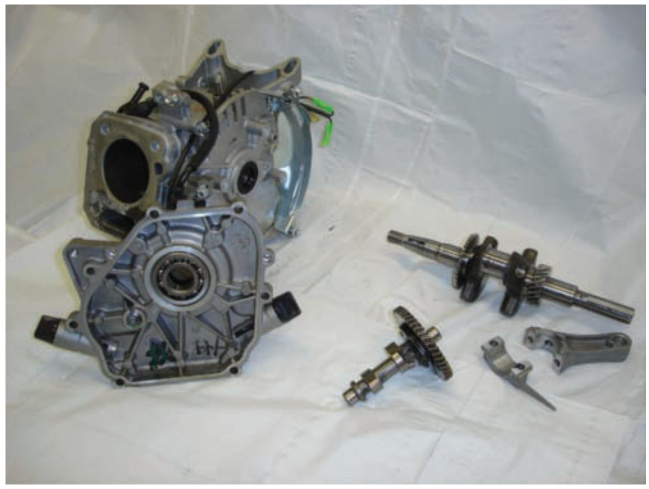


Figure 12-72 The primary components of the bottom end of a typical power equipment four-stroke engine.

assembly, malfunctions occur most commonly with engine seals, crankshaft, and connecting-rod bearings. The following brief descriptions explain these potential problem areas. Being alert to the possibility of problems in one section of an engine while you're performing repairs on another section will help you become a better power equipment engine technician.

Leaking Engine Seals

An engine seal is designed to prevent oil from getting out of a four-stroke engine and leaking between the crankcase and a moving part like the crankshaft (Figure 12-73).

A leaking engine oil seal will cause oil to leak out of the engine. Sometimes, this will be a small spot of oil under the engine while the engine is sitting, and at other times, the seal may not leak unless the engine is running. In most cases, a leaking seal will not require that the engine's lower end be disassembled.

Keep in mind that an oil leak may not always be due to a faulty seal. The cause of the leaking may be due to a cracked case or a bent shaft.

Worn Crankshaft Bearings

Crankshaft bearings are used to connect the crankshaft assembly to the crankcase. They require constant lubrication. Many manufacturers use plain bearing surfaces to support

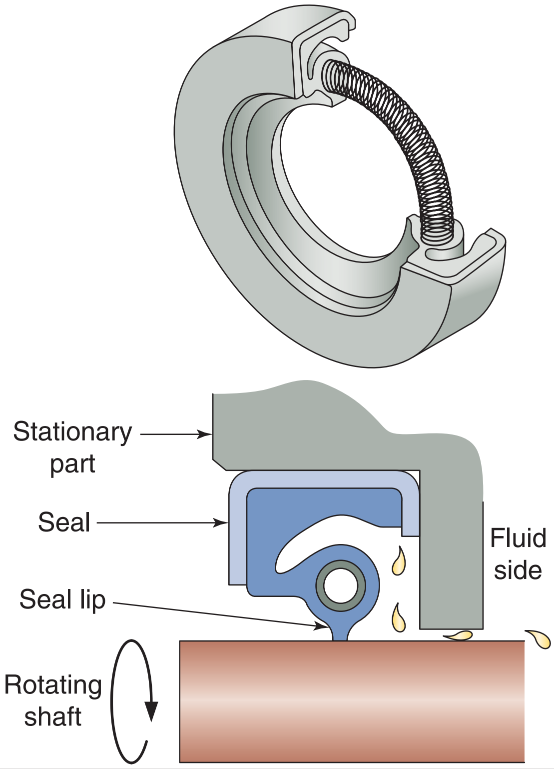


Figure 12-73 Seals are used to keep oil in the engine and wherever rotating parts are found.

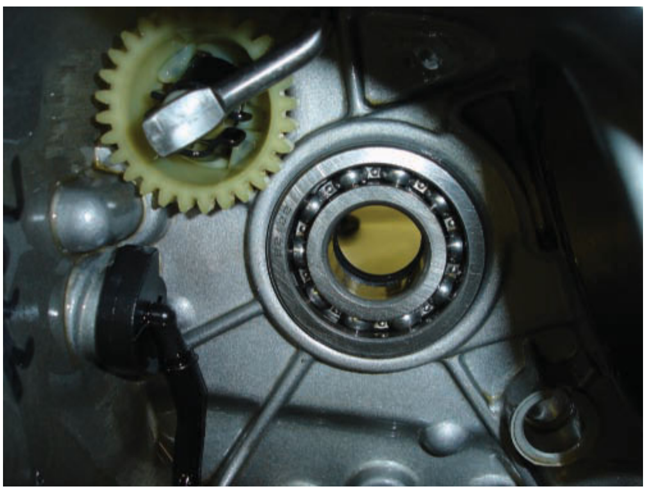


Figure 12-74 Ball bearings are found commonly in power equipment engines.

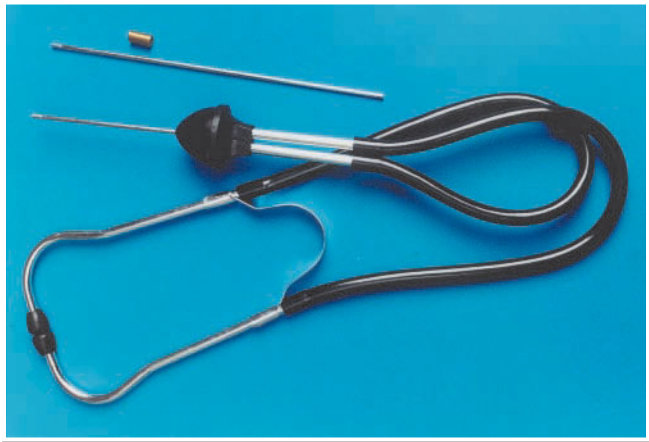


Figure 12-75 You may want to use a mechanic's stethoscope to help pinpoint the location of a bad bearing.

Figure 12-76 The bearing surface on connecting rods found in the typical four-stroke power equipment engine is of the plain bearing design.

the crankshaft. Other than the plain bearing, a ball bearing is the most popular bearing used in the power equipment engine (Figure 12-74). A bearing that is failing usually makes a rough growling sound. You may want to use, as in two-stroke engines, a mechanic's stethoscope (Figure 12-75) to help pinpoint the location of a bad bearing. Bad bearings may cause excessive up-and-down movement of the crankshaft, or worse, prevent the crankshaft from rotating.

Worn Connecting-Rod Bearings

The bearing surface on connecting rods found in the typical four-stroke power equipment engine is of the plain bearing design (Figure 12-76) and allows the connecting rod to pivot freely when the crankshaft turns.

Symptoms of a failed connecting-rod bearing are knocks, vibration, or an engine that can't be turned over (seized up). Any of these symptoms necessitate the disassembly, inspection, and repair of the bottom end of the engine.

FOUR-STROKE ENGINE BOTTOM END INSPECTION

After all the components have been removed from the engine's crankcase, it's time to inspect each one individually to check for damage or wear. Depending on the reason for disassembly, you might think that you should look only for a particular problem while the engine is completely apart. This is far from being correct!

While the engine is disassembled, you should carefully inspect all components. Because complete disassembly of the engine isn't common practice, it's important not only to ensure that the job is done right the first time but also to ensure that no existing problems or soon-to-occur problems are present. We'll begin this discussion by inspecting the components that are attached to the crankcase.

Inspecting the Engine Block/Crankcase

The engine block/crankcase should be closely inspected for cracks, loose-fitting bearings, and worn-out fastener-anchoring points. If there are stripped anchoring points, they may be repaired using a special tool and a process that places inserts into the hole (Figure 12-77), making the stripped fastener point useful again. These tools should be available at your local hardware store or tool supplier.

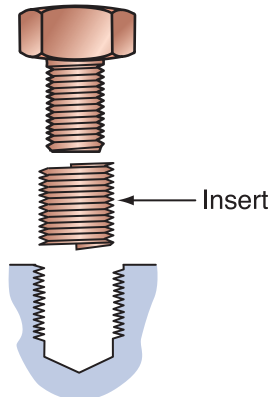


Figure 12-77 A typical fastener insert.

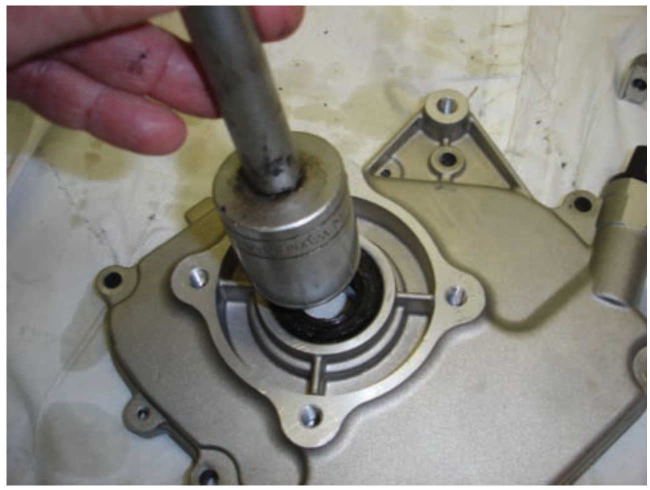


Figure 12-78 When installing seals, use a tool that will not damage the seal, as shown here.

Inspecting Engine Seals

Engine seals are located on shafts that rotate and are exposed to the outside atmosphere in a four-stroke engine. Inspect all seals to verify that they're in good condition. Ensure that they fit on the shafts properly. Inspect the seal lips for tears or rough surfaces. The rubber must be *live*, that is, the lip of the seal must be soft and springy. Most seals have a small coil spring that fits on the outer side of the seal lip. Be sure this spring is in place.

Remove seals by sliding them off the shaft, tapping them out, or prying them out of the crankcase half (Be sure to take caution with the case as damage to the soft aluminum can occur if care isn't taken.). If you remove a seal, you should replace it with a new one. New seals are tapped into place with a mallet or a special seal installation tool (Figure 12-78). Be sure to install the seal into the case properly. Incorrect fitting of a seal will cause oil leaks. Generally, the manufacturer's identification number is on the side away from the bearing to be sealed.

Inspecting Engine Bearings

The two most popular bearings that you'll find inside a four-stroke power equipment engine are the plain bearing and ball bearing. Ball bearings are found generally on the crankcase cover toward the implement side of the engine for extra support of the crankshaft. You can inspect the ball bearing race by hand while it's still mounted on a shaft or if it remains in the crankcase half (Figure 12-79). Rotate the inner race by hand and inspect it for any abnormal noise or lack of smooth operation. Visually inspect the races, balls, and rollers. If they show signs of wear, chips, cracks, or damage to the hard bearing surface, you must replace them. The plain bearing surface can be inspected visually for signs of wear and/or scoring from lack of lubrication.

Replace ball bearings if there is any doubt that they're not in good condition. Generally, to replace bearings, first remove the old bearings with the manufacturer's recommended special tools (Figure 12-80), if needed. Be sure to remove any clips that may be holding the bearing in place as you could break the crankcase half if any retaining clips are not removed.

Figure 12-79 A technician inspecting the ball bearing race by hand while it's mounted on the crankcase.

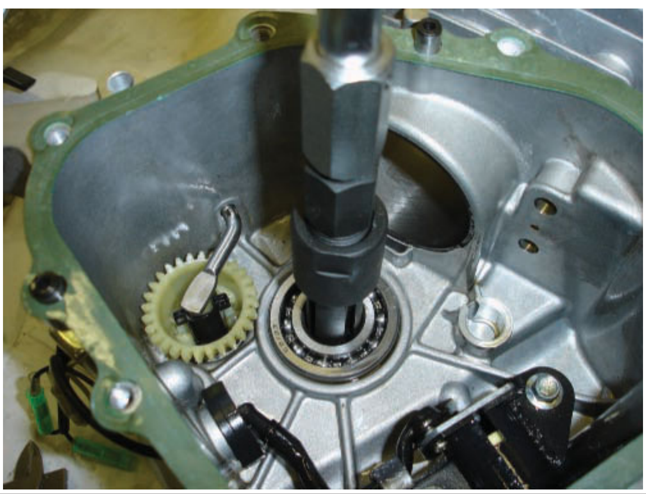


Figure 12-80 Removing a ball bearing using a special tool that fits on the inner race.

Ball bearings are held in the case by a tight fit (or interference fit). Cooling the bearing and heating the crankcase half may be recommended by the manufacturer. Placing cool bearings into a warm case ensures easy installation, as well as a snug fit, when both have returned to normal temperature. This is because the cooled bearings expand as they warm up, and the warmed case shrinks as it cools down. Use the manufacturer's special tools when replacing bearings to ensure that you do not damage the new bearing during installation (Figure 12-81).

Plain bearings are used as main bearing surfaces for crankshafts, camshafts, and two-piece connecting rods and use oil pressure from the running engine for lubrication. Plain bearings used in the crankcase are generally machined surfaces and in most cases can't be repaired or replaced if damaged. On the other hand, multi-piece connecting rods are measured for the amount of oil clearance they have, using a fine plastic string called **Plastigage**. If a bearing has too much clearance, the oil pressure will not be high enough for proper lubrication. If too little clearance is present, the component will not spin freely and could actually seize from excess friction and heat.

Figure 12-81 Using a special bearing-driver tool to install a new ball bearing will ensure that you do not damage the new bearing during installation.

Plastigage comes in long pieces (Figure 12-82) and is available in different colors that have various diameters. Before using Plastigage, you must thoroughly clean and dry the surface to be measured. Place a piece of the Plastigage string on the bearing inside surface (Figure 12-83). Then, install the opposite bearing surface and torque to the factory specification. Take the pieces back apart carefully and measure the amount of oil clearance that the bearing has (Figure 12-84). You should also inspect the plain bearing visually for signs of wear. Be sure not to turn the crankshaft when checking clearances with Plastigage as it will not allow for an accurate reading.

Figure 12-82 Plastigage comes in various colors that relate to different sizes.

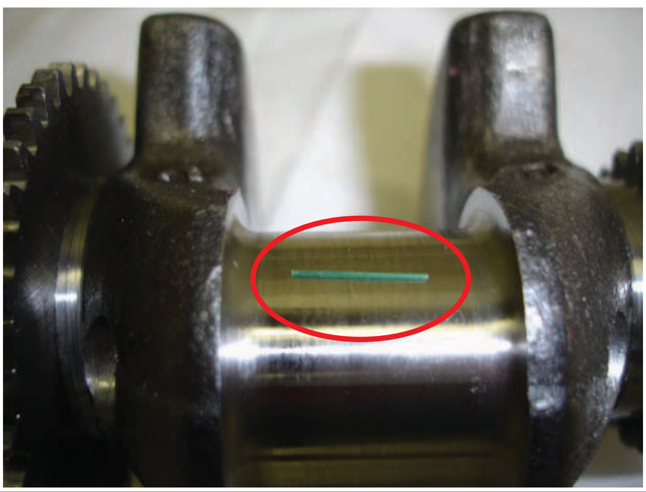


Figure 12-83 A small piece of Plastigage placed on the bearing surface to check the clearance between the connecting rod and crankshaft-bearing surface.

Inspecting the Oil Pump

Although many power equipment engines use the splash method to lubricate engine parts, an oil pump is also used in the many four-stroke power equipment engines. Among such engines, the Trochoid-type oil pump, which is better known as a rotor-type pump, is most popular. The rotor pump consists of a pair of rotors, an inner and an outer rotor (Figure 12-85), and is located in the bottom end of the engine. The inner rotor is shaft driven, whereas the outer rotor is moved by the inner rotor and is free to turn in the housing. The lobes on the rotors squeeze oil through passages in the pump body. As the inner rotor rotates, oil is constantly picked up from the inlet side, transferred, and pumped through the outlet side. Oil pressure is created when the oil is squeezed between the inner and outer rotors. The rotor-type oil pump is capable of creating both high volume and high pressure.

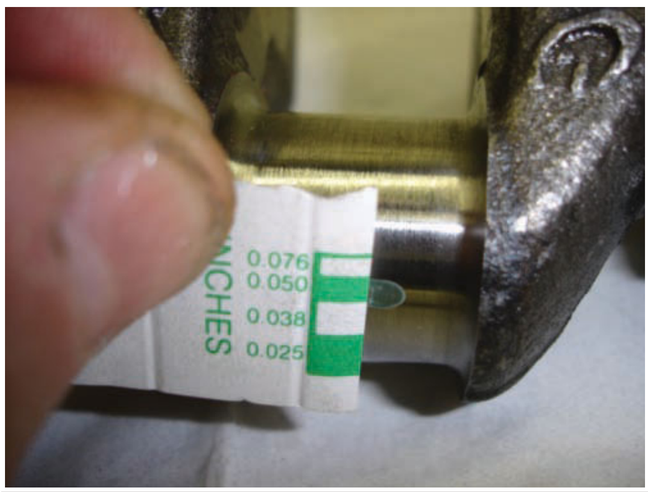


Figure 12-84 Measuring the clearance of the bearing surface.

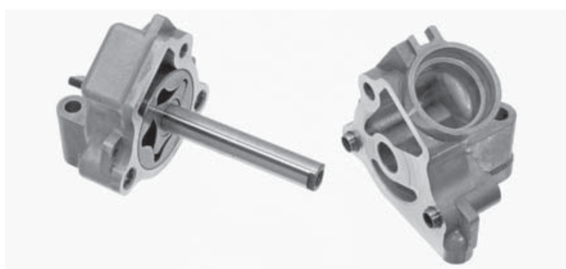


Figure 12-85 A typical rotor-type oil pump. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

To inspect this type of pump, disassemble and clean the parts of the pump and set the inner and outer rotors into the pump body properly. Measure the body clearance and tip clearance using a feeler gauge (Figure 12-86). If all measurements are within the manufacturer's specification, reassemble the oil pump in the reverse order of disassembly.

Inspecting the Crankshaft

A single-piece crankshaft can be inspected and measured after the connecting rod has been removed. One way to ensure that the crankshaft isn't bent is by checking for crankshaft run out (Figure 12-87).

Inspect the crankshaft and connecting-rod journals closely for signs of scoring or roughness. The surfaces must be smooth. You should also measure the bearing surfaces with a micrometer and check your measurements with the factory specification given in the appropriate service manual (Figure 12-88). Crankshafts used in power equipment engines are not generally rebuildable and, therefore, will need to be replaced if the measurements aren't within factory specifications.

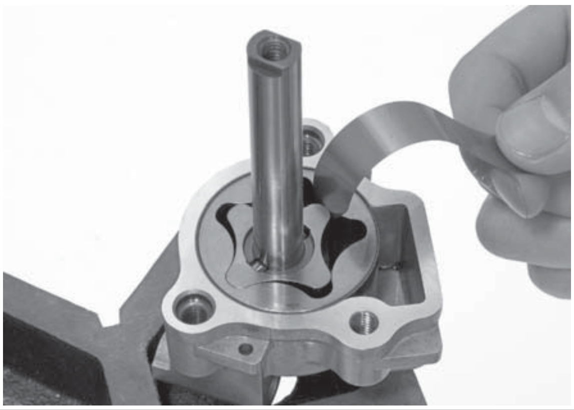


Figure 12-86 Measuring the tips of a rotor-type oil pump. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Inspecting the Camshaft

The camshaft is the component that controls the opening and closing of the valves in a four-stroke engine. There is one camshaft that drives both the intake and exhaust valves in the typical four-stroke power equipment engine. As the camshaft spins, the cam lobes (Figure 12-89) open the valves either directly or indirectly by the use of rocker arms.

When you're rebuilding an engine, the camshaft should be visually inspected for any signs of damage. Specifically, look for any cam lobes that appear to have surface damage. Also, check the camshaft's ends that are supported on a bearing surface, just as the crankshaft. Look for any signs of scoring or other surface damage.

Power equipment engine manufacturers provide a specification for the diameters of each part of the camshaft. Measure those areas using a micrometer and check your measurements against the specifications.

Figure 12-87 Measuring a crankshaft to make sure it's not bent, by checking for run out.

Figure 12-88 Measuring crankshaft-bearing surfaces with a micrometer.

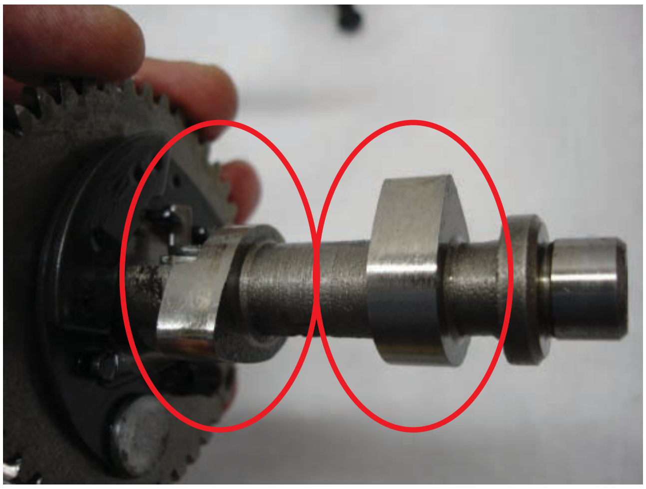


Figure 12-89 Camshaft lobes open and close valves, should be inspected visually, and are measured with a micrometer.

Figure 12-90 Using an assembly lubricant on the bearing surfaces is important to assist with additional lubrication during initial start-up of the engine.

FOUR-STROKE ENGINE REASSEMBLY

Before you begin reassembling any engine, be sure to thoroughly clean every part with a cleaning solvent. When you're prepared to begin the reassembly process, stay organized and keep the engine components separated. This will make you more efficient. Although it's important to use the manufacturer's service manual for any work on a power equipment engine, here are a few common tips to use during the reassembly process of any four-stroke engine.

Installing the Crankshaft and the Oil Pump

Install the crankshaft carefully to ensure that no damage is done to the bearing surfaces. Use engine oil or an assembly lubricant on the bearing surfaces to assist with initial startup of the engine (Figure 12-90). When used, the oil pump will generally bolt into the crankcase.

Installing the Camshaft

You should be aware that all four-stroke engines must be adjusted, or timed, so each rotating part is in the proper position, at the proper time, in relation to other moving engine parts. The timing of the camshaft rotation, in relation to the crankshaft rotation, is vital. This is because the camshaft must open the valves and allow them to close at specific degrees of rotation of the crankshaft. The induction and exhaust of gases must take place at specific times in the engine cycle.

The camshaft used in the power equipment engine industry is located inside the engine crankcase. Its rotation is synchronized with that of the crankshaft to open and close the engine valves precisely in relation to the position of the piston and the crankshaft.

Relation Between Camshaft Rotation and Crankshaft Rotation

The timing for the valves to open is determined by the position of the camshaft. This position is indicated by degrees of crankshaft rotation. You already know that there are 360 degrees in a circle. A quarter of a turn is, therefore, equivalent to 90°, half a turn equivalent to 180°, and a three-quarter turn equivalent to 270°. The valves must open and close at specified degrees of crankshaft rotation. The gear reduction ratio between the crankshaft and the camshaft is always 2:1 in a four-stroke engine. This means that the crankshaft makes two revolutions for each single revolution of a camshaft.

Another way of looking at this relation is that if the crankshaft is rotated 90° (or one-fourth of a complete rotation), the camshaft is rotated 45° (one-eighth of a complete rotation). This relation must remain constant during a complete rotation of the engine or failure will be eminent. If the timing between the crankshaft and camshaft isn't correct, valves will hit onto the piston, causing engine failure.

Timing of the camshaft position in relation to the crankshaft position is done by aligning certain marks. However, there are various ways, and various places, where these marks may appear. One of the principal pieces of information you must have for every four-stroke engine is the exact location of the timing marks. Generally, the marks are located on the crankshaft and the camshaft sprocket (Figure 12-91). These marks might be lines, dots, letters, or a combination of these.

Be sure to check the manufacturer's service manual for the correct cam timing marks and procedures.

Installing the Piston

Install the piston pin through the piston and small end of the connecting rod, making sure the piston's directional arrow is facing in the correct direction. The piston will be installed into the engine from the top of the cylinder with the connecting rod attached (Figure 12-92). This is done by compressing the piston rings and sliding the piston into the cylinder. Some manufacturers use piston ring compressors when installing the piston but most pistons can be installed by hand by carefully compressing the piston rings and sliding the piston into place. Always install new piston pin clips on the piston. Attach the connecting rod to the crankshaft by using the proper torque figures given by the manufacturer (Figure 12-93)

Installing the Crankcase Cover

When installing the crankcase cover for the engine's bottom end, be sure to use new gaskets and properly torque the cover using the engine manufacturer's recommended procedures.

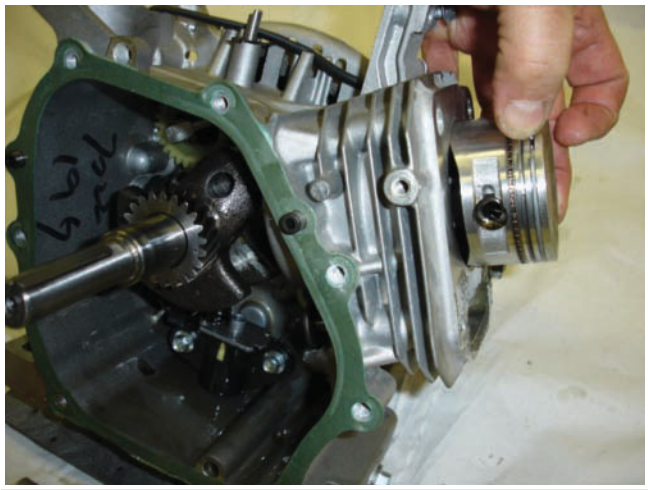


Figure 12-92 Installing the piston through the top of the cylinder.

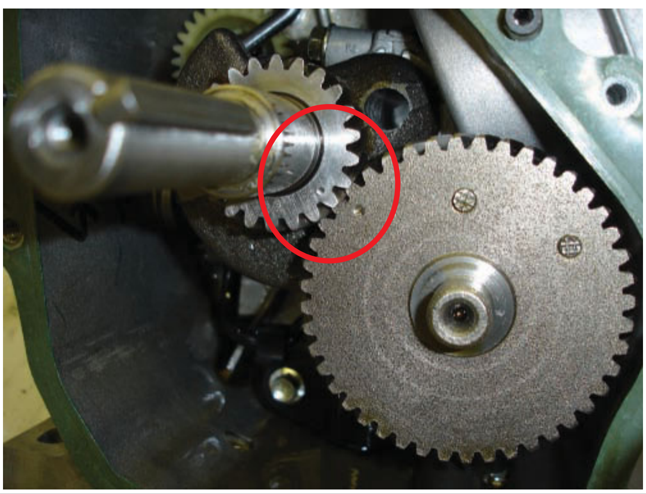


Figure 12-91 The camshaft timing marks are located generally on the crankshaft and the camshaft sprocket.

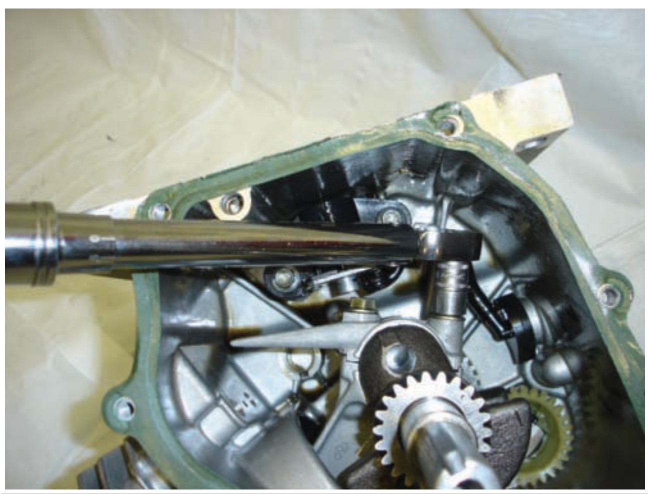


Figure 12-93 Using a torque wrench to tighten the connecting rod to the crankshaft is important.

Installing Valves

Depending on the engine design, the valves may be installed on the cylinder head or on the crankcase/block (Figure 12-94). As mentioned earlier in this chapter, valve springs should be installed so that the narrow pitch of the spring sits on the surface (Figure 12-95) of the engine block or the head (nonmoving surface). Always replace valve stem oil seals when the valves are removed, to prevent any chance of oil–seal-related problems. Good valve springs provide adequate seat pressure to allow a tight fit between the valve face and the valve seat to seal the combustion chamber. Proper valve springs also prevent the valve from bouncing on its return to the seat (especially at high engine speeds) and thus leading to loss of cylinder pressure. Valves are held in place by valve keepers, which should be installed using the manufacturer's instructions.

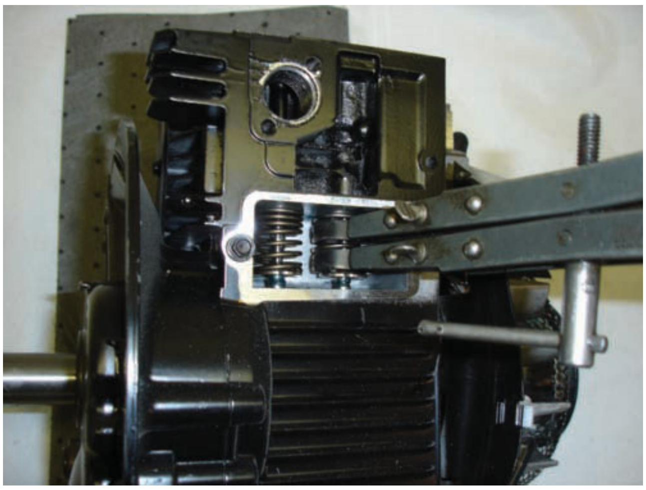


Figure 12-94 Using a special valve spring compressor to assist with spring installation.

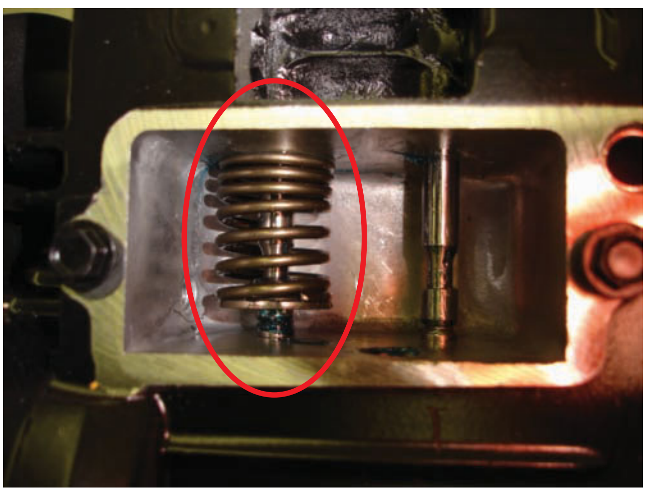


Figure 12-95 The narrow pitch of the spring sits on the nonmoving surface of the engine.

Checking and Adjusting Valve Clearance

It's important to check the clearance between camshaft and valve stem tip during reassembly of the engine. Since the space between the valve and camshaft may have changed by the reconditioning and lapping procedures, the clearances should be measured and compared with the manufacturer's specifications. If valve clearance is incorrect, it will need to be adjusted. There are different adjustment procedures for different power equipment engines. These are discussed in Chapter 16, which covers maintenance procedures.

There are different adjustment methods used for different valve arrangements. Valve clearance is generally checked when the piston is at top-dead center (TDC). At the TDC position in the compression stroke, both the intake and exhaust valves for the cylinder should be completely closed. Generally, valve clearance is greater on the exhaust valve than on the intake valve because the exhaust valve gets hotter, resulting in a higher rate of metal expansion. Valves are adjusted when the engine is at room temperature. Specifications for valve clearance vary with each model of power equipment engine. It should be noted that in some engines, a compression release is used and in these cases, the valve clearance may need to be checked at a different crankshaft position. Be sure to check the appropriate service manual to ensure that you're checking the clearance at the correct spot.

Bench Testing

It's good practice to verify that all components move freely and properly before completing the engine reassembly process. Turn the crankshaft over to make sure it moves freely. Nothing is more frustrating than finding a problem in the crankcase after you've completely reassembled the engine and installed it into the implement.

Engine Break-In

Most manufacturers recommend that a new (or reconditioned) engine be properly broken-in to ensure that all components are sealing and meshing together properly. With the four-stroke power equipment engine, the time needed to properly break-in an engine varies depending on its use.

During the assembly process, it's recommended that you use the best possible materials and original equipment manufactured parts. Even so, it's necessary to allow the parts to break-in before subjecting the engine to constant maximum stress. The future reliability as well as the performance of the engine depends on a proper break-in procedure. The reason for power equipment **engine break-in** is to optimize the compression seal between the combustion chamber and the underside of the piston, which in turn will minimize pressure loss in the cylinder.

The piston ring seal is really what the break-in process is all about. Piston rings do not seal the combustion pressure by spring tension. Ring tension is necessary only to "scrape" the oil as the piston goes back down the bore of the cylinder. A typical piston ring exerts less than 10 pounds (lbs) of spring tension against the cylinder wall. That level of low spring tension can't seal pressures exceeding 1,000 lbs that are created from the combustion chamber gases.

The true sealing of the piston ring to the cylinder wall comes from the actual combustion gas pressure. The gases created by the rapid ignition and burning of the fuel–air mixture in the combustion chamber take the path of least resistance, which means they pass over the top of the ring and get behind the ring to force it outward against the cylinder wall (Figure 12-96).

The problem is that new piston rings are far from a perfect match for the cylinder and must be worn in properly as quickly as possible for the ring to completely seal all the way around the bore of the cylinder. If the gas pressure is strong enough and the piston ring is mated correctly with the cylinder, the entire ring will make contact with the cylinder surface, thus minimizing combustion gas loss and allowing for maximum power in the engine. Many engine builders recommend that a power equipment engine be used as the owner would generally use it, that is, not sustaining high engine rpm for the first 1–2 hours. These numbers are general and it's recommended that you follow the manufacturer's instructions.

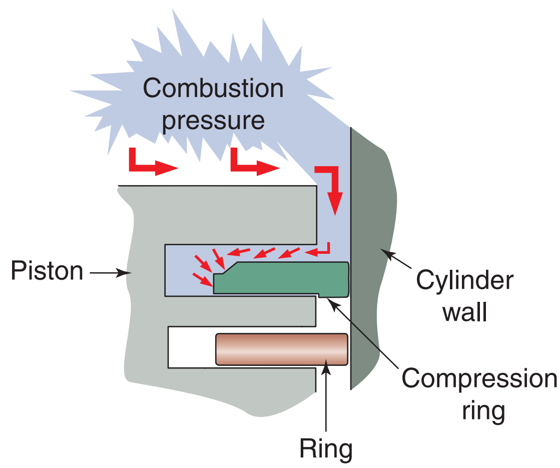


Figure 12-96 Shown is how the gases inside the combustion chamber actually seal the piston ring to the cylinder.

Summary

- Many components in the four-stroke engine require careful inspection and measurement. A visual inspection is critical for successful completion of a four-stroke engine rebuild, as is correct and proper measurement using appropriate tools. As a technician, you must understand the importance of inspecting the various components of the four-stroke engine using the correct and appropriate tools and equipment.
- Although a diagnosis may not be confirmed until the machine is actually disassembled, when there is an engine-related problem, the technician must diagnose the condition.
- The two primary types of power equipment four-stroke engine top ends are the OHV and L-head.
- Common bottom end engine failures in a four-stroke power equipment engine include

leaking engine seals, worn crankshaft bearings, and worn connecting-rod bearings.

- Plastigage is required to ensure the correct measurement of the bearing surfaces of a connecting rod.
- A technician who completes the reassembly process of an engine without bench testing it risks the consequence of the engine not functioning correctly because a component had been installed incorrectly.
- Breaking in a newly rebuilt engine correctly is critical for the longevity of the engine.

Chapter 12 Review Questions

1. Pistons used in most power equipment four-stroke engines have _____ piston rings.
2. The difference between measurements taken on the same axis (*x* or *y*) of a cylinder is called _____.
3. The process used to mate the valve and the valve seat together is called _____.
4. _____ must be installed so the narrow pitch sits on the nonmoving surface of the engine.
5. The _____ valve usually has more clearance between it and the camshaft.
6. Valves are adjusted at room temperature. (True/False)
7. The gear ratio between the crankshaft and the camshaft is _____.
8. Camshafts are timed in relation to the _____.
9. The valve seat is part of the
   a. valve spring.
   b. cylinder head.
   c. piston.
   d. camshaft.
10. The marks on the piston rings should always be installed
    a. facing the piston crown.
    b. facing each other.
    c. facing downward.
    d. facing away from the piston crown.
11. To measure piston ring end gap, you use a _____.
12. The most common cylinder head problem is damage to the _____.
13. Refacing valves that are coated with stellite
    a. is a common practice in the power equipment engine industry.
    b. is not recommended.
    c. is only occasionally needed.
    d. is better than replacing them.

CHAPTER

13 Fundamentals of Electricity

Learning Objectives

- Understand the importance of proper safety procedures when working with electrical systems
- Explain the two basic theories of electricity
- List the types of electrical circuits
- Explain the terms voltage, current, and resistance
- Calculate voltage, current, and resistance using Ohm's law
- Describe how to use a multi-meter to measure voltage, resistance, and current
- Understand the term *schematic* and understand how to read a simple wiring diagram

Key Terms

Block diagram
Electrolyte
Grounded circuit
Magnetic induction
Mutual induction
Open circuit
Parallel circuit
Rectifier
Semiconductor
Series circuit
Short circuit
Silicon-controlled rectifier (SCR)
Solenoid
Transistor
Zener diode

INTRODUCTION

This chapter, the first of three that will concentrate on the subject of electricity, will show you the basics of electricity, where electricity comes from, and how we measure electricity. In Chapters 13 and 14, we'll discuss charging systems, ignition systems, and other electrical circuits found in power equipment engines.

Since electricity can't normally be seen, many technicians know little about it and are somewhat afraid of it. Electricity isn't a difficult subject to master as long as you understand the basics of how electricity works. It's true that you don't have to be an engineer with a background in the theory of electrical systems to competently service the electrical systems in modern power equipment engines. But of course, for you to understand why something isn't functioning properly, you must first know how it works.

The technician who understands how electrical systems produce, conduct, store, and use electrical energy will find it easier to locate and correct problems in these systems. Therefore, in this chapter, we'll discuss the fundamentals of electricity, including the terms used in this field, and cover the primary tool used to measure various electrical components.

You may be wondering what exactly is electricity? Although there are many answers to this question, we'll state that, for our purpose of working on power equipment engine electrical systems, electricity is a natural force produced by the movement of electrons.

Although you should understand the basic theory and facts presented in this chapter, you won't be expected to memorize complex electricity formulas and theories and become an expert at electrical systems. In fact, I've tried very hard to make learning of electricity and electrical systems as easy as possible. Only the simplest terms have been used to help you to understand this interesting subject area of power equipment engine repair.

The electrical system is perhaps the most important support system used with power equipment engines. Without electricity, an engine would not run. Electricity provides the needed spark for combustion as well as the power required for electric starting, lights, instrumentation, and many other accessories found on various types of power equipment. Advances in the field of electronics have brought new technologies to the power equipment engine industry that make them more efficient. Today's technicians need to understand basic electrical circuits before they can diagnose and service these new technologies. Although test equipment used on modern engines simplify a technician's job, understanding electrical principles, circuit design, and testing procedures continue to be necessary for a successful modern power equipment engine technician.

SAFETY PRECAUTIONS WITH ELECTRICITY

Electrical devices and circuits can be dangerous. Safe practices are necessary to prevent shock, fires, explosions, mechanical damage, and injuries resulting from careless or improper use of tools.

Perhaps the greatest hazard of working with electricity is the electrical shock. Electricity affects the body by overriding brain impulses and contracting muscles. Therefore, a current in excess of 10 milliamperes running through the human body can make it difficult or impossible for you to let go of "live" conductor. Current over 100 milliamperes can be fatal. And how much is a milliampere? One thousandth of an ampere!

When dry, your skin can have approximately one thousand times more resistance to the flow of electricity than when it's wet; this resistance would be in the vicinity of several hundred thousand ohms. When moist or cut, however, the skin's resistance may become as low as several hundred ohms. In this condition, even so-called safe voltages of 30 or 40 volts might produce a fatal shock. Naturally, the danger of harmful or fatal shock increases directly as the voltage increases. You should be cautious, even with low voltages. Never assume a circuit is dead, even though the switch is in the off position.

Safe electrical practices will protect you and those around you. Study, memorize, and adhere to the following rules.

- Don't work when you're tired or taking medicine that makes you drowsy.
- Don't work in poorly lighted areas.
- Don't work in damp areas.
- Use approved tools, equipment, and protective devices.
- Don't work if you or your clothes are wet.
- Remove all rings, bracelets, and similar metal items.
- Never assume that a circuit is off. Check it with a device or equipment that you're sure is operating properly.
- Don't tamper with safety devices. Never disconnect an interlock switch to bypass it.
- Keep your tools and equipment in good condition. Use the correct tool for the job.
- Verify that capacitors have discharged. Some capacitors may store a lethal electrical charge for a long time.
- Don't remove equipment grounds. Verify that all grounds are intact.
- Don't use adapters that bypass ground connections.
- Use only an approved fire extinguisher. Water can conduct electric current and increase the hazards and risk of damage. Carbon dioxide (CO_2) and certain halogenated extinguishers are preferred for most electrical fires. Foam types may also be used in some cases.
- Follow directions when using solvents and other chemicals. They may explode, ignite, or damage electrical circuits.
- Certain electronic components affect the safe operation of equipment. Always use correct replacement parts.
- Use protective clothing and safety glasses.
- Don't attempt to work on complex equipment or circuits without proper training. There may be many hidden dangers.
- Some of the best safety information for electrical and electronic equipment is the literature prepared by the manufacturer. Find it, read it, and use it!
- When possible, keep one hand in your pocket while working with electricity. This reduces the possibility of your body providing an electrical path through the heart.

Any of these rules could be expanded. As your study progresses, you'll learn many of the details concerning proper procedures. Learn them well because they're the most important information available. Remember, always practice safety; your life depends on it.

BASICS OF ELECTRICITY

As mentioned previously, perhaps the main reason that most people find it difficult to understand electricity is that they can't actually see it. By actually knowing what electricity is and what it's *not*, one can easily understand it. One thing is for sure: electricity is *not* magic! It's something that either takes place or can take place in everything around us. It not only provides power for the lights and refrigerator in your house but also is the basis for the communications between your brain and your eyes as you read this sentence!

Electricity can't be seen, because it results from the movement of extremely small objects that move at close to the speed of light (which is 186,000 miles per second!) However, although electricity can't be seen, its effects can be seen, felt, heard, and even smelled. One of the most common displays of electricity is a lightning bolt. Lightning is electricity, albeit a large amount of electricity. In fact, the power of lightning is incredible. Using electrical power in much smaller amounts to perform some work is the working basis for a power equipment engine's electrical system.

The typical power equipment engine electrical system has many paths through which electricity can flow. The four major electrical systems found are

- Starting systems, which are used on many power equipment engines to rotate the crankshaft for the purpose of starting the engine

- Ignition systems, which provide a high-energy spark to ignite the air–fuel mixture inside the engine's combustion chamber
- Lighting systems, which are used to power the lights as well as operate other electrical equipment on the machine
- Charging systems, which are used to produce the electricity to recharge a battery that is used to store electricity

There are also many other electrical subsystems.

Let's take a closer look at electricity, starting with some basic theories in electricity, a basic electricity storage container, and a simple circuit.

Electricity Theories

There are two basic theories of electricity. It's important that you understand the two theories as well as the difference between them.

Conventional Theory of Electricity

The conventional theory of electricity states that electric current flows from the positive terminal of the voltage source, through the circuit, to the negative terminal. Simply stated, this theory states that electricity flows from positive to negative.

It's not known with certainty as to who came up with the conventional theory of electricity. In the mid-1700s, Ben Franklin studied electricity and is credited with the first use of the terms *battery*, *positive*, and *negative*, to describe the terminals of a battery. Many of the characteristics of electricity that we take for granted today were not known in Franklin's time. It was thought, per the conventional theory, that electric current flowed from the positive terminal of the voltage source, through the circuit, to the negative terminal.

You should know that the conventional theory of electricity is generally used in the explanation of electrical circuits in the power equipment engine industry.

The Electron Theory

One hundred and fifty years after the conventional theory was proposed, a group of scientists developed the electron theory of electricity. Like most new ideas, the electron theory of electricity was not accepted at first. In many industries, including ours, it's still not in wide use. However, the electron theory is the basis of modern electronics.

The electron theory of electricity states that electricity is the flow of electrons from the negative terminal of a source through a conductor, completing the circuit back to the positive terminal of the source. Simply stated, this theory states that electricity flows from negative to the positive.

Scientists now generally accept as true the electron theory concerning the nature of electricity.

Atoms

All matter is composed of molecules, and each molecule contains two or more atoms. Atoms, in turn, are made up of neutrons, protons, and electrons (Figure 13-1). It's the arrangement of these particles that makes materials to exist in the form of liquids, solids, and gases.

The core of the atom, called the nucleus, contains protons and neutrons. Protons have a positive electrical charge and neutrons are neutral, meaning that they have no electrical charge. Electrons have a negative charge and rotate around the nucleus of the atom. Atoms normally have an equal number of protons and electrons and therefore an equal number of positive and negative electrical charges. These

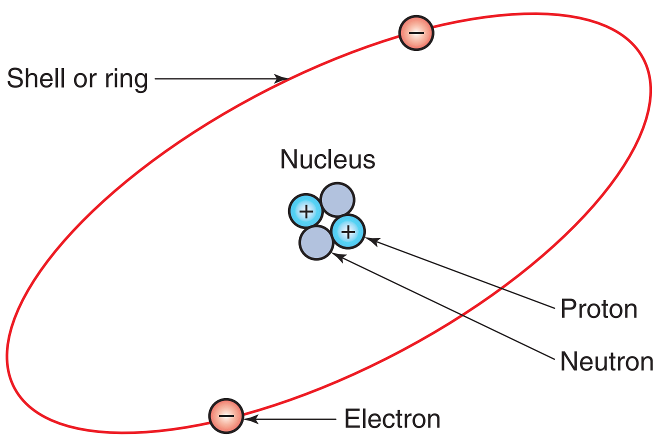


Figure 13-1 Atoms are composed of electrons, protons, and neutrons.

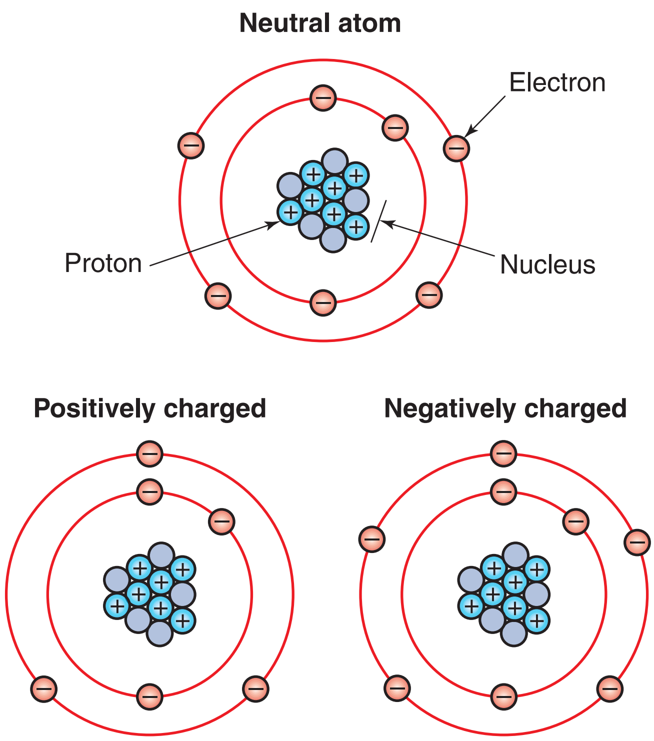
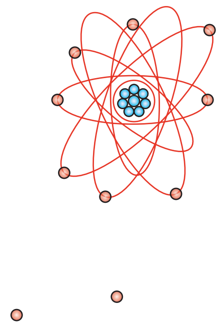


Figure 13-2 A neutral atom has an equal number of protons and electrons. A positively charged atom has more protons than electrons. A negatively charged atom has more electrons than protons.



of electrons from you to the metal caused the small shock that you felt.

Thus, you can see that it's not impossible to get electrons moving from one place to another. However, it's easier to get electrons moving in some materials than in others. The structure of an individual atom determines how easily an electron can be removed from it. For example, in Figure 13-3, you can see from the structure of the copper atom that the outermost electron can easily be dislodged from its orbit. Therefore, it's easy to get a flow of electricity moving in copper.

Any material in which electrons can move freely is called an electrical conductor. Copper, silver, gold, and other metals are good electrical conductors. In fact, silver and gold are better electrical conductors than copper, but because silver and gold are so expensive, they generally are not used to make electrical wires in power equipment engines. Materials, such as plastic, nylon, and ceramic, that have electrons tightly bonded to the nucleus offer resistance to the flow of electricity and are classified as insulators.

The Battery

We'll now discuss the battery, which is a storage device for electricity used on many types of power equipment. We'll also discuss the basics of batteries here. They're discussed in more detail in Chapter 14.

Note that batteries have two ends. The end of the battery that's labeled with a minus sign (−) is called the negative terminal. The opposite end of the battery that's labeled with a plus sign (+) is called the positive terminal. The negative terminal of the battery has a negative charge, as it contains too many electrons. The positive terminal of the battery has a positive charge, as it contains too few electrons.

The negative and positive charges in a battery are produced by a simple chemical reaction. The battery terminals, or electrodes, are two strips of lead. Each electrode is made from a different type of lead. When these strips of metal are placed into an **electrolyte** solution, a chemical reaction occurs. An electrolyte is a chemical compound which, when molten or dissolved in certain solvents (usually water), conducts an electric current. As a result of this reaction, a negative charge forms on one electrode and a positive charge forms on the other electrode.

You've probably heard the phrase *opposites attract*. This phrase really holds true with electricity! Opposing electrical charges (positive and negative) strongly attract each other and try to balance each other out. Because of this attraction, whenever too many electrons are in one place, the electrons will try to move to a place where there are fewer electrons. This is the basic operating principle of a battery. The negative terminal of a battery has a high concentration of electrons, whereas the positive terminal has very few electrons. So, the electrons at the negative battery terminal will be drawn toward the positive battery terminal. But to actually move from the negative terminal to the positive terminal, the electrons need a path to follow. We can create a path for the electrons by connecting a conductor and a load between the battery terminals. By connecting these pieces, we actually build a circuit.

In the simple circuit shown in Figure 13-4, electrons flow from the negative battery terminal to the positive terminal through the conductors and the lightbulb. Note that the flow of electricity produced by the battery will continue as long as the chemical reaction in the battery keeps up. After

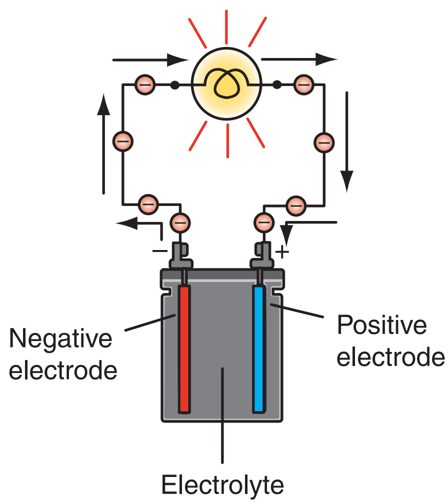


Figure 13-4 Shown is a chemical reaction between the electrodes and the electrolyte solution. This reaction produces an electrical charge on each of the electrodes.

some time, the chemical reaction in the battery will stop, and the battery will stop functioning. At that point, the battery will need to be recharged or replaced. This is why power equipments that use batteries also have charging systems.

Capacitors

Capacitors, also known as condensers, are also used to store electricity. In an electrical circuit using a capacitor, the capacitor charge usually equals the circuit voltage. If the circuit voltage falls or if the circuit is open, the capacitor will release its charge. In a circuit where short bursts of voltage are needed, capacitors are very useful. Chapter 15 provides an example of capacitor usage in power equipment engine ignition systems.

Circuits

There are three requirements to complete a simple circuit: a power source, a conductor, and a load. A power source is simply a source of electrical power. The power source in an electrical circuit in a power equipment engine is generally a battery. Conductors are the wires that carry the electricity. A load is any device, such as a lightbulb, that we want to run with electricity. In order to use electrons to perform useful work, we've connected a lightbulb to the circuit, which is our load (Figure 13-5).

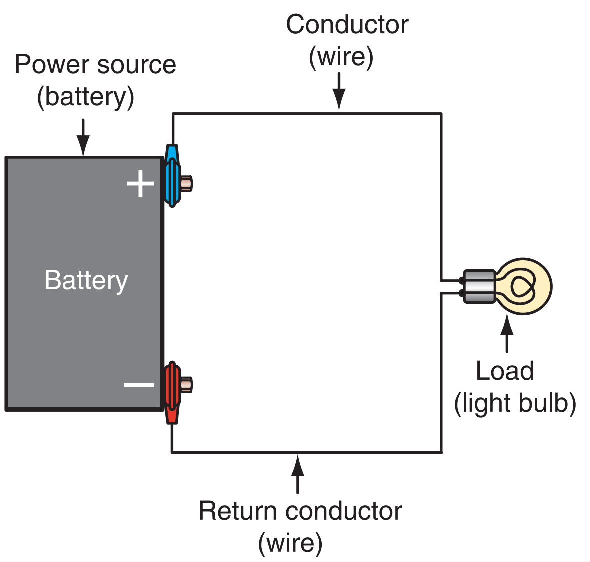


Figure 13-5 There are three requirements to complete a circuit: a power source, a conductor, and a load.

We may choose to allow a circuit to be closed or open. In a closed circuit, when the switch is turned on, electrical power from the power source flows through an unbroken path to the load, flows through the load, and then returns to the power source. In other words, when we turn the switch on, electrons from the negative battery terminal travel to the positive battery terminal. This flow of electrons through a circuit is called electric current. In contrast, in an open circuit, the switch is turned off, which breaks the path of the circuit so that power doesn't reach the load. Figure 13-6 shows a simple lighting circuit. The power source in this circuit is a battery, the conductors are copper wires, and the load is a lightbulb. Figure 13-6a shows an open switch (i.e., the switch is in the off position). The electrical circuit is therefore open, and power can't flow through the wires to reach the bulb. Figure 13-6b shows a closed switch (i.e., the switch is in the on position). This circuit is complete, and electricity flows through the wires to reach the bulb, causing the filament to heat up and glow. The simple circuit that we've just described is known as a series circuit.

You should note that all electrical systems, no matter how large, can be broken down to simple circuits similar to the circuit that we've just discussed.

Electron Flow in a Circuit

Let's take a closer look at how electrons flow in an electrical circuit. Figure 13-7 shows a simple series circuit, in which a copper wire is connected to a battery. One section of the copper

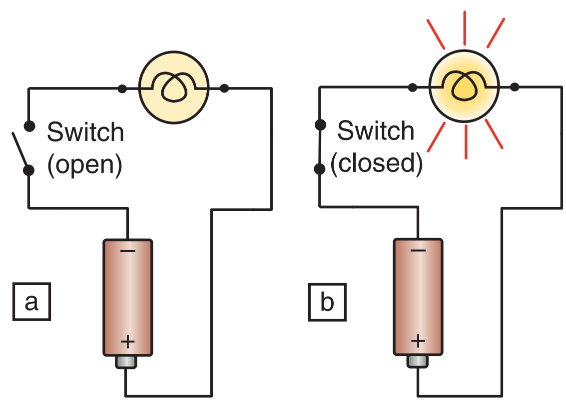


Figure 13-6 A simple circuit: In (a) the circuit is open; in (b) the circuit is closed.

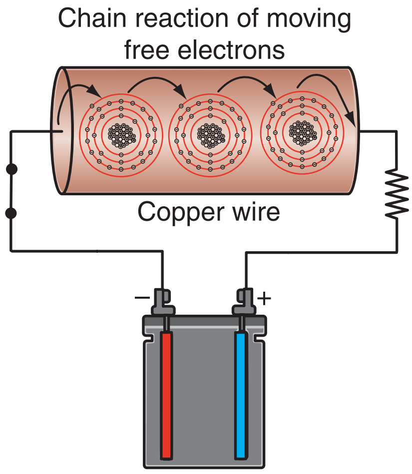


Figure 13-7 The enlarged portion shows you how electrons flow through a wire. A free electron from the battery enters the wire. The free electron then creates a chain reaction within the wire, where free electrons bump other electrons from the outer shell of the atoms. The remaining free electrons are drawn to the positive side of the battery, completing the circuit.

wire is enlarged so that you can see how electrons flow through it.

In the figure, the circuit is closed, and the electrons from the negative terminal are drawn to the positive terminal. Remember that the outermost electron in each copper atom is easily dislodged from its orbit. An electron is drawn from the negative battery terminal into the copper conductor wire. This electron then collides with a free electron in a copper atom, bumping a free electron and taking its place. The displaced free electron moves to a neighboring copper atom, bumps a free electron out of the copper atom's orbit, and takes its place. As this chain reaction continues, free electrons bump their neighboring electrons out of their orbits, taking their place. This chain reaction of moving electrons constitutes electric current.

In reality, of course, atoms are much too small to see; so we can't follow the movement of just one electron through a wire. Many millions of copper atoms make up a single strand of wire. When a circuit is closed, millions of electrons move through the wire at the same time, at a high speed. The greater the number of electrons moving through a circuit, the stronger the current in the circuit.

Types of Circuits

There are many types of circuits used in electrical systems (Figure 13-8). We've already talked about one simple electrical circuit, the **series circuit**. A series circuit is a circuit that has only one path for electrons back to the source of power. In a series circuit, if one lightbulb burns out, the whole circuit shuts down since there's no path for electricity to continue to flow. A **parallel circuit** is a circuit that has more than

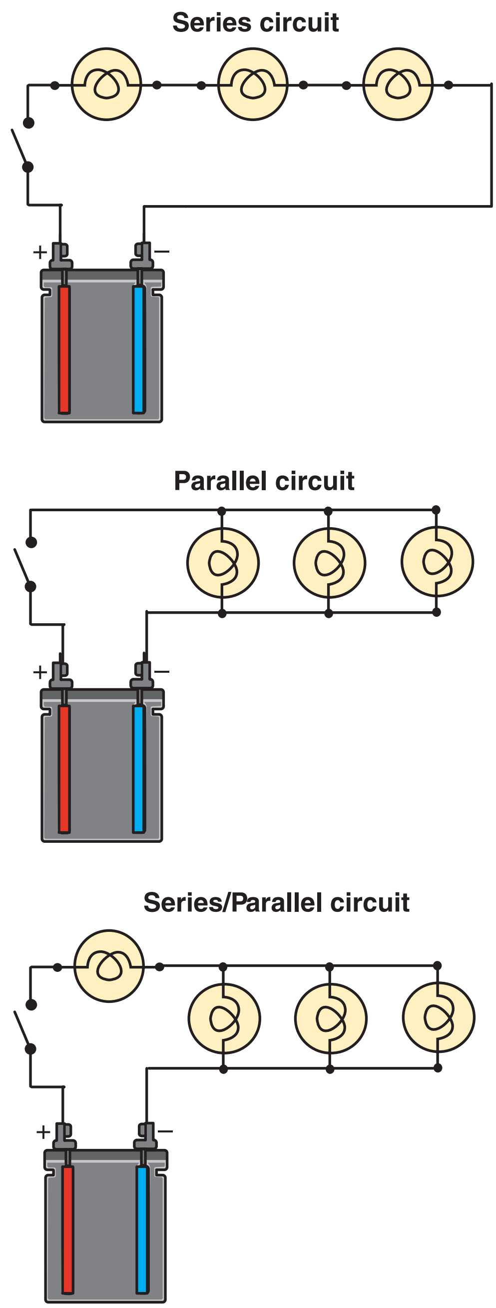


Figure 13-8 A series, parallel, and series/parallel circuit.

one path for electrons back to the source of power. In a parallel circuit, if a lightbulb burns out, it won't have any effect on the other bulbs in the circuit because each of them functions as separate return path for electrons to the source of power. A popular type of circuit that you'll find in power equipment engines is a combination of the series and the parallel circuit, called the **series/parallel circuit**. The series/parallel circuit contains a load in series and a parallel load in the same circuit.

Unwanted Circuit Conditions

There are several possible conditions in an electrical circuit that have an adverse effect on electrical systems. These circuit conditions are opens, shorts, and grounds.

As you already know, an **open circuit** is a circuit in which the path for current to flow is incomplete. An example of an open circuit, which is generally an unwanted circuit condition, is a broken wire or a blown lightbulb. A **short circuit** is a circuit that has developed a path for electricity to flow to the source of power before it reaches the load. A short circuit will blow fuses in the circuit as well as damage wires and components in the electrical system. A **grounded circuit** is a circuit that allows power to flow back to the source after the load, but before the means of control, that is, a component used to control current or voltage in a circuit (such as a transistor switch). An example of a grounded circuit would be a horn that blows without pushing the horn button.

Properties of Electricity

Confused yet? If so, don't worry, you'll understand! Let's take a look at the properties of electricity in a way that may make all of this easier to comprehend. Electric current flowing through a wire can be compared to water flowing through a pipe (Figure 13-9). The laws governing electric circuits are easily explained by this analogy.

Voltage

Water pressure is measured in pounds per square inch, while electrical pressure is measured in volts. When the two water tanks in our

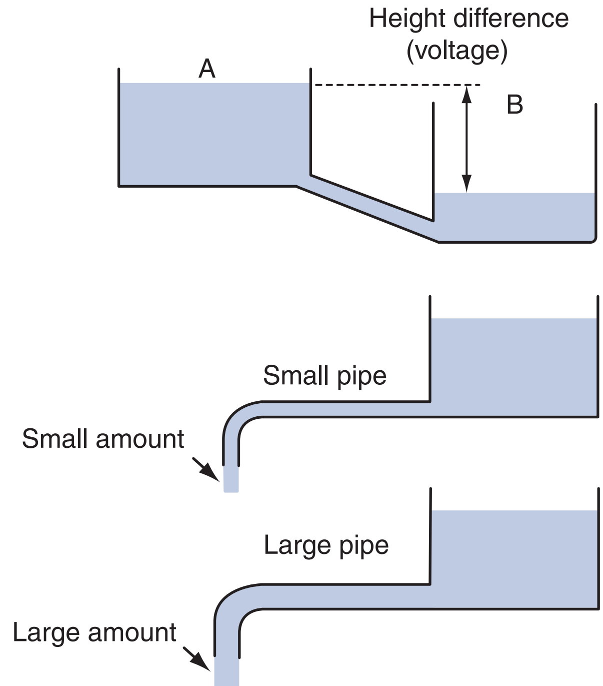


Figure 13-9 Electric current flowing through a wire can be compared to water flowing through a pipe. When Tanks A and B are connected, water will flow from Tank A to Tank B. This flow is the result of a pressure difference, which is similar to the pressure difference found between voltages at different points in a circuit. If the connecting pipe is small, less water flows compared to water flow in the larger pipe. This is analogous to electrical resistance.

illustration, A and B, are connected, water flows from Tank A to Tank B.

This flow is the result of a height difference between the two tanks. Water will flow through the pipe from the full tank to the empty tank until the water level is even in both tanks. The pressure from the weight of water in the full tank will naturally cause the water to flow. A valve could be installed to open or close the water passage and another could be used to decrease the flow or increase it as desired.

Similarly, electrical current will flow through a wire because of electrical "pressure" created by a battery or an alternator. The electrical pressure is measured as voltage (V).

Resistance

Water will have a lower rate of flow through a smaller or longer pipe because of the increased resistance. Similarly, electrical current will have a lower rate of flow through a smaller or longer conductor such as wire. Partially closing off the flow from the pipe decreases water flow. Similarly, a load or resistance in an electrical circuit, such as a lightbulb, decreases voltage.

UNITS OF ELECTRICITY

We just discussed a couple of the key electrical units of measurement, voltage and resistance. Throughout this chapter, you'll learn terms that are used in connection with electrical systems, and learn some basic formulas. There are three basic units of measurement used to measure electricity: current, voltage, and resistance.

Each unit of measurement is named after a famous experimenter in electricity: The ampere after the Frenchman Andre M. Ampere, the volt after the Italian Alessandro Volta, and the ohm after the German Georg Simon Ohm.

Amperes (Current)

As you've already learned, when a complete conducting path is present between two opposing electrical charges, electrons flow between the two points. Current is the rate of flow of electrons through a conductor. Current is measured in units called amperes, also called amps, which is often abbreviated with the letter "A." For instance, "3 amperes" would be abbreviated to "3 A." In electrical work, electrical drawings, diagrams, and mathematical formulas, the letter *I* is used to represent current. Small amounts of current can be measured in milliamperes, which is abbreviated to "mA." One milliampere of current is equal to one-thousandth of an ampere, or 0.001 A of current.

Volts (Voltage)

Now, let's look at the electrical term *voltage*. Remember that in a battery, one terminal has a negative charge and the other terminal has a positive charge. Whenever a positive charge and a negative charge are positioned close to each other, a force is produced between the two charges. This force is called electrical potential, which is simply the difference in electrical charge between the two opposing terminals. Electrical potential can also be thought of as the amount of electrical pressure in an electrical system. The bigger the difference between the two opposing charges, the greater the electrical potential will be. Voltage is a measurement of the amount of electrical potential in a circuit. Voltage is measured in units called volts, which is often abbreviated to "V." For instance, 12 volts would be abbreviated "12 V." In electrical diagrams and mathematical formulas, voltage is usually represented by the letter *E*.

Ohms (Resistance)

The last electrical term we'll look at is called *resistance*. Resistance is a force of opposition that works against the flow of electrical current in a circuit. You've already seen that current flows easily through copper wires in a circuit. However, frayed wires, corroded connections, and other obstructions will reduce the flow of electrons through a circuit, that is, the circuit will resist the flow of current through it. When a lot of resistance is present in a circuit, more voltage is needed to increase the flow of electrons moving through the circuit. Resistance is measured in units called ohms, which is often abbreviated with the Greek letter omega, represented by the symbol "Ω." In electrical diagrams and mathematical formulas, the letter *R* is usually used to represent resistance. Power equipment engine service manuals often provide electrical specifications in ohms. A service manual may tell you, for example, that the resistance you should be able to measure between the leads on a charging system stator should be 0.2 Ω. Note that we'll discuss charging systems, their components, specifications, and how to measure circuit quantities in more detail in Chapter 14.

Ohm's Law

Although it seems simple to guess why the letter *R* is used for resistance, you must be wondering why the abbreviation for voltage is the letter *E* and that for current is *I*, right? Well, the letter *I* for current represents the *intensity of electron flow*, and the letter *E* represents *electromotive force.*

There is an important law relating the values of resistance, current, and voltage in a circuit. The amount of current flowing through a completed circuit is directly proportional to the voltage applied across the conductor. This relation between resistance, current, and voltage is known as Ohm's law. Ohm's law states that a resistance of 1 ohm (1 Ω) permits a current flow of 1 ampere (1 A) in a circuit that has a source voltage of 1 volt (1 V). This rule can be applied to any voltage, resistance value, or amperage. *If* you have any two of the values, the third can be determined by using Ohm's law.

This relation, known as Ohm's law, is expressed with the mathematical formula:

Voltage (E) = Current (I) × resistance (R)

Two other useful variations of the Ohm's law equations are

Current (I) = Voltage (E) divided by resistance (R)

Resistance (R) = Voltage (E) divided by current (I)

To understand how to use these equations, consider Figure 13-10 and then the following example. As you can see in the illustration, if you cover the unknown quantity with your finger, you can determine the unknown by using the remaining pieces of the formula.

If you have a circuit that draws 3 amperes of current from a 12-volt battery, how much resistance is in the circuit? To solve this equation, simply install the known measurements in the formula as follows:

Resistance (R) = 12 (E) divided by 3 (I)

The answer is 4 ohms.

Ohm's law yields a useful formula that you should know. The Ohm's law formula is used frequently to analyze circuits and troubleshoot problem areas. By using these three given variations of the Ohm's law formula, it's easy to find the proper voltage, resistance, and current values for any circuit.

You should note that as the resistance in a circuit increases, the current decreases. Conversely, if the resistance in a circuit decreases, the current increases. All circuits are designed to carry a particular amount of current. In fact, most circuits are protected by fuses that are rated at an amperage value that's just slightly higher than the current value of the circuit. Thus, if a problem develops in a circuit, the circuit will draw too much current from the battery and the fuse's elements will melt (the fuse will blow), creating an open in the circuit. This design prevents any further damage to the electrical circuit.

Watts (Electrical Power)

When consumers buy electricity, they buy power. The unit of power for electricity is the watt. A simple formula for relating watts to voltage and current is

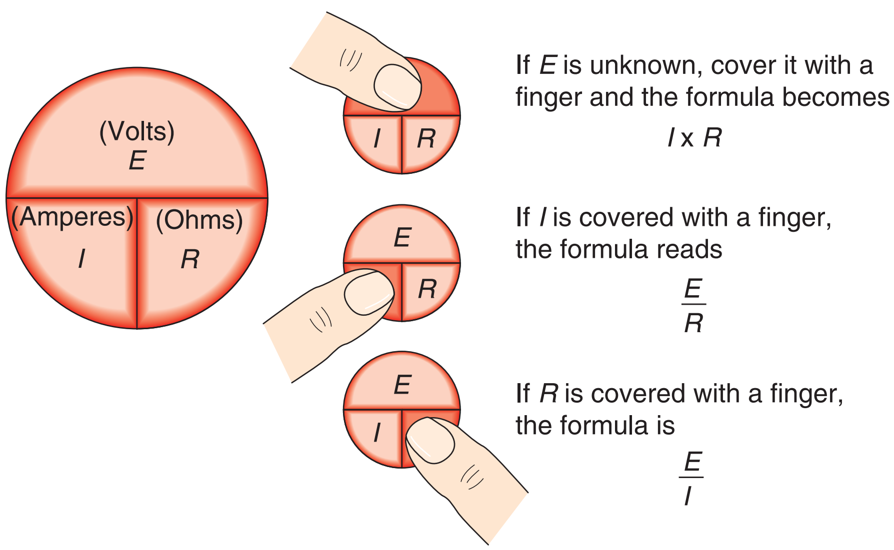


Figure 13-10 An illustration of how Ohm's law works. By covering the unknown quantity with your finger, you can determine the unknown by using the remaining pieces of the formula.

Power = voltage × current, or watts = volts × amperes

Thus, if there are 5 amperes going through a resistor, due to a voltage of 200 volts, the power consumed by the resistor is 1000 watts (power = voltage × current = 200 volts × 5 amperes = 1,000 watts).

These measurements, plus an understanding of the nature of electricity, are essential to anyone working with electricity. The user of any electrical test equipment or tools should have some knowledge of the operation and mechanics of the particular circuits and/or the device being tested.

Common Electricity Quantities

Table 13-1 lists common electrical quantities, their abbreviations, and their multiples in terms of the base unit. You should become familiar with these abbreviations, as you'll see them in different areas of a service manual when working with electrical systems on power equipment engines.

Relation Between Current, Voltage, and Resistance

Let's use the water analogy illustration once again to help you understand better the relation between current, voltage, and resistance in an electrical circuit. We can then compare it to an electrical circuit example (Figure 13-11). The following text is a list describing the water analogy.

- The water pipes form a path for the water to follow. The water pipes are similar to the conductors in the adjacent electrical system.
- The water valve turns the flow of water on and off. The water valve is similar to the switch in the electrical system.
- The waterwheel is being operated by the flow of water. The waterwheel is similar to the lightbulb (the load) in the electrical circuit.
- The water reservoir (the water source) is similar to the battery (the power source) in the electrical circuit.
- The flow of water is similar to the flow of electrons. The amount of flow would be the current.
- The water pump is the pushing force that causes the water to flow into the pipes, just what voltage does in the electrical circuit.
- The water returns to the pump just as the electrons flow through the ground path back to the battery.

Figure 13-11a shows both the water system and the electrical circuit turned off. Both the water valve and the electric switch are in

Table 13-1: Common Electrical Quantities

Unit	Abbreviation	Value
Ampere	A	1 ampere
Milliampere	mA	0.001 ampere
Volt	V	1 volt
Millivolt	mV	0.001 volt
Kilovolt	kV	1,000 volts
Megavolt	MV	1,000,000 volts
Ohm	Ω	1 ohm
Kilohm	KΩ	1,000 ohms
Megohm	MΩ	1,000,000 ohms

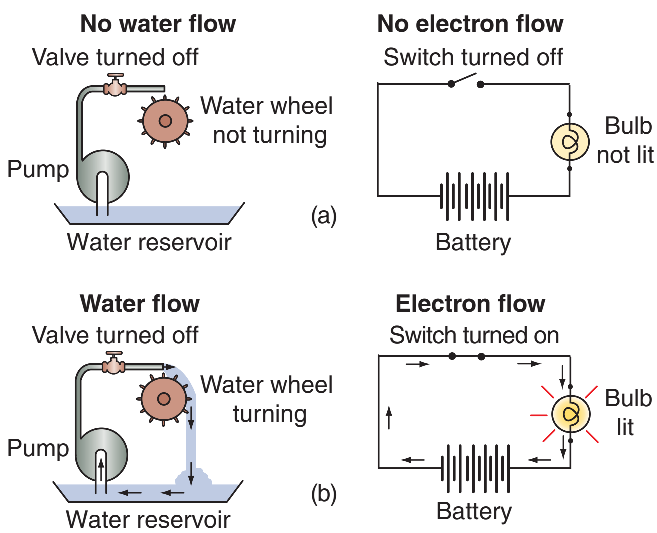


Figure 13-11 The basic principles of electricity can be easily visualized when you compare an electrical circuit to a water flow.

the off position; so no water or current flows. The waterwheel doesn't turn and the lightbulb doesn't illuminate. Figure 13-11b shows the water system and the electrical circuit turned on. Water is pumped out of the reservoir and into the pipes; the water flows through the pipes, turns the waterwheel, and then returns to the reservoir. With the electrical circuit, the switch is turned on. Electric current flows out of the battery through the wires, lights the bulb, and returns to the battery.

In this example, you can think of resistance as being like a blockage or a clog in the water pipe. If some debris were stuck in the pipe, the flow of water through the pipe would be reduced. Similarly, excessive resistance in an electrical circuit reduces the flow of current through the circuit.

Alternating Current, Direct Current, and Voltage

There are two types of electrical current: direct current and alternating current. It's important that you understand the differences between these two types of current.

Direct Current

Direct current (DC) is the flow of electrons in one direction only. A DC voltage reading is non-varying and on a power equipment engine is usually produced by a battery. For example, if we were to graph a DC voltage of 12 volts over a period of time, the graph would appear as shown in Figure 13-12. Whatever the voltage value, a DC voltage remains constant and unchanging over time.

Alternating Current

In contrast to DC, alternating current (AC) is the flow of electrons first in one direction and then in the opposite direction. AC reverses direction continually and is produced by an AC voltage source. AC is the type of current found in household electrical systems and wall outlets. Power equipment engines also produce AC in various ways. (We'll discuss AC in more detail in Chapter 14.) As you see in Figure 13-13, AC starts at zero and then rises to a maximum positive value. At the maximum positive point, the current reverses direction and falls back to zero and continues to drop until it reaches the maximum negative value. The current then reverses direction again and rises back to zero. One complete transition of current from zero to the positive peak, down to the negative peak, and back up to zero is called a cycle. These AC cycles repeat continuously as long as the current flows.

As related to power equipment engines, there are three key items needed to produce AC voltage: a magnetic field, a conductor, and motion.

Power equipment engines that don't have a battery or a DC storage device use AC voltage and current for their lighting and ignition systems.

Implements that use a battery use the DC voltage produced by the battery to power the starter, lights, and other accessories. These implements also use AC voltage to keep the charging system working properly, which keeps

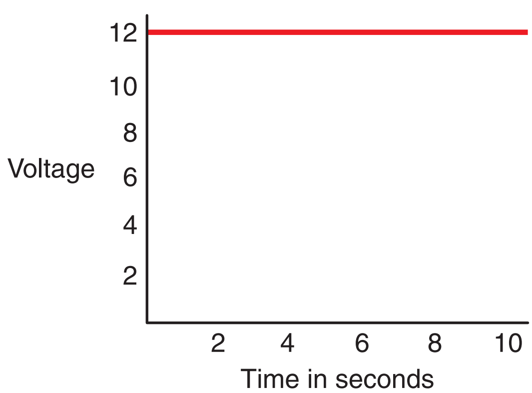


Figure 13-12 A DC voltage level remains constant over time.

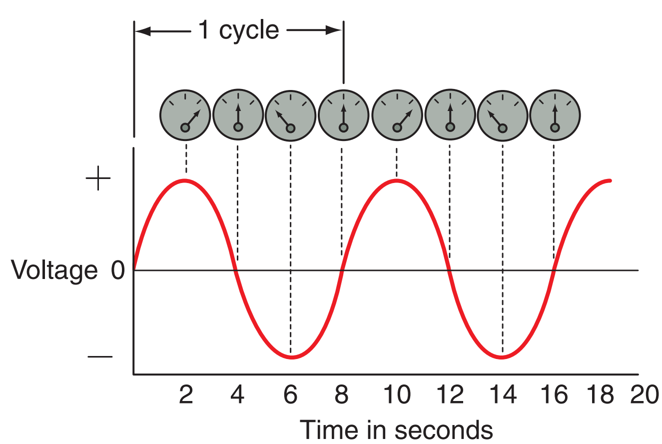


Figure 13-13 An AC voltage level changes over time.

the battery's voltage level correct. To do this, the AC has to be converted into DC by a process called rectification.

ELECTRICAL METERS AND MEASUREMENTS

Although we can observe the effects of electricity, such as a glowing lightbulb, we can't see the flow of electrons that we call electricity. We can, however, use various meters to observe the action of electric current in a circuit. When you begin working with electrical meters, you'll notice that they use two basic types of readouts, or displays, to present the information: analog and digital. The function of these two types of meters is the same—to display electrical measurements—but the way in which the data is displayed is different.

- **Analog electrical meter**. The display of an analog electrical meter has a movable pointer and a scale (Figure 13-14). The meter is usually enclosed in a case and has terminals (test leads), which connect to jacks on the front of the case. In most cases, a red jack indicates a positive terminal and a black jack a negative.
- Most analog meters have scales from zero up to some maximum number. Some meters may have zero centered in the middle of the scale, with numbers on the right and the left. Most analog meters have what's called a mechanical zero adjustment. This means that by turning a screwdriver inserted into a small screw on the front of the meter, the pointer can be adjusted so that it's exactly over the zero on the scale. (During this adjustment, the meter shouldn't be connected to any circuit; instead, both leads should touch each other while in the rx1 scale.) The amount of movement of the pointer is called pointer deflection.

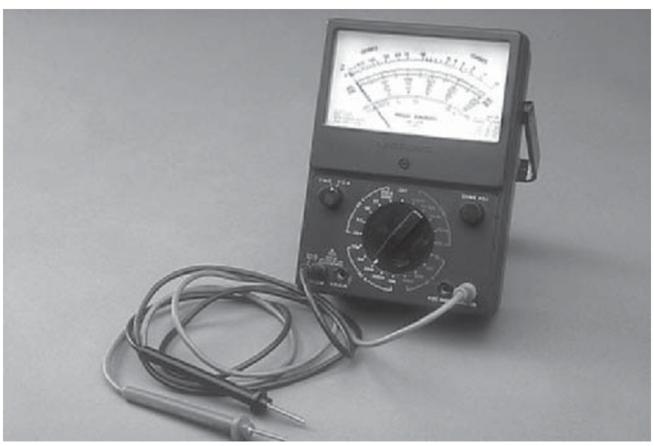


Figure 13-14 An analog electrical meter.

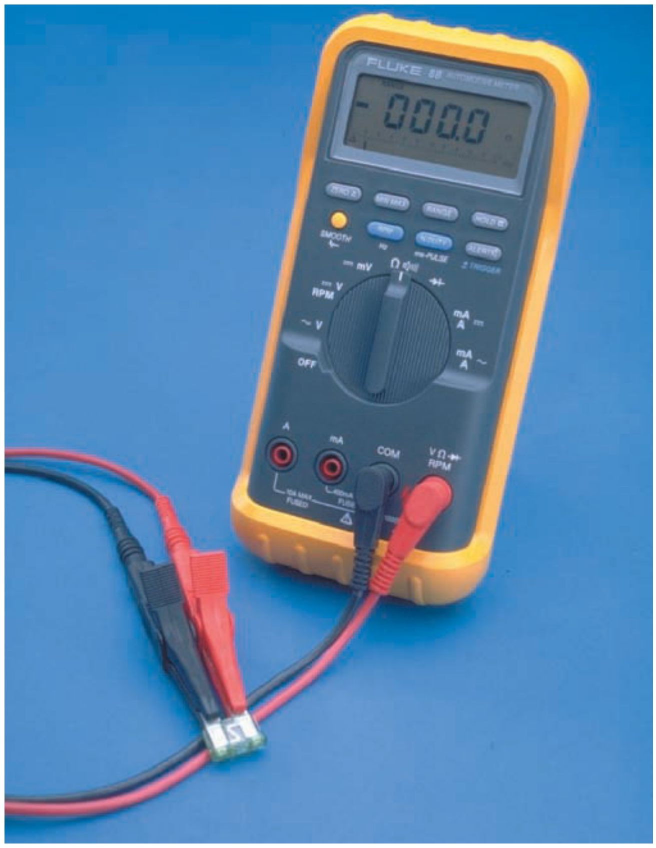


Figure 13-15 A digital electrical meter.

- **Digital electrical meter**. The display of a digital electrical meter has a numeric readout (Figure 13-15). Like the analog meter, the digital meter is also enclosed in a case and has positive and negative terminals (test leads), which connect to jacks on the front of the case.

Electrical Meters

As you use electrical meters, you'll find that there are three primary types: voltmeter, ammeter, and ohmmeter. A multi-meter is a meter that incorporates the functions of all these three meters. These meters may have either analog- or digital-type displays. Most meters also contain a battery within them. Be sure to turn the meter to the off position when not in use.

Voltmeters

Voltmeters are used to measure the voltage, or potential difference, between two points in a circuit (Figure 13-16). A voltmeter can be used to check voltage at any point in a circuit. Remember that voltage is like pressure and exists between two points; it doesn't flow like current. Therefore, a voltmeter isn't connected in series, but must be connected across a circuit, or in parallel (Figure 13-17). You can change the meter settings to measure volts in both AC and DC circuits.

Ammeters

Ammeters are used to measure current flow through a circuit. As we know, current is measured in amperes. The scale of an ammeter shows the number of amperes in a particular circuit. Unlike a voltmeter, ammeters are always connected in series in a circuit (Figure 13-18). An ammeter must be connected in series because the entire current must flow through both the circuit and the ammeter. As with voltmeters, there are both AC and DC ammeters. Settings can also be changed to measure ampere in AC and DC circuits.

Ohmmeters

Ohmmeters are used to measure the resistance of a circuit or component by applying a known voltage to the circuit and measuring the resulting current (Figure 13-19). Ohmmeters usually have a built-in power supply, such as a 9-volt battery, which supplies the voltage to test the component. Thus, when connecting an ohmmeter to a circuit, you must be certain the power source is removed from the circuit. It's good practice to disconnect the battery of the power equipment engine when testing using an ohmmeter.

Multi-Meters

A multi-meter is a meter that combines the testing capabilities of a voltmeter, ammeter, and ohmmeter. Multi-meters are the most widely

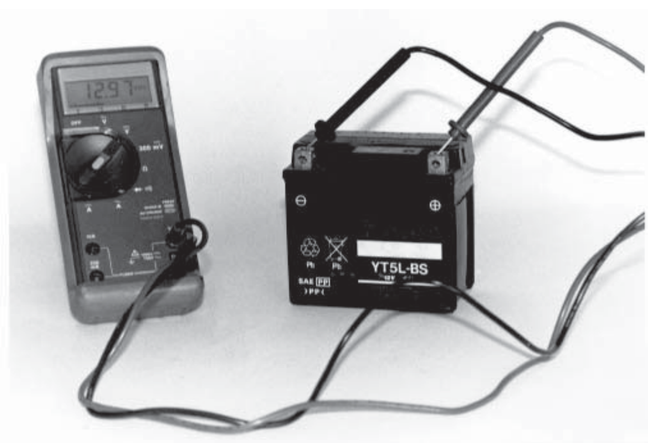


Figure 13-16 Voltmeters are used to measure the electric potential difference between two points.

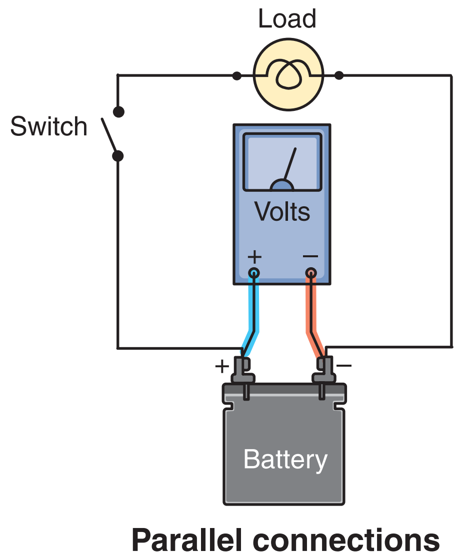


Figure 13-17 A voltmeter is connected always in parallel to check the voltage of the battery.

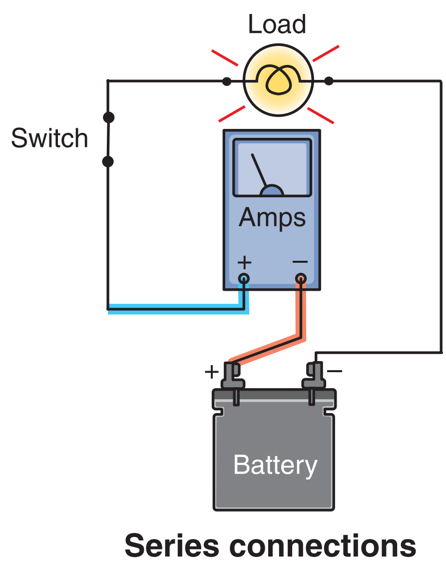


Figure 13-18 An ammeter is connected always in series to check the current draw of the load (i.e., the lightbulb).

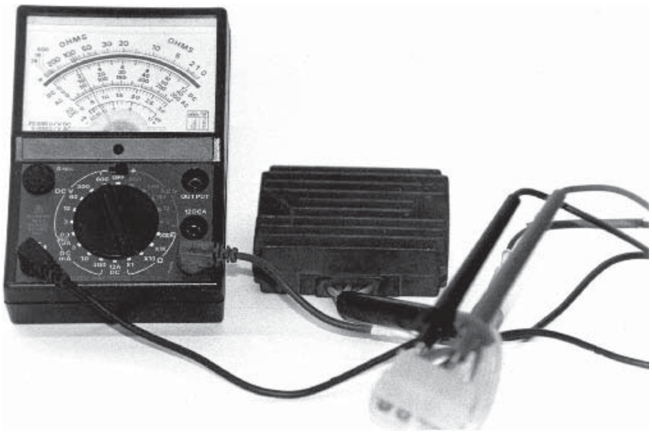


Figure 13-19 Ohmmeters are used to measure the resistance of a circuit or component by applying a known voltage to the circuit and measuring the resulting current.

used item among electrical testing equipment in the power equipment engine industry. The multi-meter may be referred to as a volt/ohmmeter (VOM), or if it's a digital meter with ampere-testing capabilities, it may be referred to as a digital volt/ohm/amp meter (DVOAM). The DOVAM is also called a digital multi-meter (DMM).

Figure 13-20 shows a DMM. A dial on the front of the multi-meter is used to select what you want to measure—voltage, current, or resistance. Many multi-meters will also have range selectors that can be set for the quantity being measured. For example, in our illustration, you can see multiple Direct Current Volt (DCV) ranges: 200 millivolts, 2,000 millivolts, 20 volts, 200 volts, and 1,000 volts. When the selector switch is set to the "20" position, the meter only measures values between 0 and 20 volts, which is the most common range found on power equipment engines.

You'll also note that jacks, which are used to hook up the leads, are used for different testing applications. Having the test leads in the correct jack is crucial in electrical testing.

Multi-Meter Operation

Since multi-meters are the most widely used measurement instruments in the power equipment engine industry, we'll cover their primary functions. But first, let's go through some basic information.

Measuring AC

The connection of the positive and negative terminals of an AC voltmeter or ammeter doesn't matter because, as you'll recall, AC is constantly reversing itself (Figure 13-21). Therefore, the positive and negative terminals are constantly alternating from positive to negative and negative to positive.

When measuring AC voltage, certain requirements must be met:

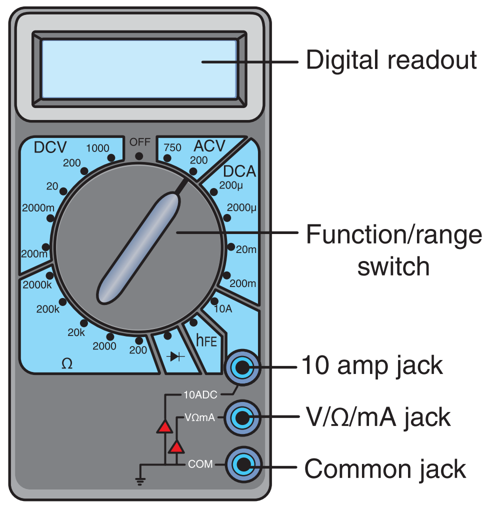


Figure 13-20 A multi-meter is a meter that combines the testing capabilities of a voltmeter, an ammeter, and an ohmmeter and is the most popular electrical testing tool found in a technician's toolbox.

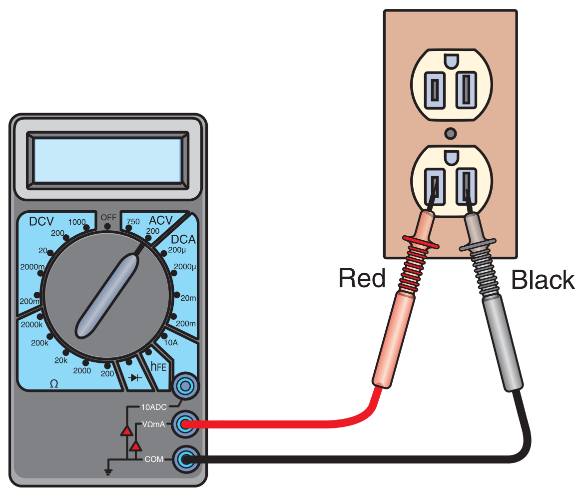


Figure 13-21 Measuring AC voltage from a home electrical outlet.

- Whenever you're checking for any kind of voltage (AC or DC), the meter must be connected in parallel to the circuit.
- We had briefly mentioned earlier that to produce AC voltage, there are three requirements: a magnet, a conductor, and motion. To get an AC voltage reading on a power equipment engine, there must be engine motion, that is, the crankshaft of the power equipment engine you're testing must be turning.

Measuring DC

The connection of the positive and negative terminals of a DC voltmeter or ammeter is important.

When measuring a DC circuit, you must connect the negative terminal of the meter in the circuit toward the negative terminal of the battery (Figure 13-22). Likewise, the positive terminal of the meter must be connected in the circuit toward the positive terminal of the battery. If the meter is connected improperly, it will read exactly opposite of the actual measurement!

When working on power equipment engines, the only current measurements that you'll take will be for DC. Be sure to hook the meter up in series when checking for DC (Figure 13-23). Also be sure to hook the meter leads up correctly. One way to verify that the leads are correctly hooked up is to turn the power on after the meter is connected and look at the reading while the engine isn't running. The meter must read a negative number if the key is on and the engine is off. If the meter is reading a positive number, simply switch the meter leads and check again.

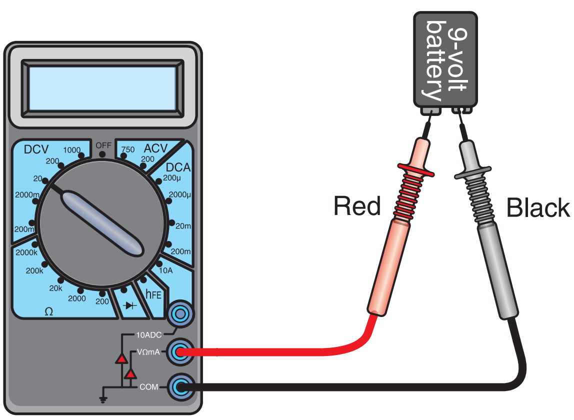


Figure 13-22 Measuring DC voltage across a 9-volt battery. Note that the leads must be connected correctly to yield an accurate reading.

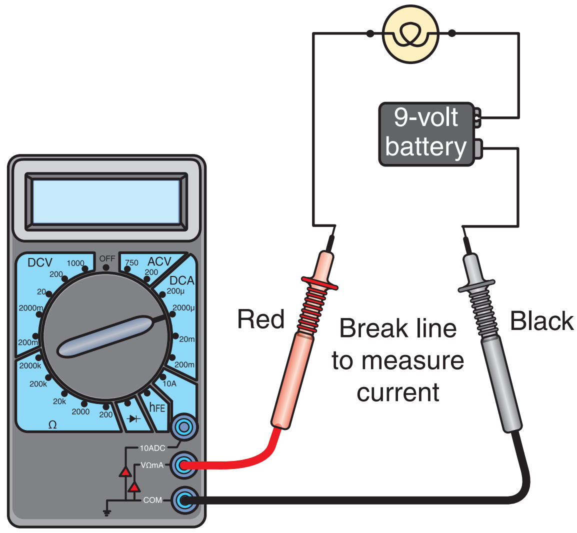


Figure 13-23 A multi-meter, when used to measure current, must be connected in series to the circuit to allow the current to flow through the meter.

Never electric start a power equipment engine while the ammeter is hooked up in series to the battery. The meter isn't designed to handle the large amount of amperage that the starter motor requires to turn the engine over, and it will almost certainly damage the meter.

A type of ammeter commonly used in connection with power equipment engine electrical troubleshooting is a 20-0-20 DC ammeter. This meter has a scale with a zero in the center and the number "20" on the far right and far left of the scale. Thus, 20 amperes is the full-scale value, or maximum amperage, that can be measured with this instrument. The pointer rests over the zero when no amperes are being measured. When current is being measured, the position of the pointer to the right or left of the zero not only tells you the rate of current flow but also whether current is flowing into or out of the battery. If the needle points to the right side of the scale, it indicates a flow of DC into the battery. In other words, the battery is being charged. If the needle points to the left side of the scale, it indicates that current is flowing from the battery. In other words, the battery is being discharged. Let's look at a couple of examples.

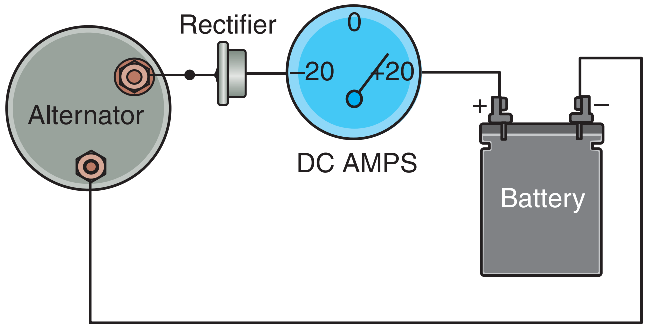


Figure 13-24 This ammeter is measuring a rectified current flow into the battery, at a rate of about 17 amperes.

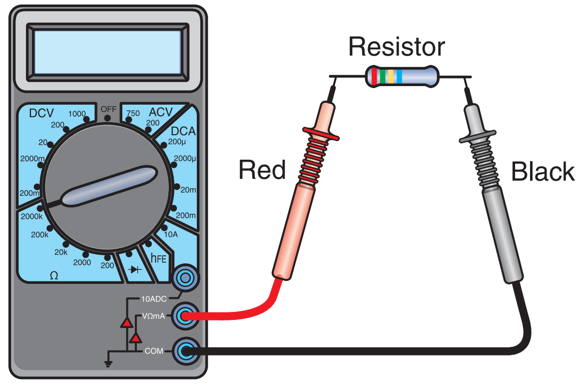


Figure 13-26 Resistance is measured with the component disconnected from the circuit.

On a power equipment engine, AC power flow is converted to DC and is delivered to the battery where it's then stored (Figure 13-24). Before it reaches the battery, it flows through a component called a **rectifier**, which changes the AC to DC. Therefore, to check the current, you would connect a DC ammeter between the rectifier and the battery. In this example, our ammeter is reading a current of about 17 amperes. This tells us that the battery is being charged.

If an ammeter were connected between the light and the battery on our implement with the key on and engine off, the ammeter would read a current of negative amperage (Figure 13-25). In this scenario, the battery is being discharged.

Measuring Resistance

As we discussed earlier, whenever you're using an ohmmeter, it's important to first disconnect the component being tested from the rest of the electrical system (Figure 13-26). In other words, isolate and de-energize the component. If you don't isolate the component from the rest of the electrical system, you risk damaging the meter. You may also receive a false resistance reading, as there may be other resistances in the circuit that you're about to test.

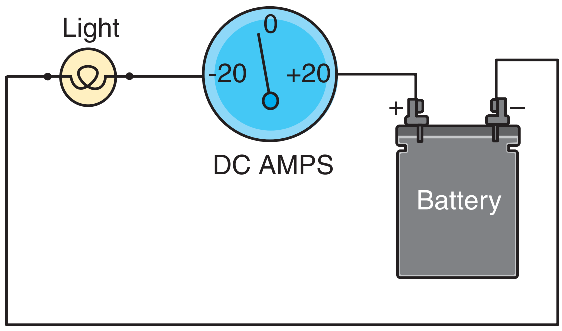


Figure 13-25 This ammeter is measuring a current discharge of about 3 amperes from the battery to the lights.

Precautions when Using a Multi-Meter

You can destroy a multi-meter if you use it improperly. Here are some basic steps you should know about how to operate a multimeter:

1. Determine what you want to measure (voltage, current, or resistance).
2. Set the meter up to the proper unit of measurement (volts, amperes, or ohms).
3. Connect the test leads to the meter.
4. Select the quantity you want to measure by turning the dial.
5. Holding the two test leads, touch the probes with two points in a circuit.
6. Read the resulting information on the meter's display.

Note that this is a basic description of the operation of a multi-meter. The actual operation may be somewhat different than described here; so be sure to read the instruction manual provided with the meter.

As a general note, when you're using meters, you need to ensure that they're connected properly to the circuit being tested. An improper connection can result in an incorrect measurement and, in some cases, damage the meter.

When using an analog meter, it's also important that you learn to read the scales on each meter scale properly.

Voltage Drop

As previously discussed, voltage is the electrical force or push of electricity. Voltage drop is the consumption of the available voltage from the battery as it crosses some form of resistance, such as a lightbulb or a switch. A voltage drop measurement allows you to identify if all of the available voltage is being used up by the component it's intended to power.

When electrical current reaches a load, such as a lightbulb, current is forced through the filament of the bulb. Each connection in a circuit offer's a very slight resistance to electron flow. Normal voltage drop for a connection in a circuit is 0.1 (one-tenth) volt or less.

Generally speaking, in the power equipment engine industry, voltage drop should not exceed the limits set (for the following components):

- Wires or electrical cables: 0.2 VDC
- Switches: 0.3 VDC
- Electrical connections: 0.1 VDC
- Electrical grounds: 0.1 VDC

As you would recall, current remains the same throughout any circuit; what is lost or used up is the voltage. Therefore, if you measure 12 volts before the load and 0 volts after the load, all is working well. However, if the full 12 volts isn't powering the load, there is unwanted resistance somewhere in the circuit. Now, it must be determined if the unwanted resistance is before or after the load. You can quickly isolate the area of the unwanted resistance by dividing the circuit in two: positive and negative.

The purpose of any circuit is to allow an electrical load to operate as designed. No matter what the load is—a lightbulb, a clock, a starter motor, or an electronic control module—it must have power to it and it must have a ground to make the circuit complete.

The voltage supplied is consumed by the load as it operates. This provides a clue that makes troubleshooting electrical problems much simpler. We know that voltage is going into the load and being consumed within the load. Therefore, in a basic circuit, we should have full source voltage from the battery to the load, and since the load consumes the voltage as it operates, we should have 0 volts coming out of the load. So remember: you should expect about 12 volts (depending on the total source voltage on hand) on the positive side, and 0 volts on the negative side of the load (Figure 13-27).

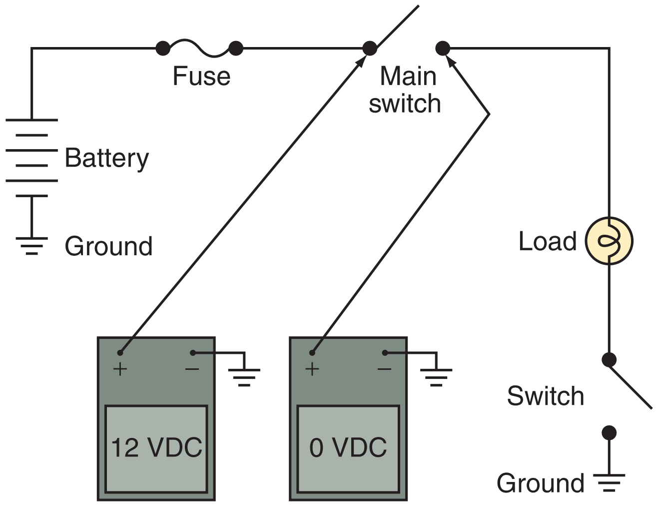


Figure 13-27 Testing the positive side of an electrical component in a circuit should show the source voltage, whereas testing on the negative side of the circuit should read zero or near zero volts. This is known as voltage drop.

MAGNETISM

Magnetism, like electricity, is a force we can't see. However, like electricity, we can observe its effects. The subject of magnetism isn't completely understood, and most of it's well beyond the scope of this textbook; however, it's important for you to understand some basics about magnets so that you can understand better how alternators and generators produce electricity in a power equipment engine.

Many years ago, scientists discovered that fragments of iron ore attracted each other. Researchers also found that when a magnetized iron bar was suspended in the air, one end would always point north. This was called the north "pole" of the magnet. The opposite end of the bar came to be known as the south "pole" of the magnet.

It was also found that when a piece of nonmagnetized metal, such as steel, was rubbed over a magnetized metal, the magnetic properties of the metal were transferred to the steel.

The area affected by a magnet is called the field of force or magnetic field (Figure 13-28a). Note that the "lines" of force, or flux lines, as they're sometimes called, are for illustrative purposes only—we can't actually see the lines. Well, actually, we can see the lines if we do a small experiment using a magnet, a sheet of paper, and iron filings. If we place a sheet of paper over a magnet and then sprinkle iron filings over the paper, we'll see the iron filings aligning themselves along the magnetic lines of force created. This is one way we can "see" magnetic lines of force.

As with electricity, one important property of magnets you should know is that opposites attract. When opposite poles of a magnet or magnets are placed near each other, they'll attract each other (Figure 13-28b). Conversely, when two like poles are placed together, they'll repel each other (Figure 13-28c). This is because the lines of force are going in opposite directions. Another property of magnets is that when a nonmagnetic substance (such as a piece of wood) is placed in a magnetic field, the lines of force aren't deflected. Magnetic forces pass through nonmagnetic materials!

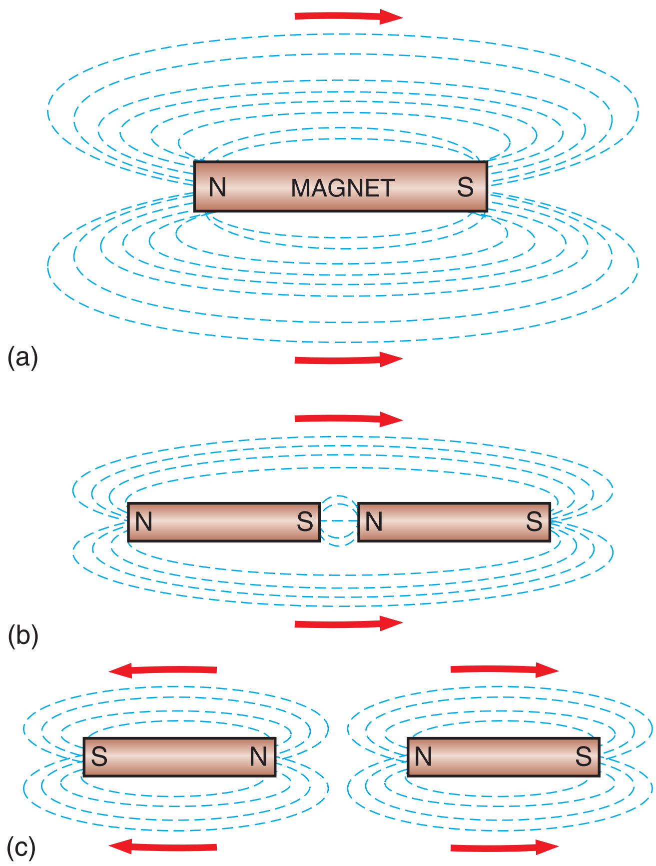


Figure 13-28 (a) The area affected by a magnet is called the field of force or magnetic field. (b) When opposite poles of a magnet or magnets are placed near each other, they attract each other. (c) When two like poles are placed together, they repel each other.

Types of Magnets

There are three types of magnets. Let's briefly describe them now:

- **Magnetite**. A natural magnet, it occurs in rock form. It's a weak magnet and isn't used in power equipment engine components.
- **Permanent magnet**. A man-made material, a permanent magnet is very strong and long lasting. Permanent magnets are found commonly in different parts of power equipment engines.
- **Electromagnet**. An electromagnet, which is also man made, is another magnet that may be found in power equipment engines. An electromagnet consists of a coil wound around a soft iron or steel core. The core becomes strongly magnetized when current flows through it and becomes almost completely demagnetized when the current flow is interrupted; hence the term *electromagnet*, as it combines electric current with magnetic properties.

Magnetic Forces

Magnetic force is the amount of force exerted between two opposite magnetic poles, which produces magnetism. There are different ways to control and create magnetic forces of desired strength. Let's look at the most common types of magnetic forces used in a power equipment engine.

Electromagnetism

The concept of electromagnetism is important to the operation of electrical systems used in power equipment engines. Electromagnetism is the magnetic effect produced when an electric current flows through a conductor (wire). When the current flows through the wire, the wire becomes surrounded by a magnetic field (Figure 13-29). The magnetic field is strongest in the space immediately surrounding the conductor.

Magnetic Coils

Electromagnetism has many interesting and highly useful applications. If an insulated piece of conductor wire is looped around an iron bar to form a coil, the resulting device is called a magnetic coil (Figure 13-30). When current flows through a magnetic coil, each separate loop of wire develops its own small magnetic field. The small magnetic fields around each separate loop of wire then combine to form a larger and stronger magnetic field around the entire coil. The coil develops a north pole and a south pole. The magnetic field at the center of a magnetic coil is stronger than the fields above or below the coil.

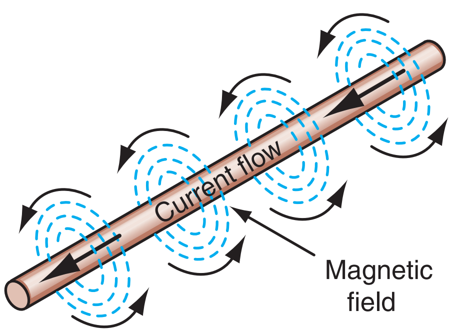


Figure 13-29 When current flows through wire, a magnetic field is produced.

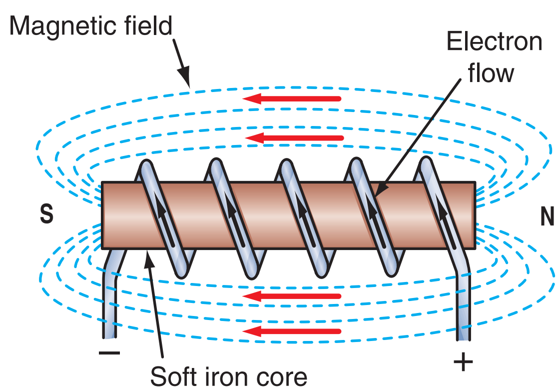


Figure 13-30 A magnetic field can become highly concentrated when an iron core is installed in a coil of wire.

Magnetic Induction

When a conductor (wire) is moved through a magnetic field so that it moves across the lines of force, an electromotive force (EMF), or potential voltage, is induced in the wire. If the wire is part of a complete electrical circuit, a current will flow through the wire. This important fact is the working basis for the various kinds of AC-producing generators used in power equipment engines. This kind of generator may also be called an alternator. We'll explain electricity-generating systems in greater detail in Chapter 14, but it's important for you to understand that they all function on the basis of the same principle.

That principle is that when an electrical conductor is passed through a magnetic field (or a magnetic field is moved past an electrical conductor), an electric current, or voltage, is induced in the conductor wire. This effect is called the generator action of **magnetic induction**. Note that current won't flow through the wire until the wire is connected in a complete circuit.

Mutual Induction

The final electromagnetic property we'll look at is called **mutual induction**. If two conductors are placed close together and current is applied to one of the conductors, a voltage will be induced in the other conductor. This occurs because when two conductors are physically close to each other, the energy in the live conductor will stimulate the other conductor to become energized too. This effect is called mutual induction, and it can be used to operate ignition coils. Note that if the conductors are moved apart from each other, the effect of mutual induction isn't as great. If the conductors are moved sufficiently far apart, the energy of the live conductor won't be strong enough to influence the other conductor, and the mutual induction effect will cease.

In Chapter 15, we'll see how the principle of mutual induction is used to help operate a power equipment engine's ignition system.

AC Generator Operation

The generator action of magnetic induction is fundamental to operating a charging system in an engine. We'll discuss this property using Figure 13-31, which shows a very basic AC charging system. A permanent magnet is suspended within a soft iron frame, which completes the circuit for the permanent magnet's lines of force. The soft iron core becomes a temporary magnet, concentrating lines of magnetic force around the coil of wire in the magnetic field to produce an electric current. The coil, known as a stator in a charging system, is made up of many loops of conductor wire. As the magnet rotates, the magnetic polarity of the soft iron frame is reversed. With each 180° of rotation, the magnetic lines of force around the soft iron frame collapse and then reestablish themselves in the opposite direction. Each time the lines of force collapse and rebuild, the coil of wire within the magnetic field cuts them and an electric current is produced.

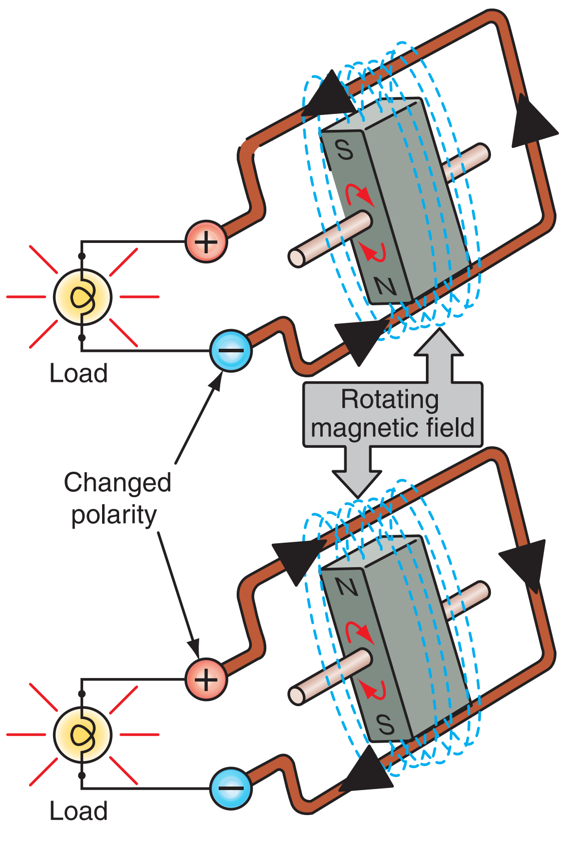


Figure 13-31 In this AC generator, as the magnet rotates, the induced current reverses.

The voltage and current produced by the simple generator shown would be quite low. But if we wound many loops of wire into a coil and rotated the coil in the magnetic field, a much larger voltage and current would be produced. This is the arrangement in a real AC generator. The amount of voltage and current produced by a generator is based on

- The number of turns in the coil and the diameter of the wire
- The strength of the magnetic field
- The speed at which the wire coil passes by the magnets

All power equipment engines that use a battery use the AC generator action of magnetic induction, which is changed to DC to charge the battery through rectification. In such implements, generators charge the batteries, and the energy from the batteries is then used to power the various electrical systems. It should be noted that AC generators are sometimes called alternators, depending on the manufacturer.

Solenoids

Some electromagnets have special movable cores. This type of electromagnet is called a solenoid or relay. Inside the solenoid coil, there is a movable piece of metal called a plunger. When a solenoid coil is energized by a flow of current, the resulting magnetic field moves the plunger in the coil. When the flow of current stops, a spring forces the plunger back into its original position. Solenoids are used in electric starter systems as well as in some safety devices in power equipment engines. Solenoids are designed in one of two designs:

- A normally open solenoid is a solenoid that doesn't allow current flow unless the solenoid is activated. This type of solenoid is found in electric starting systems and allows a high current flow after a very small current flow activates the solenoid.
- A normally closed solenoid is a solenoid that allows current to flow unless the solenoid is

activated. This type of solenoid is found in safety devices, such as lockout safety devices, and creates an open circuit after a very small current flow activates the solenoid.

Electromagnetism in Motors

You've just learned that when a conductor moves through a magnetic field, a voltage is produced in the conductor. Now, suppose that a current-carrying conductor is placed in a magnetic field. What happens? Well, the interaction between the magnetic field and the moving electrons in the conductor causes a physical force that's applied to the conductor. If the conductor is free to move, this physical force will cause the conductor to move for as long as the conductor current and the magnetic field are maintained. This property is called the motor action of electromagnetic induction.

The motor action of electromagnetic induction is shown in Figure 13-32. In this figure, a conductor (wire) is connected to a battery to form a complete circuit. Current is already flowing in the conductor when it's placed in a magnetic field between two magnets. The reaction between the magnetic field and the moving electrons in the conductor causes the conductor to rotate, as shown by the arrow in the figure. The motor action of electromagnetic induction is the basic property that's used to operate electric starter motors.

Figure 13-33 shows the basic parts of an electric starter motor. The armature in a starter motor is a rotating component that's mounted on a shaft and positioned between the motor's field magnets. Loops of conductor wire, called armature windings, are connected to the armature's commutator. Note that for simplicity, only one winding is shown in the figure. Brushes are electrical contacts that slide over the surface of the commutator when the armature rotates. The brushes are connected to a battery. Electrical wires, called field windings, are wound around the field magnets. When current flows into these wires, the field magnets become electromagnets and produce a powerful magnetic field inside the motor. When current is applied to the brushes, the current moves through the brushes and into the commutator and armature windings. The current flowing through the armature windings produces magnetic fields around the windings. The interaction of all these powerful magnetic forces causes the armature to spin.

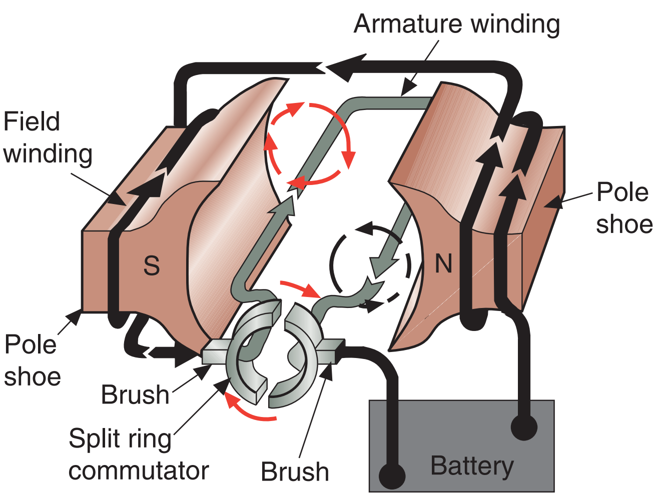


Figure 13-32 When the field windings are energized, the field magnets produce a magnetic field in the motor. When current flows through the armature windings, magnetic fields are produced around the windings. The interaction of these fields causes the armature to rotate.

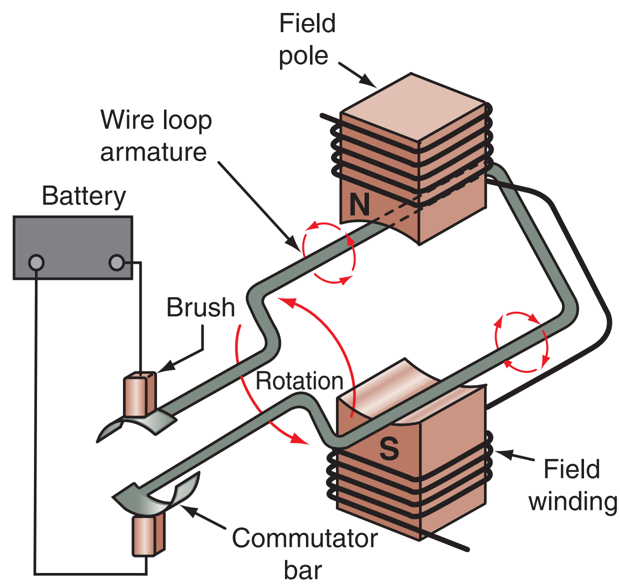


Figure 13-33 The basic parts of an electric starter motor.

Many power equipment engines use electric starter motors. The output shaft of the electric motor in such a system is generally connected to gears that engage the crankshaft of the power equipment engine. The spinning motion of the electric motor's armature is transferred through these gears to the crankshaft. Some people may use the word *motor* when talking about either the electric starter motor or the power equipment engine. Don't confuse the starter motor with an engine!

ELECTRONIC DEVICES

Now you should have a basic understanding of the principles of electricity and magnetism. Now let's take a brief look at some electronic devices. We'll start by reviewing a few terms. You'll remember that a conductor, such as a copper wire, is a material that allows electrical current to flow through it easily. An insulator, such as plastic or nylon, is a material that resists the flow of electricity through it. There are other materials called semiconductors, which as the name implies, allow some flow of electricity through them.

A semiconductor is a substance whose electrical conductivity is between that of a conductor and an insulator. A semiconductor's electrical conductivity also increases as its temperature increases. Silicon, germanium, and selenium are common semiconductor materials that are used to make electronic components.

Semiconductor devices are manufactured in laboratories under very special conditions. Semiconductor materials are specially processed and combined to form electronic devices such as diodes and transistors, which are capable of controlling the flow of electrons in a way normal conductors can't. So, as a result of these special manufacturing processes, the conducting and insulating properties of semiconductor materials can be used to perform useful work in a circuit.

Electronic Components

Electronic devices contain components that are used to control the flow of electrons in a circuit. Many electronic components are used in circuits in power equipment engine electrical systems, but we'll look just at the most common ones. These devices are the diode, the zener diode, the transistor, and the **silicon-controlled rectifier** (**SCR**).

Diodes

A diode is a simple electronic device that has two terminals and acts like a one-way valve. The two terminals are called the anode and the cathode. The anode is the positive (+) terminal, whereas the cathode is the negative (−) terminal.

When a positive voltage is applied to the anode of a diode, electric current moves through the diode and exits at the cathode. In this situation, the diode acts like a conductor. When a positive voltage is applied to the cathode of a diode, the diode resists the flow. Current won't flow through the diode. In this situation, the diode acts like an insulator. Diodes allow current to flow through them in one direction only. The electrical symbol for a diode (Figure 13-34) illustrates this principle.

Zener Diodes

Like a regular diode, a zener diode allows current to flow in one direction. However, the zener diode allows current to flow in the opposite direction also if the voltage exceeds a predetermined value (Figure 13-35). Thus, at a predetermined voltage, called the reverse or breakdown voltage, the zener diode becomes conductive in the opposite direction also. This characteristic makes the zener diode useful for

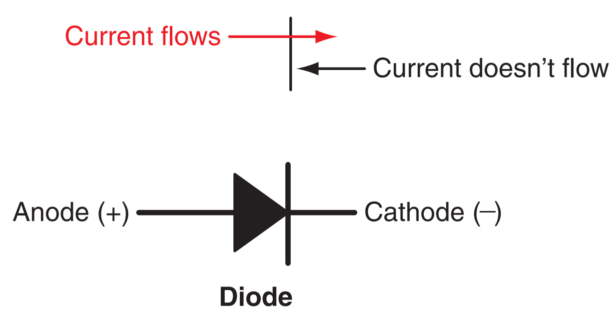


Figure 13-34 The electrical symbol for a diode. A diode will allow electrical flow in only one direction.

voltage regulation in power equipment engine charging systems.

Silicon-Controlled Rectifiers (Thyristors)

An SCR is another type of semiconductor component. SCRs are used as switching devices in electronic circuits. An SCR, often called a thyristor, has three terminals: the anode, the cathode, and the gate. Except for the gate, the construction of an SCR is similar to that of a diode (Figure 13-36).

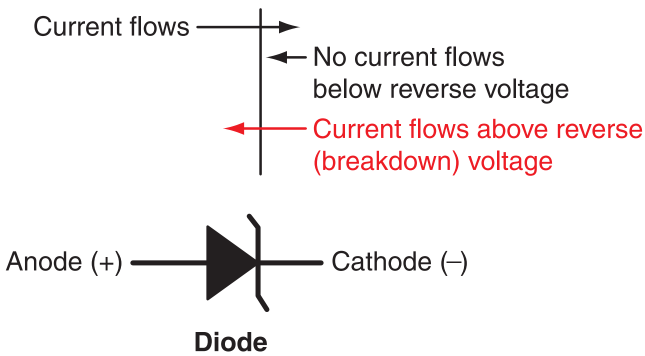


Figure 13-35 A zener diode allows current to flow in the reverse direction only when a predetermined voltage is sent in the opposite direction.

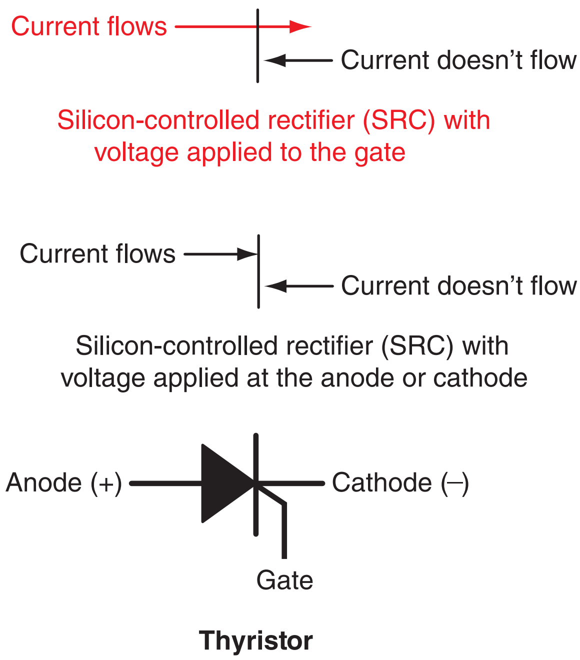


Figure 13-36 An SCR, or thyristor, is a diode with a gate that allows current to flow only when a predetermined voltage is applied to the gate.

Unlike a diode, an SCR will block current in both directions. If you apply a voltage across an SCR, current won't flow. If a small amount of voltage is applied to the gate of an SCR, however, current will flow through the SCR in the forward direction. Current will continue to flow until the voltage is removed from the gate. Thus, an SCR can be switched on and off by applying a voltage to the gate. In Chapter 15, we'll look at how these electronic components function in electronic ignition system and charging system circuits.

Transistors

A transistor is another type of semiconductor device that's widely used in power equipment engine electrical systems. Transistors are used to control the flow of current in a circuit and function like relays. They switch a current on and off when they receive a small current. The key difference between a relay and a transistor is that a transistor has no moving parts.

A transistor has three wire terminals: the base, the collector, and the emitter. There are two types of transistors: PNP and NPN (Figure 13-37).

With PNP-type transistors, when positive voltage is applied to the emitter and the base is at a lower voltage level, a small current flows from the emitter to the base, during which time, a large current flows from the emitter to the collector (Figure 13-38).

With NPN-type transistors, no current flows when a positive voltage is applied to the collector and a negative voltage to the emitter. When a small current flows from the base to the emitter, a large current flows from the collector to the emitter.

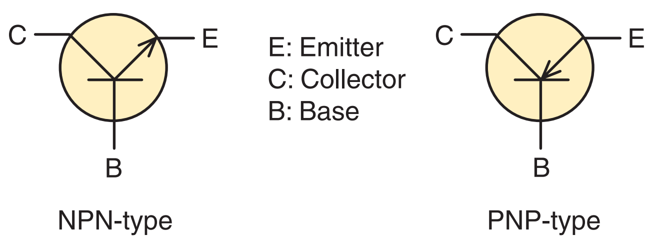


Figure 13-37 The electrical symbols of the PNP and NPN transistor types.

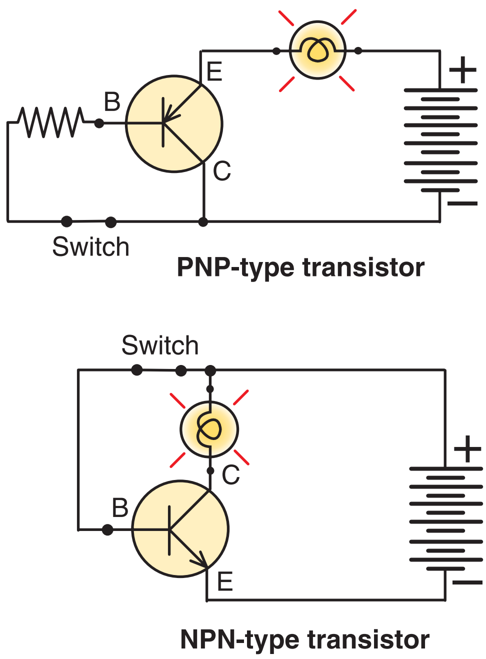


Figure 13-38 The circuitry of the PNP and NPN transistors and their power flow.

ELECTRICAL SCHEMATICS AND SYMBOLS

Before you can begin working on a power equipment engine electrical system, you must know how to read electrical schematics (also known as wiring diagrams). A schematic is like a road map but instead of connecting cities and towns through the numerous roads and highways, it connects the wires in the electrical system to the various components that require electricity to function properly. Schematics use symbols to describe the various components in the system. Figure 13-39 shows some of the most common types of electrical symbols used on power equipment engine wiring diagrams.

All manufacturers use schematics to assist you with tracing a wire to a component. In general, manufacturers use certain colors to help you to know right away whether the wire you're looking at leads to the component you're trying to test or trace. However, such color coding is not standardized. For instance, some manufacturers use the colors green for ground and black for switched-on power, whereas some other manufacturers may use these colors for an entirely different electrical action. It's because of this possibility that you must rely on the manufacturer's service manual to ensure that you're on the right path. Although some manufacturers illustrate their schematics in full color, most use simple black-and-white diagrams in their service manuals (Figure 13-40).

To assist a technician with diagnosis of an electrical complaint, most manufacturers create a more precise schematic of the various subsystems within the electrical system of the power equipment engine. These are known as **block diagrams**. With a block diagram, you can separate the desired subsystem, such as the ignition system (Figure 13-41) or the charging system (Figure 13-42) from the rest of the implement. This helps the technician focus on the system in question.

ELECTRICITY TERMS

The following terms are found often in material related to electrical repairs. Your job as a technician will be much easier if you know and understand these terms. For ease of reference, they're listed in alphabetical order. Many of these terms have been discussed in this chapter, but those not discussed are important terms to understand just as well.

AC Abbreviation for "alternating current"; is one form of electric current that reverses direction and polarity while flowing through a circuit, e.g., a 110-volt AC in household electrical systems reverses direction and polarity 60 times per second (60 Hz)

Alternator An AC generator that uses magnetic induction to produce electricity; a revolving magnet and stationary stator windings are used, and the current produced is AC

Amperes Commonly called amps; electrical unit of current flow through a circuit (similar to gallons per minute of water through a hose)

Amp hour Discharge rate of battery in amperes times hours

Armature A group of rotating conductors that pass through a magnetic field; the current produced, after the conductors are passed through a commutator device, is usually DC; armatures are also used in electric motors

Symbols used in wiring diagrams	
Positive	Temperature switch
Negative	Diode
Ground	Zener diode
Fuse	Motor
Circuit breaker	Splice
Condenser	Not connected
OHMS	Volt meter
Fixed value resistor	Ammeter
Variable resistor	Eyelet terminal
Fusible link	Thermal element
Coil	Multiple connectors
Open contacts	Digital readout
Closed contacts	Single filament bulb
Closed switch	Dual filament bulb
Open switch (SPST)	Light-emitting diode
Double-throw switch (SPDT)	Thermistor
Momentary contact switch	PNP bipolar transistor
Pressure switch	NPN bipolar transistor
Relay	Battery

Figure 13-39 Some of the most common electrical symbols found on a power equipment engine schematic or wiring diagram.

Battery A chemical device used to store electrical power; within the battery, a chemical reaction takes place that produces a voltage potential between the positive and negative terminals

Bench test Isolated component inspection

Capacitor Also called condenser; a component which, in a discharged state, has a deficiency of electrons and will absorb a small current and hold it until it's discharged again

Circuit Composed of three components/requirements: a power supply, load, and completed path

Circuit breaker Heat-activated switch that interrupts current when overloaded; a circuit breaker can be reset and replaces the function of a fuse

Coil A conductor looped into a coil-type configuration which will produce a magnetic field when current is passed through it

Conductor A wire or material (such as a frame) that will allow current to flow through it with very little resistance

Continuity A continuous path in a circuit for current to flow

Current The flow of electrons in a circuit

DC Abbreviation for "direct current"; one form of electric current in which current flows only in one direction—from positive to negative, per the conventional theory

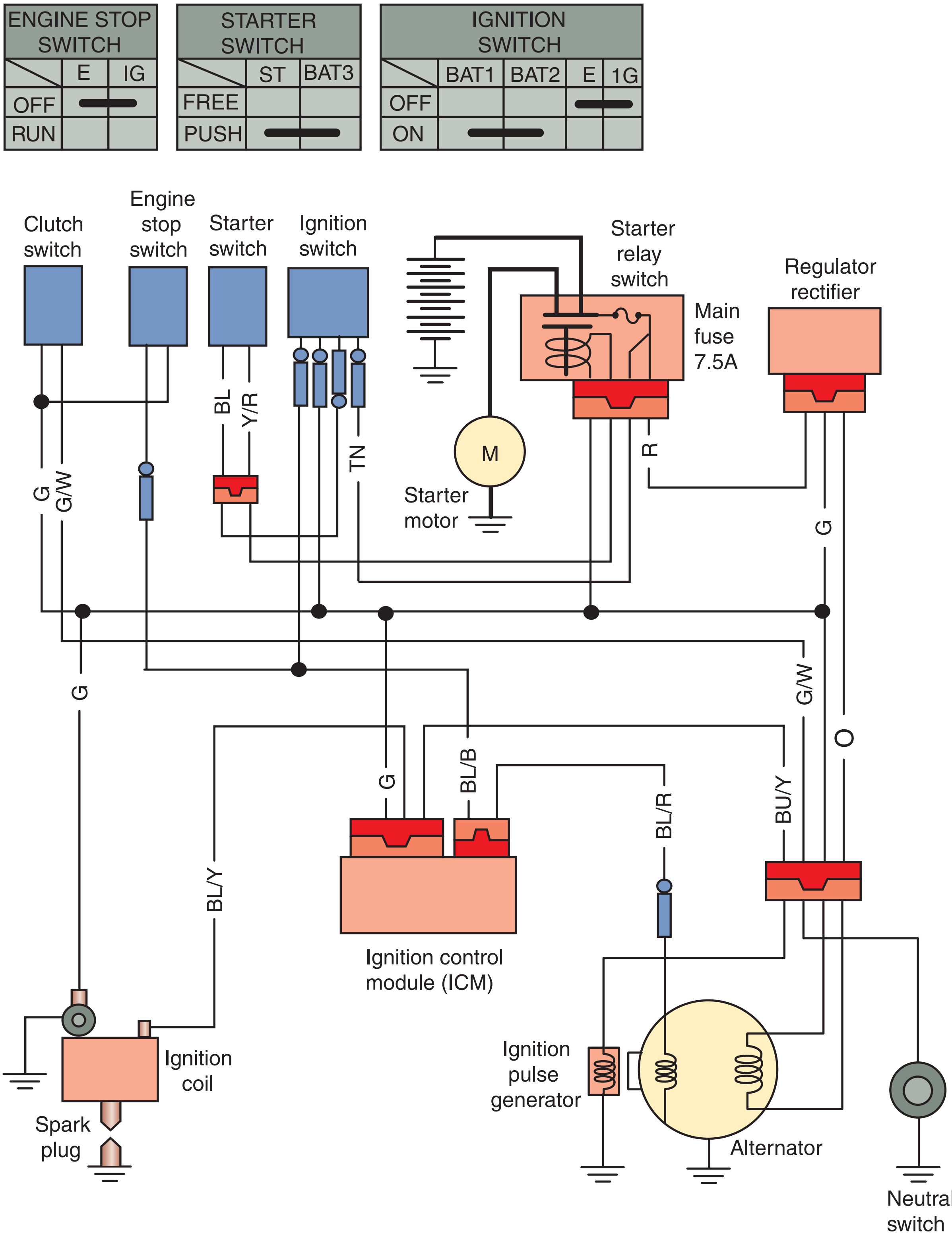


Figure 13-40 A complete schematic. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

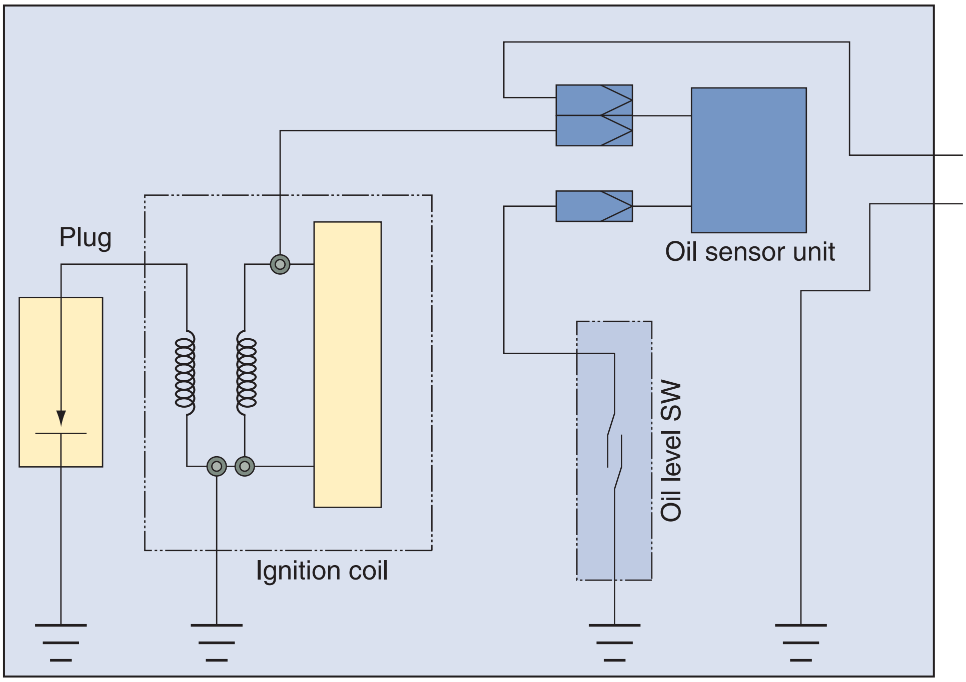


Figure 13-41 A typical block diagram of an ignition system. Block diagrams separate the system you're looking at from the rest of the electrical system. This aids in diagnosing problems within the system in question.

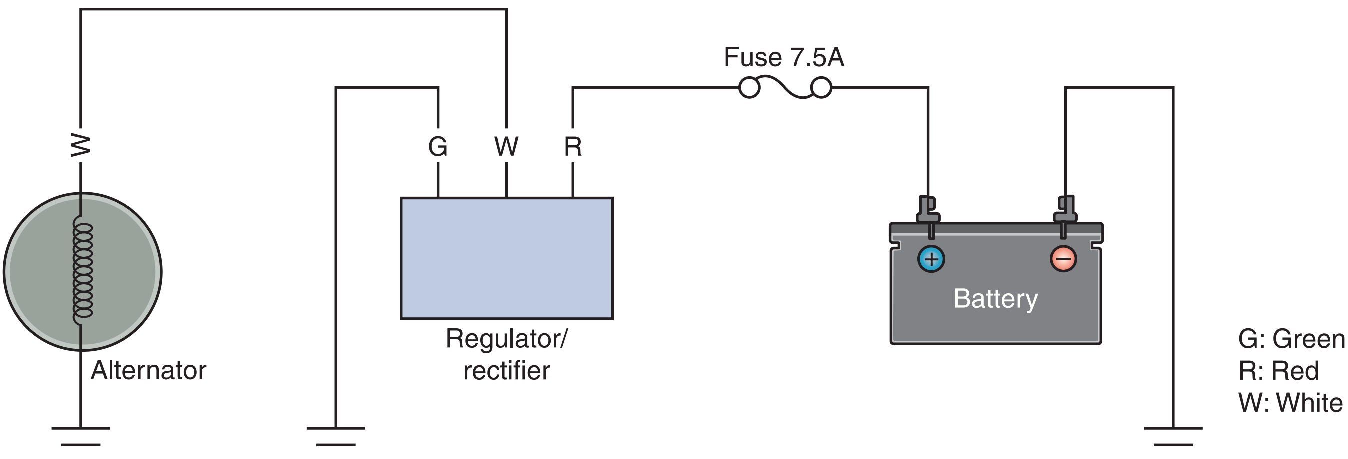


Figure 13-42 A typical block diagram of a charging system. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Dielectric A nonconductor of electricity; dielectric materials don't allow electricity to flow through them. *See also insulator*

Diode A semiconductor often used in a rectifier in power equipment engines; a diode has the characteristic of allowing current to pass through in only one direction, and it's thus used to change AC to DC

Dynamic Spinning or rotating in motion; refers to making a test when the component is in use

Electricity The flow of electrons through a conductor

Electron The revolving part or moving portion of an atom; electrons moving from atom to atom constitutes electrical current

Electrolyte The sulfuric acid and distilled water solution that batteries are filled with at setup

Electromagnet A coil of wire that is wound around a soft iron core; acts as a magnet when current is passed through it

Electromotive force Abbreviated as "EMF"; the pressure of electrons in a circuit (also known as voltage); created by difference in potential between positive and negative terminals of power supply; also called pushing force of electricity

Electrolysis The movement of electrons through an electrolyte solution; a battery charges and discharges through electrolysis; electroplating (chroming) is an example where electrolysis is used to move and deposit metals from one electrode to another; in cooling systems, contaminated coolant (tap water) becomes an electrolyte, allowing electrolysis and the deposition of metal oxide scale on cooling system components

Free electron An electron in an atom's outer orbit, which is held only loosely within the atom; free electrons can move between atoms

Field coil An electromagnet; the flux lines may be used for generating electricity, for electric motor operation, or for operating a solenoid/relay

Fuse A short metal strip that's protected by a glass or plastic case that's designed to melt when current in the circuit exceeds the rated value

Flux lines All the magnetic lines of force from a magnet

Ground A common conductor used to complete electrical circuits (negative side); the ground portion of power equipment engine electrical systems is often the frame

Ignition The spark produced by the high-tension coil by which the spark plug ignites the air–fuel mixture

Insulator A material that does not conduct electricity, thereby preventing the passage of electricity; all electrical wires are protected by a plastic or special rubber insulation

Lines of force Refer to a magnetic field whose lines run from its north pole to its south pole. *See also Flux lines*

Load Anything that uses electrical power, such as a lightbulb, coil, or spark plug

Magnetism The characteristic of some (ferrous) metals to align their molecules in a particular direction; the alignment of the object's molecules will cause the object to act as a magnet; every magnet has both a north pole and a south pole; like polarities repel, opposites attract; around every magnet, there's a magnetic field, which contains lines of force

Magnetic induction Introduction of electricity in a circuit when a conductor is moved through a magnetic field; occurs when the flux lines of the magnetic field cut through the conductor

No-load test A dynamic test with the component insulated or disconnected from its main system

NPN A transistor in which the emitter and collector layers are N-type and the base layer is P-type (negative, positive, negative)

Permeability Ability of material to "absorb" magnetic flux; can be temporary or permanent. *See Reluctance*

Pole The north "pole" or south "pole" of a magnet; also refers to the lugs (iron cores) of a stator around which the AC generator's wires are wound

Polarity In magnets, polarity is north and south; in electricity, polarity is positive and negative

PNP Transistor in which the emitter and collector layers are P-type and the base layer is N-type (positive, negative, positive)

Rectifier Changes AC to DC; usually a group of four or six diodes comprises a bridge rectifier. *See Diode*

Regulator Used to limit the output of a generator or alternator

Resistance The opposition offered to the flow of current in a circuit

Rotor The revolving magnets or electromagnets that form the magnetic field in an alternator or ignition signal generator

Reluctance Resistance to magnetism. *See also Permeability*

Reluctor Magnetic field interrupter used as a signal generator in ignition systems

Silicon A material used in the construction of semiconductors; because of its characteristics, the material allows current flow only under certain predetermined conditions

Sine wave A graphic depiction of the form of AC usually taken from an oscilloscope

SCR An abbreviation for silicon-controlled rectifier, which is an electronically controlled switch. *See Thyristor*

Selenium Similar to silicon materials in characteristics; it's used as a rectifier on older models

Solder Tin–lead alloy with rosin core used to form lower-resistance connections of electrical components or wires

Static Stationary; usually a test made of a stationary component rather than a bench test

Stator A stationary conductor (usually several coils of wire); when magnetic flux cuts the stator windings, a voltage potential is induced in the windings

Switch A device that opens or closes an electrical circuit

Schematic A wiring diagram showing in detail the electrical components and circuitry

Thermo-switch A bimetallic switch that, when heated, opens or closes a circuit

Thyristor An electronically controlled switch that opens when signaled at the gate and closes after current flow falls

Unloaded *See No-Load Test*

Valence electrons The electrons contained in the outermost electron shell of an atom; also known as free electrons

Voltage *See Electromotive Force*

Watt The unit of electric power; $W = E \times I$ (wattage = voltage × current)

Wire gauge Wire diameter; usually specified by an AWG (American Wire Gauge) number; the smaller the number, the larger the wire diameter

Wiring diagram Similar to a schematic, but less in detail; a wiring diagram usually shows components in block form rather than illustrating their internal circuitry

Zener diode Similar to a standard diode, but allows current flow in the reverse direction when the breakdown voltage is reached

Summary

- Electrical devices and circuits can be dangerous. Safe practices are necessary to prevent shock, fires, explosions, mechanical damage, and injuries resulting from the careless or improper use of tools.
- There are two theories of electricity: the conventional theory of electricity and the electron theory of electricity.
- There are three types of electrical circuits: series circuit, parallel circuit, and series/parallel circuit.
- Voltage, resistance, and current are common terms used with electricity.
- The amount of current flowing through a completed circuit is directly proportional to the voltage applied to the conductor, provided resistance is maintained constant. This relation between resistance, current, and voltage is known as Ohm's law.
- The multi-meter is the most widely used electrical testing tool in the power equipment engine industry and integrates three measuring devices into one handy-to-use tool: the voltmeter, the ammeter, and the ohmmeter.
- Before you can begin working on a power equipment engine electrical system, you must know how to read electrical schematics (also known as wiring diagrams).

Chapter 13 Review Questions

1. A circuit that has more than one path to the power source is a
   a. series circuit.
   b. open circuit.
   c. parallel circuit.
   d. short circuit.

2. When a conductor is moved through a magnetic field, a voltage is induced in the conductor. However, current won't flow through the conductor unless it's
   a. formed into a coil.
   b. connected in a complete circuit.
   c. moved very quickly through the magnetic field.
   d. made of copper.
3. What is the voltage of a circuit having a current flow of 3 amperes and a resistance of 4 ohms?
   a. 0.12 V
   b. 12 V
   c. 7 V
   d. 36 V
4. A circuit that has an incomplete path for current to flow is called
   a. a grounded circuit.
   b. an open circuit.
   c. a short circuit.
   d. a closed circuit.
5. EMF is measured in
   a. watts.
   b. ohms.
   c. amperes.
   d. volts.
6. An ohmmeter is always connected to an electrical circuit
   a. in series.
   b. to measure voltage.
   c. after the component being tested has been isolated from the rest of the electrical system.
   d. after the power has been turned on.
7. The terminals of a diode are the
   a. gate, anode, and cathode.
   b. primary and secondary.
   c. emitter, collector, and base.
   d. anode and cathode.
8. What would be the resistance of a 12-volt lightbulb with 5 amperes flowing through it?
   a. 2.4 ohms
   b. 2.4 volts
   c. 0.416 ohms
   d. 0.417 volts
9. An ammeter is always connected to an electrical circuit
   a. after it has been isolated from the rest of the electrical system.
   b. in parallel.
   c. in series.
   d. after the power has been turned on.
10. The conventional current flow theory can best be described as
   a. electron flow from the negative terminal to the positive terminal.
   b. electron flow from the cathode terminal to the anode terminal.
   c. electron flow from AC to DC and then back to AC.
   d. electron flow from the positive terminal to the negative terminal.
11. Electrical current flow is measured in
   a. ohms
   b. amperes
   c. watts
   d. volts
12. The abbreviation "AC" stands for ______ .
13. The abbreviation "DC" stands for ______ .
14. With a ______ , you can separate the desired subsystem, such as the ignition system, from the rest of the schematic.
15. Which theory of electricity is used in explanation of electrical circuits in the power equipment engine industry?
   a. Electron
   b. Electro-conventional
   c. Conventional
   d. Nonconventional

CHAPTER

14 Power Equipment Engine Charging Systems and DC Circuits

Learning Objectives

- Explain why power equipment engines have charging systems
- Describe the theory behind a basic charging system
- Visually identify from a schematic the different types of charging systems found in power equipment engines
- Describe how alternators generate AC power
- Describe how a charging system converts AC to DC
- Read block diagrams for various DC electrical system circuits

Key Terms

Alternator
Battery
Distilled water
Excited-field electromagnet alternator
Half-wave rectification
Maintenance-free (MF) batteries
Permanent-magnet alternator
Rectifier
Rotor
Stator
Voltage regulator

INTRODUCTION

This chapter is the second of three chapters devoted to electrical systems in power equipment engine. In Chapter 13, you learned about the basics of electricity, where electricity comes from, and how to measure it. In this chapter, you'll learn how to apply this electrical theory to understand power equipment engine charging and other related electrical systems. We'll begin by describing the basics of a charging system. Next, we'll take a closer look at each of the components in the charging system and how they operate. After we've discussed each of the components, we'll review the overall operation of the charging system, and explain how to maintain and troubleshoot components. We'll then take a look at some of the other electrical circuits found in power equipment engines.

A charging system is necessary in any power equipment engine that uses a battery to assist with powering electrical components. As in Chapter 13, we'll start with the basics. To understand how a charging system works, you must first understand what a charging system does. Then, you need to know the components that make up the charging system and how they work. You'll find that many of the figures in this chapter are line drawings of the components discussed. This is to allow you to understand better how these components are illustrated in the manufacturer's service manual. You'll also be shown actual images of the components on a power equipment engine.

CHARGING SYSTEMS

The purpose of a charging system is to replenish the voltage in a battery as it's used when the power equipment engine is operating. An **alternator** generates the electrical power source in the charging system. The alternator provides an alternating current (AC) output, but, as we know, a battery stores direct current (DC).

In order to convert the AC output of the alternator to DC, which is what is needed by the battery, a **rectifier** is used. The rectifier converts the AC (which, you'll remember, alternately flows in one direction, and then in the other direction) into DC (which flows in only one direction). This process is known as rectification. The voltage from the charging system to the battery is maintained within a predetermined range by a **voltage regulator.** By controlling the output of the charging system, the voltage regulator prevents undercharging or overcharging the battery.

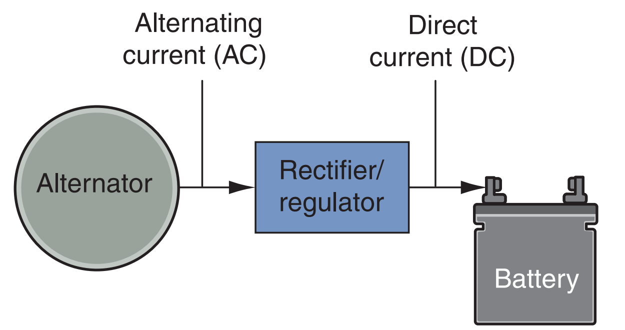


Figure 14-1 A block diagram of a simple charging system. All charging systems have the same basic components.

From the smallest single cylinder engine to large multi-cylinder power equipment engines, all charging systems have the same common basic components (Figure 14-1). Although these components may have different designs and sizes in various power equipment engines, they all perform the same functions.

The Alternator

Depending on the manufacturer, there are many terms used for an alternator, some of which are generator, dynamo, and magneto. For the purpose of this chapter, we'll simply refer to it as alternator as it's used to create AC. The alternator is driven by the rotation of the engine's crankshaft and may be directly connected to the crankshaft or it may be driven by a gear and placed elsewhere on the power equipment engine, depending on the size of the machine it's connected to. An alternator produces electrical output only when the crankshaft is rotating. Remember from Chapter 13 that there are three key requirements needed to produce AC voltage: a magnetic field, a conductor (coils of wire), and motion (Figure 14-2). The output

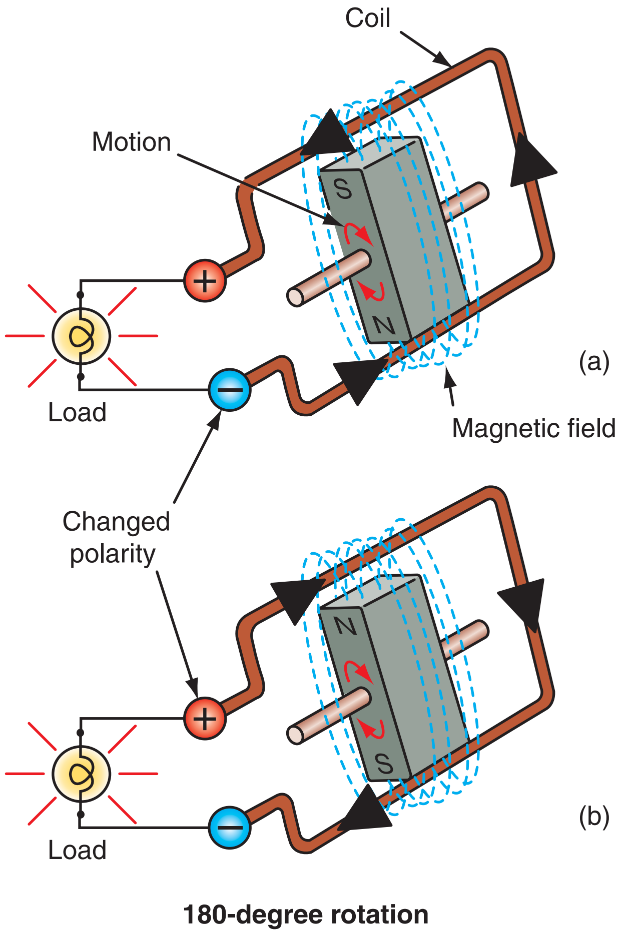


Figure 14-2 The three key requirements needed to produce AC voltage are a magnetic field, a conductor (coils of wire), and motion. (a) Current flow in one direction; (b) Current flow reverses direction. This creates alternating current (AC).

from the alternator varies with the speed of the engine. The faster the engine's crankshaft turns, the stronger the AC voltage that is produced.

An alternator has two main components: the **rotor** and the **stator.** The rotor has a series of magnets and rotates either inside or outside the stationary windings of the stator. The stator consists of sets of coils, which are used to produce power for the power equipment engine's electrical circuits and to charge the battery.

From the viewpoint of design and construction, alternators used in the power equipment engine industry can be divided into two general types: **permanent-magnet alternators** and **excited-field electromagnet alternators.**

Permanent-Magnet Alternators

The permanent-magnet alternator (Figure 14-3) is the most commonly used type of AC generating system found in power equipment engines. You'll find this type of alternator as an integrated component under the flywheel cover, with the flywheel mounted directly on the crankshaft (Figure 14-4). Permanent magnets are incorporated into the flywheel on the rotor (Figure 14-5). With this design, the flywheel is fitted onto the crankshaft and is held in place by a woodruff key (Figure 14-6) and a mounting bolt. In most cases in power equipment engines, the stator will be located on the crankcase (Figure 14-7).

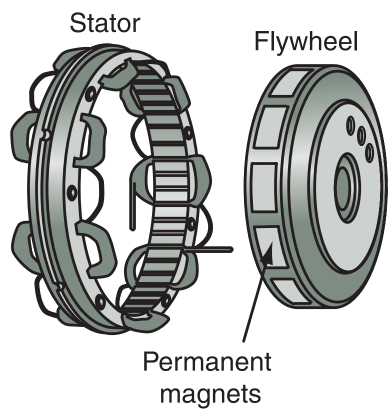


Figure 14-3 Permanent-magnet systems are the most popular types of charging systems found in power equipment engines.

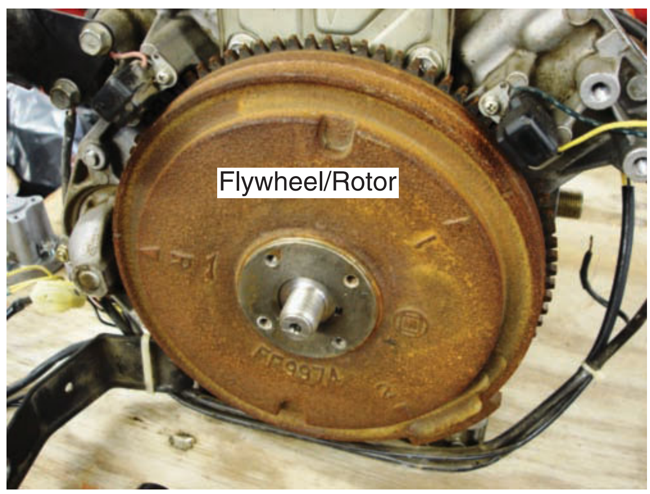


Figure 14-4 Permanent-magnet charging systems are generally located on the crankshaft of the engine under an engine cover.

Figure 14-5 Permanent magnets are attached to the rotor.

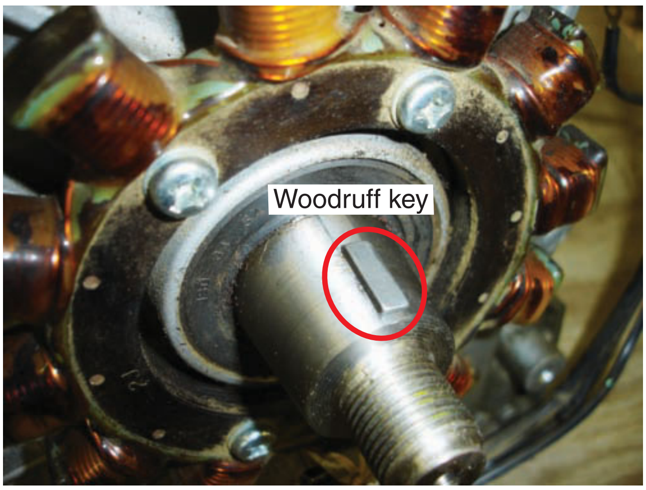


Figure 14-6 Alternator rotors are held in place generally by a woodruff key.

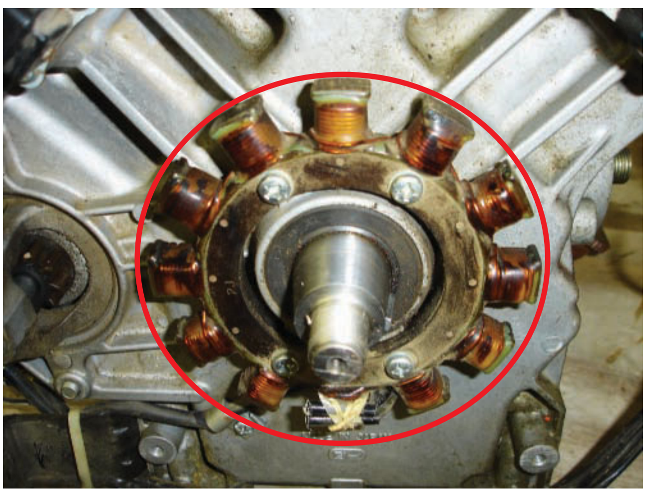


Figure 14-7 The stator is mounted onto the crankcase in most power equipment engines.

Excited-Field Electromagnet Alternators

Excited-field electromagnet alternators don't use a permanent magnet. Instead, they have a field coil, which, energized with DC, becomes a powerful magnet. Power is generated as the rotor spins past the stator. Excited-field electromagnets are located in different areas of the engine besides the crankshaft to help cool them, as in the case of the permanent-magnet alternator. When not connected to the crankshaft directly, the rotor's speed can be multiplied by gears or chains. This is done to increase the rotor's speed of rotation if it's deemed necessary by the manufacturer.

The excited-field alternator is potentially the most powerful AC generator available because of the strong magnetic fields that it can create. In most cases, the excited-field alternator will be found in larger, multi-cylinder engines and is fully self-contained, just as an alternator in an automobile. There are two types of excited-field electromagnet alternators, brush-type and brushless-type, which we'll discuss now.

Brush-Type Excited Field The brush-type excited-field coil has the field coil placed within the rotor (Figure 14-8). Current flows through

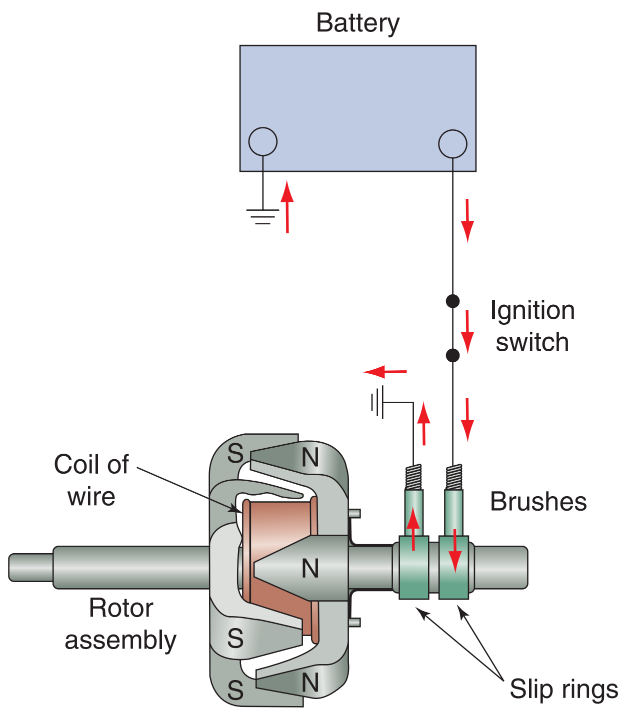


Figure 14-8 A diagram of a simple brush-type excited-field alternator.

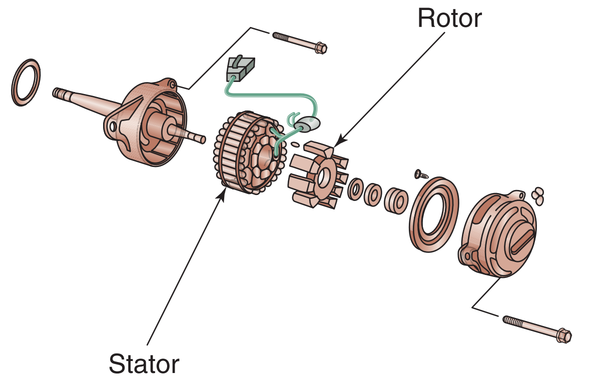


Figure 14-9 A brushless-type excited-field alternator. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

carbon brushes to the field-coil slip rings. When the carbon brushes are energized, current is induced in the rotor electromagnetically, and the rotor becomes a strong magnet. The rotation of the magnetized core acts on the stator coils to produce AC.

Brushless-Type Excited Field The brushless-type excited-field coil (Figure 14-9) has the rotor placed around the inner field coil, thereby eliminating the need for maintenance, which is required with the excited-field coil. When the field coil is energized, the magnetic field magnetizes the rotor core. The rotation of the magnetized core acts on the stator coils placed on the outside of the rotor to produce AC.

The Rectifier and the Voltage Regulator

A rectifier is required to convert the AC from the alternator into DC that is used by the battery. The rectifier uses a diode or a group of diodes to convert the AC into DC. It does this by preventing the negative half of the AC from progressing, thereby allowing only current in the positive half to flow. Voltage regulators are used to allow current to flow into the battery to charge it when needed and also to stop current flow to the battery to prevent it from being overcharged. Virtually all voltage regulators use thyristors (SCRs) and zener diodes, which provide a current-limiting function to control battery charging.

Although they're two separate components, voltage regulators and rectifiers are generally integrated as a single unit to reduce the cost of production (Figure 14-10).

Figure 14-11 shows a simplified schematic of a charging system. Note the dashed lines surrounding the regulator/rectifier. Inside the lines you can see diodes and SCRs. Diodes make up the rectifier, whereas SCRs are used for the regulator. To ease your understanding of these critical components of a power equipment engine charging system, we'll discuss the rectifier and regulator separately even though, in practice, they're generally combined as one unit.

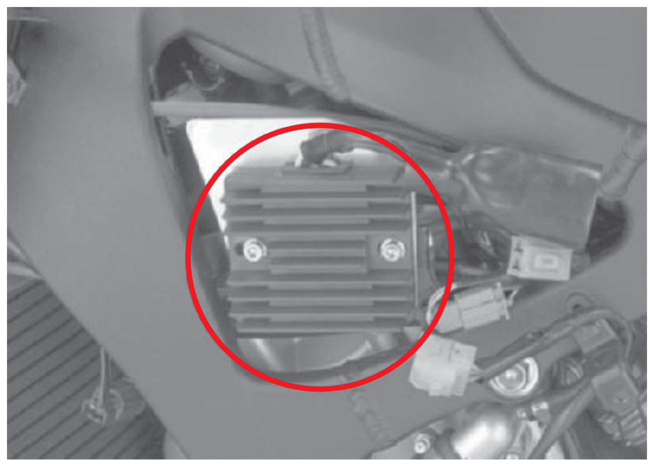


Figure 14-10 A voltage regulator/rectifier. The cooling fins help remove the heat produced from the regulator when it sends excess current back to ground. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

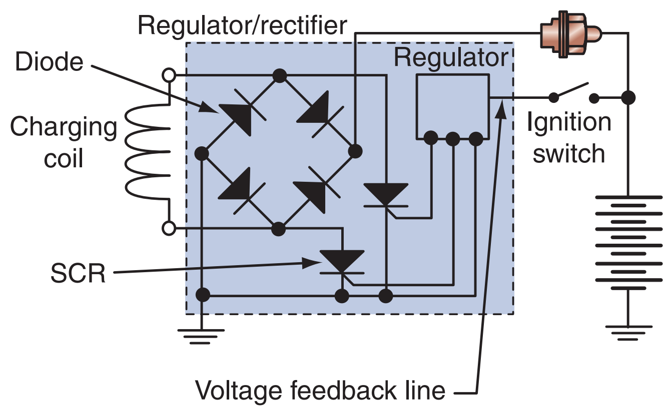


Figure 14-11 Although two separate components, the regulator and the rectifier are generally assembled as one unit, as shown by the dashed lines in this illustration.

Rectifiers

The purpose of a rectifier is to change the AC that's produced by the alternator into DC to charge the battery. A rectifier may consist of one to six diodes, depending on the requirements of the charging systems as determined by the manufacturer. Remember that the diode serves as a one-way electrical device that allows current to flow in one direction and not in the other.

The basic principle behind a rectifier's function is that it allows current to pass through in only one direction—like a one-way electricity gate. Because AC is constantly reversing direction, the rectifier must change it to DC so that it can be used by the battery, which stores electrical energy only as DC voltage. A single-diode rectifier wired in series into a circuit will block half of the AC flowing into it and allow the other half of the current to flow to the battery (Figure 14-12). This is known as **half-wave rectification** and is used in smaller power equipment engines that require a small amount of DC to keep a battery charged.

In order to allow more current produced by the alternator to reach the battery, additional stator coils and diodes are used. We'll discuss these systems in more detail later in this chapter. When rectifiers no longer work properly, they must be replaced as a unit as they can't be repaired. We'll also cover how to test rectifiers later in this chapter.

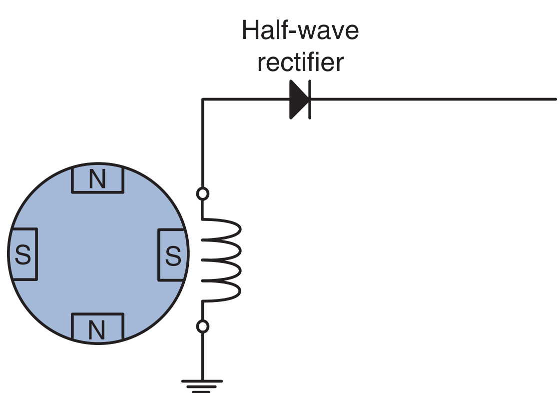


Figure 14-12 This simplified schematic shows a half-wave rectifier, which blocks one-half of the AC waveform.

Voltage Regulators

The purpose of a voltage regulator is to control the voltage in order to prevent undercharging or overcharging the battery. There are two types of voltage regulators: mechanical and electronic. The mechanical voltage regulator was widely used in power equipment engines until the 1970s but now is all but extinct. Therefore, we'll concentrate on electronic voltage regulators.

Electronic voltage regulators are used in virtually all power equipment engines today that have a need for voltage regulation. Electronic regulators contain no moving parts and never need to be adjusted. Generally speaking, most electronic regulators, or current limiters, as they're sometimes called, have a solid-state, transistorized arrangement of electronic devices, such as thyristors and zener diodes. Voltage regulators are difficult to test as they require a voltage input to turn the component on and off, and, as mentioned before, an ohmmeter can't be used to test a component when there is power applied to it. Therefore, most manufacturers set a predetermined voltage to check to verify that the voltage regulator is working properly. As with rectifiers, electronic voltage regulators are sealed units and can't be repaired. If a rectifier fails, the unit must be replaced.

An obvious disadvantage of having both the regulator and the rectifier assembled as one integrated unit is that if either the regulator or the rectifier fails, the entire unit must be replaced.

The Battery

Technically speaking, a **battery** is an electrochemical device that converts chemical energy to electrical energy. For the purpose of our discussion, a battery is a power source and an electrical storage device that supplies uninterrupted energy for the electrical system in the power equipment engine. For example, implements need lights that operate when the engine isn't running. They get the power for this from the battery. Accessories such as clocks and alarms require a battery, as does the electric starter. As the battery discharges because of use, the charging system charges the battery as required. Most modern power equipment engines use 12-volt electrical systems and therefore use 12-volt batteries.

Lead Acid Batteries

Power equipment engine batteries are also known as lead acid batteries. A conventional wet-cell power equipment engine battery consists of a series of cells (Figure 14-13). Each cell has positive and negative metal plates and is capable of storing about 2.1 volts of electricity.

The dissimilar metal plates are placed in an electrolyte solution of sulfuric acid and water. The plates are then insulated from each other with a permeable, nonconductive material, which allows the transfer of ions. The transfer of ions occurs during the discharge and recharge of the battery. The battery produces electricity from a chemical change that takes place between the positive and negative plates in the electrolyte solution (Figure 14-14).

Also occurring is the change in specific gravity or density (weight) of the electrolyte (Figure 14-15). During the discharge cycle, sulfuric acid is drawn from the electrolyte into the pores of the plates. This reduces the specific gravity of the electrolyte and increases the concentration of water. During recharge, this action is reversed and the sulfuric acid is driven from the plates, back into the electrolyte, increasing the specific gravity.

A key point to remember is that during the discharge cycle, lead sulfate crystals are formed on the battery plates (Figure 14-16). This is known as sulfating. Although sulfation is a normal reaction with all batteries during the discharge cycle, the battery must be recharged to drive out the sulfuric acid back into the electrolyte, without which, lead sulfate crystals will continue to develop and become difficult and eventually impossible to break down during a normal recharge cycle. There are two basic types of batteries used in a power equipment engine electrical system: conventional and maintenance free.

Conventional Batteries The conventional battery has a cap over each battery cell. When you charge a lead acid battery, electrolysis breaks the water down into its components: hydrogen and oxygen gas. Conventional batteries have a vent, usually routed into a tube, to remove the gases produced during the normal battery charge cycle. When current is supplied to the battery, gas

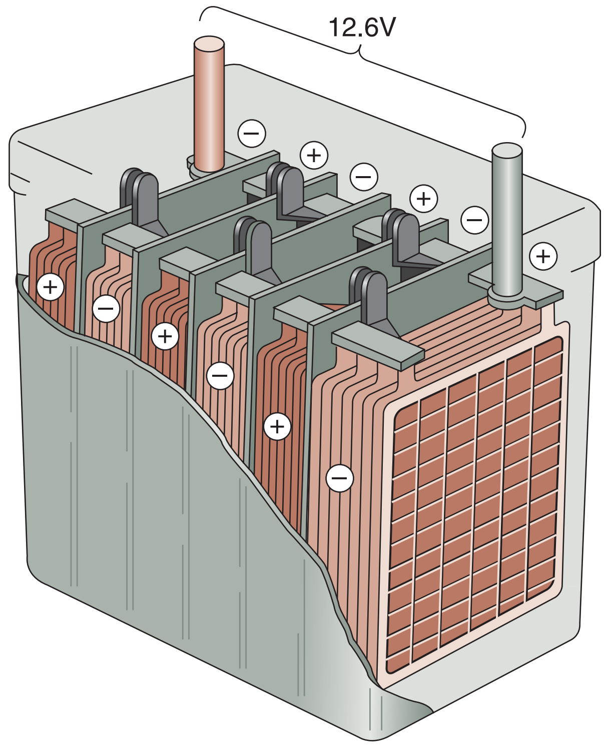


Figure 14-13 Batteries consist of a series of cells that contain positive and negative plates.

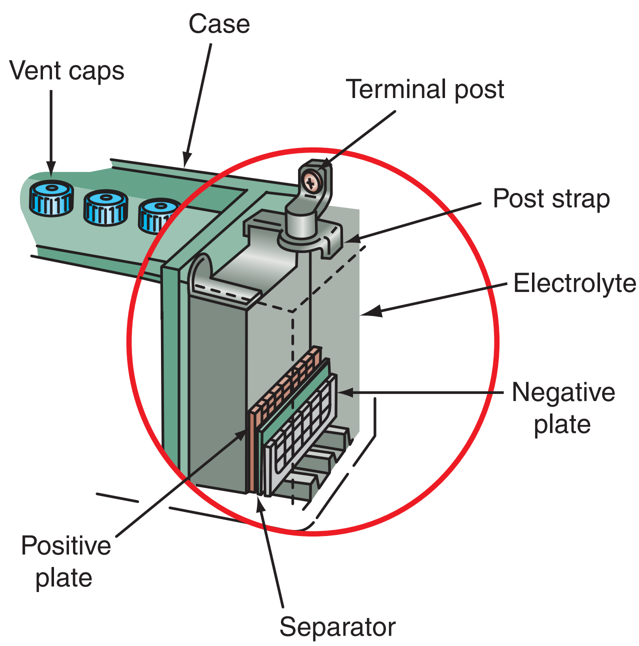


Figure 14-14 When the plates of a battery are placed in an electrolyte solution, electricity is created because of a chemical reaction.

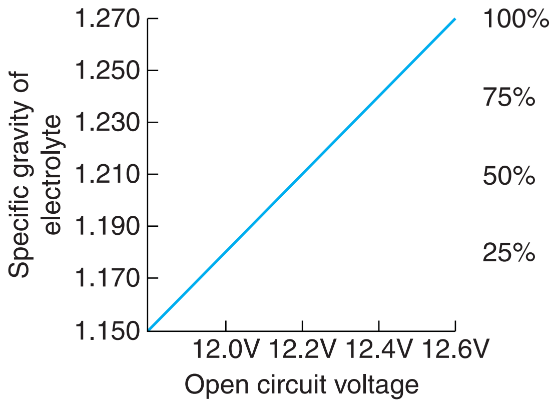


Figure 14-15 Electrolyte is measured by its specific gravity or weight as compared to water.

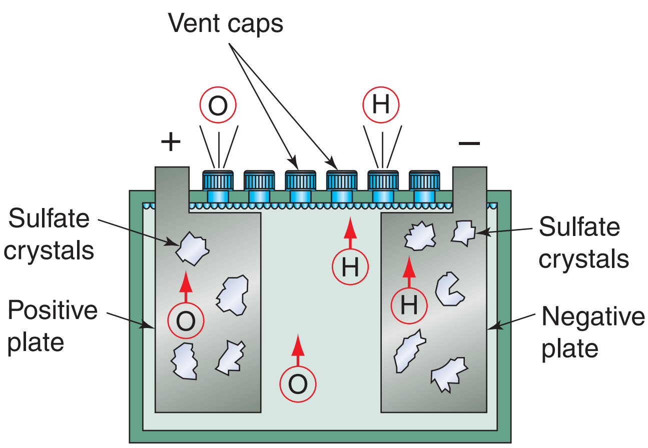


Figure 14-16 Sulfation is a normal action of any battery during its discharge cycle.

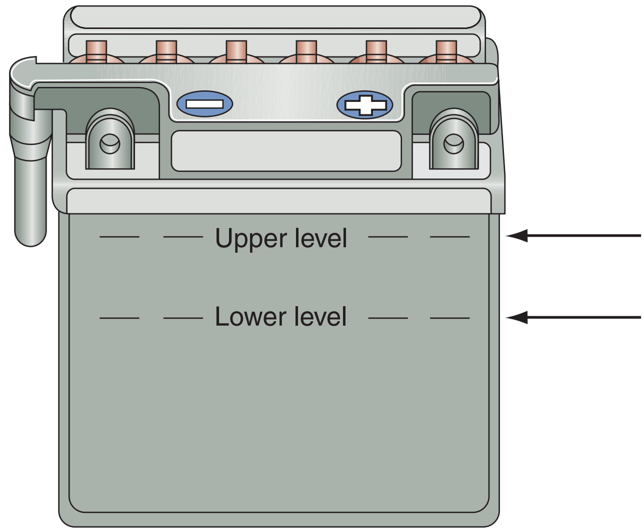


Figure 14-17 A battery's upper and lower level markings. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Figure 14-18 Distilled water can be purchased at any grocery store and is the only type of water that should be used to refill a conventional battery.

is emitted from the plates, and electrolyte temperature increases. This increase in heat causes a loss of water from the battery electrolyte over time. The loss of water and increased heat drastically reduce the life of the battery and, if left uncorrected, will damage the battery beyond repair. With the conventional battery, the water must be replaced as the level drops.

Because a battery is constantly subjected to charging and discharging cycles, the water in the electrolyte is slowly boiled off during normal use. Because of this, you should check the electrolyte level in a conventional battery on a regular basis. When the electrolyte level drops to a low level, add distilled water until the electrolyte reaches the upper level line on the battery case (Figure 14-17).

The volume of acid lost in this process is so small that acid replenishment is never required during the service life of a battery. However, the vent tube must be routed so that it does not discharge near critical parts that are susceptible to acid damage. Use only **distilled water** when refilling the battery (Figure 14-18). Distilled water is water that has virtually all of its impurities removed through distillation. Distillation involves boiling the water and recondensing the steam into a clean container, leaving the contaminants behind. Tap water contains chlorine, iron, and other elements, which will contaminate the electrolyte and reduce its effectiveness.

When the loss of water due to boiling reaches a point where the plates become exposed, the sulfation process drastically accelerates. This damages the battery and shortens the battery life. Sulfation can occur not only when the electrolyte level is low but also when the battery is discharged for long periods of time.

Remember to always replenish the battery with distilled water only.

Maintenance-Free Batteries **Maintenance-free** (**MF**) **batteries** are similar in design to conventional batteries. The difference is that the positive and negative lead plates in the MF battery use an absorbed glass mat (AGM), which totally seals all of the acid in the special plates and separators. Therefore, you don't need to add water to an MF battery.

Unlike the conventional battery, MF batteries do not have a vent to allow for the escape of excess gases. Instead, they use a safety valve that's designed to open when extreme gas pressures are produced. The safety valve closes and seals the battery when the internal pressure returns to normal. Figure 14-19 shows a cutaway illustration of a typical MF battery and its internal components.

MF batteries require that the included special acid pack (Figure 14-20) be installed prior to initial setup (Figure 14-21). Some MF batteries come prefilled directly from the manufacturer (Figure 14-22).

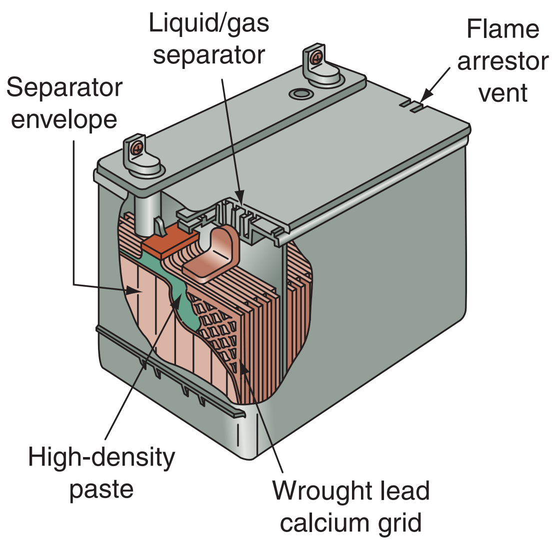


Figure 14-19 The various parts of a maintenance-free (MF) battery.

Figure 14-20 Most MF batteries come with their own acid pack, which must be installed prior to initial use.

Figure 14-21 The acid pack is installed using the manufacturer's instructions.

Figure 14-22 Some MF batteries come prefilled with acid from the battery manufacturer.

CHARGING SYSTEM OPERATION

Now that you know about the basic components in the charging system of a power equipment engine, let's see how these components work together to charge a battery. Later in this chapter, you'll learn how to perform various charging circuit tests. Let's now look at an example of a complete schematic (Figure 14-23). Note that all the wires are color coded. Oftentimes, the wire colors are abbreviated and a color code box included on the bottom of the schematic.

The schematic may seem quite complex at first, but if you break down the individual electrical system that you're working on, it becomes much easier to read and understand. You can break down a schematic by drawing a block diagram of the system (Figure 14-24). Use this figure as we discuss the operation of a basic charging system.

Locate the alternator on the block diagram. The alternator produces electricity in the form of AC when the engine is running. Notice the three stator leads connected to the alternator. Current flows through these leads, which are color coded and labeled "Y" (yellow). These wires carry AC from the alternator to the regulator/rectifier unit as the alternator rotor spins past the stator windings. The AC enters the rectifier and is changed to DC, which leaves the rectifier through the R (red) wire. This red wire provides DC to the battery for charging. The current from the red wire also sends a signal internally to the regulator of the regulator/rectifier unit. The rectifier and regulator are connected to the common ground by the G (green) wire. When the voltage reaches a predetermined level, the voltage regulator sends the excess rectified DC to ground to prevent the battery from being overcharged.

As you can see, by connecting individual components to work together as a system, DC is provided for charging the battery and supplying power to the lighting system. The AC is changed into DC by the rectifier. The amount of charging current is controlled by the voltage regulator. Each component in the charging system must be kept in good working condition to allow the charging system to continue to function properly. This includes keeping all wiring connections clean and tight fitting to prevent excessive resistance.

TYPES OF CHARGING SYSTEMS

Now that you understand how a basic charging system operates and can identify the individual components in a charging system, we'll move on to a discussion of the various types of charging systems that are found in power equipment engines. We'll begin with the simplest charging system and then learn about the more complex systems. Remember, all charging systems operate in the same basic fashion; they just have different ways of producing AC. One way that charging systems differ is related to the number of charging coils at the input. The charging system is also based on the needs of the electrical system. More electrical components require a larger output charging system.

Half-Wave Charging System

The half-wave charging system is the simplest charging system. This charging system uses only one "grounded" charging coil, and only one-half of the AC output is actually used. As shown in Figure 14-25, the alternator has two pairs of magnets, and it produces two cycles of AC for each complete rotation (360°) of the rotor (flywheel).

A single diode is used to rectify the AC output into DC to charge the battery. When the AC flows through the diode, the negative voltage wave of the AC is cut off and the positive voltage wave is passed to charge the battery.

This type of charging system has a low output, and its small size is best suited for very small implements with small electrical loads. Because of its low-output potential, this charging system isn't used very much anymore.

These low-output systems regulate the DC voltage by the use of a relatively simple half-wave regulating system (Figure 14-26). In this system, the charging current from the alternator is rectified by Diode D1, the output of which charges the battery. When the AC voltage

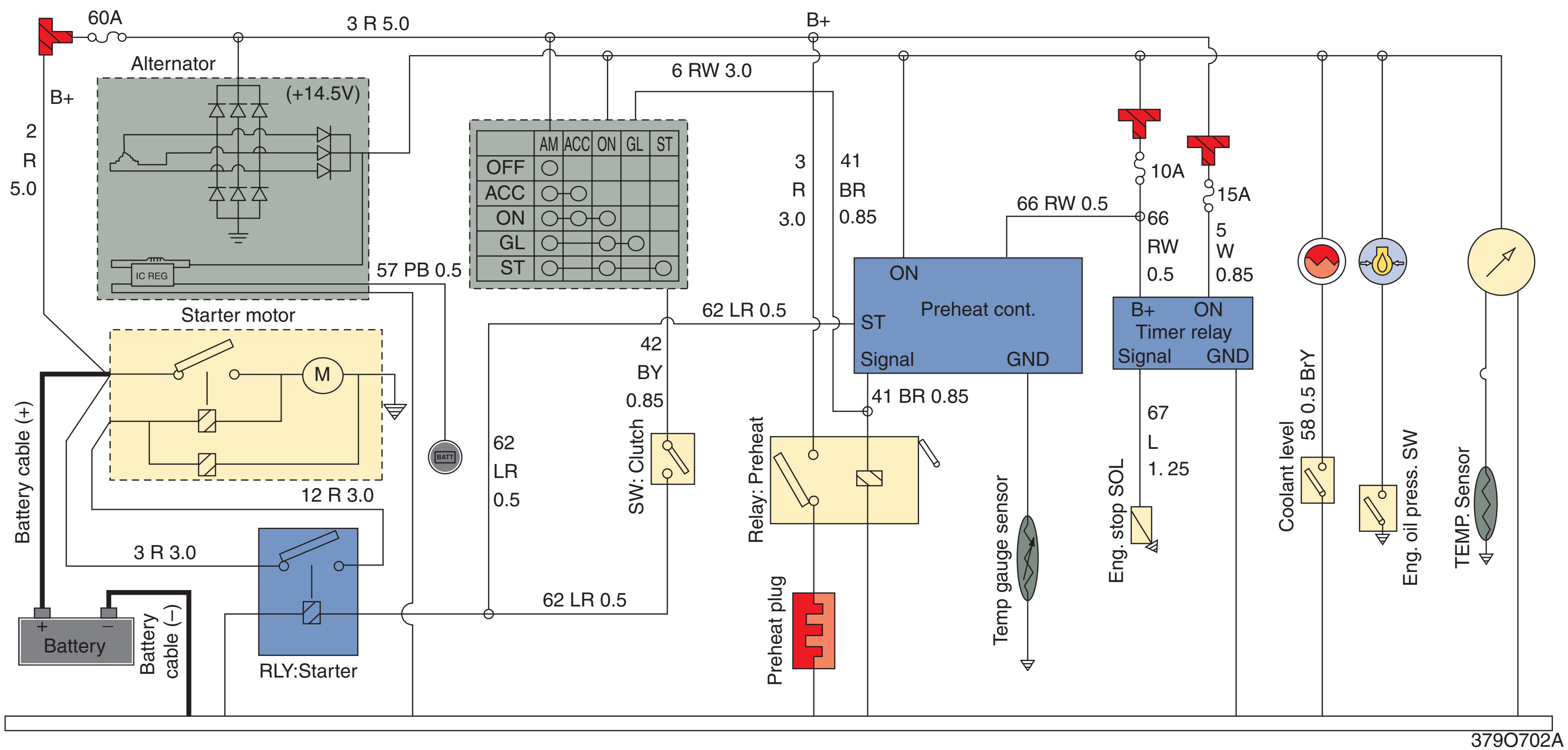


Figure 14-23 A complete schematic of a tractor's electrical system.

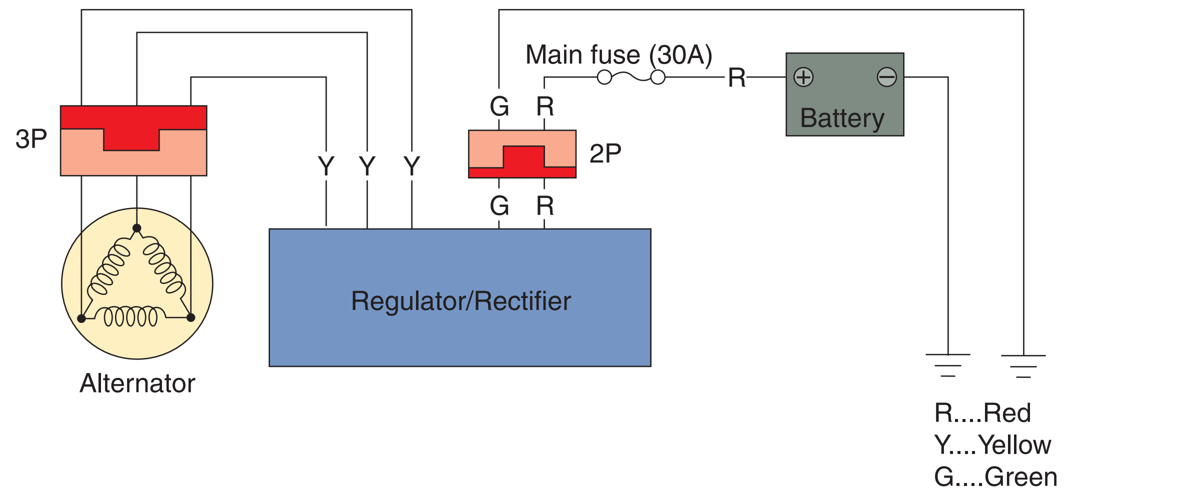


Figure 14-24 A block diagram of a charging system. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

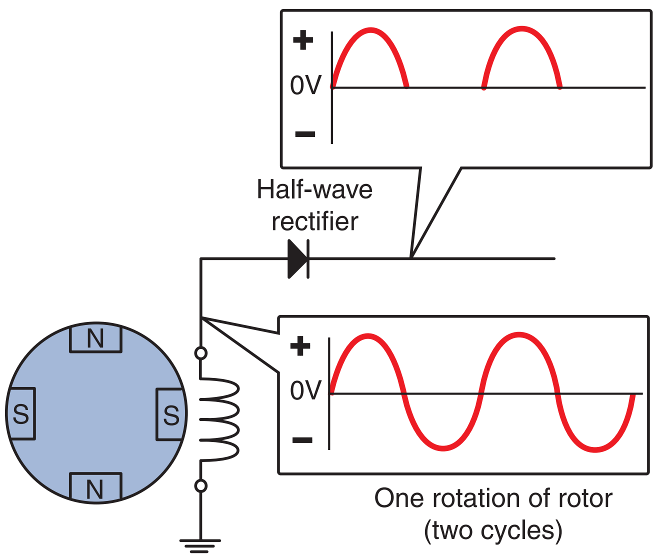


Figure 14-25 The half-wave charging system is simple in design as it only has one diode.

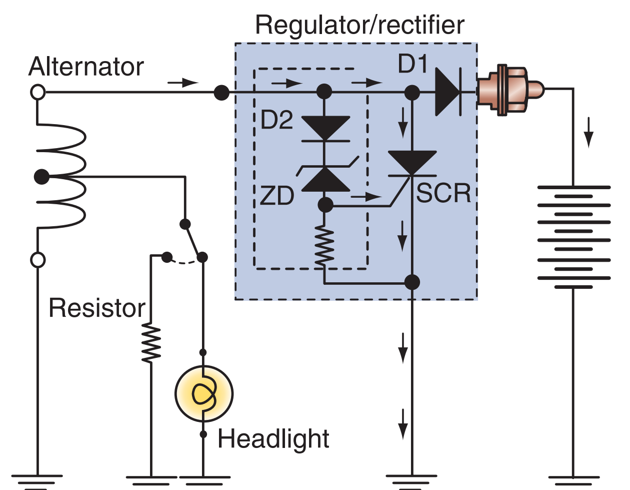


Figure 14-26 A half-wave charging system with a voltage regulator either fully charges or does not charge the battery at all.

increases (as the engine rpm increases), the AC wave rectified by Diode D2 goes through the zener diode and enables the gate of the SCR to open. The SCR shorts the AC input from the alternator to ground. Therefore, the half-wave charging system with a voltage regulator either fully charges the battery or does not charge the battery at all. This is the major disadvantage of the half-wave charging system and the main reason that it's not used much any more. You may also notice from the figure that this system uses AC to power the headlight system. When the headlight isn't on, the excess power is sent back to ground through a resistor.

One other type of voltage regulation found in some half-wave charging systems is known as the "balanced" charging system. In this system, the alternator is designed to allow the maximum amount of AC that won't overcharge the battery. The proper AC level is maintained independent of engine speed. Therefore, the balanced charging system needs no voltage regulator. The complete charging system consists of an alternator, a single diode, and a battery.

Full-Wave Charging System

A full-wave charging system also uses one charging coil, similar to the half-wave system, but instead, uses the full output potential of the charging coil instead of sending one half of the coil's output to ground. Full-wave charging systems are used in some medium-sized power equipment engines. Compared to the half-wave charging system, the full-wave charging system is more efficient because it uses almost all of the alternator's output for charging the battery.

The full-wave charging system uses four diodes to rectify the AC from the alternator (Figure 14-27). When the AC input voltage is positive, current flows from the alternator through Diode D1, to the battery, through Diode D2, and back to the alternator, as shown by the red arrows. When the AC input voltage reverses direction, current flows from the alternator, through Diode D3, to the battery, through Diode D4, and back to the alternator, as shown by the black arrows. Operating in this fashion, the AC output of the alternator is converted into a full-wave DC waveform.

The voltage regulation system used in a full-wave charging system generally has a voltage feedback line (Figure 14-28). The feedback line "tells" the voltage regulator when the battery no longer needs to be charged. The regulator then opens the gates on the SCRs. The SCR shorts the AC input from the alternator to ground and cuts off one-half of the current to the battery; it also has the capability to cut off all the current to the battery if needed.

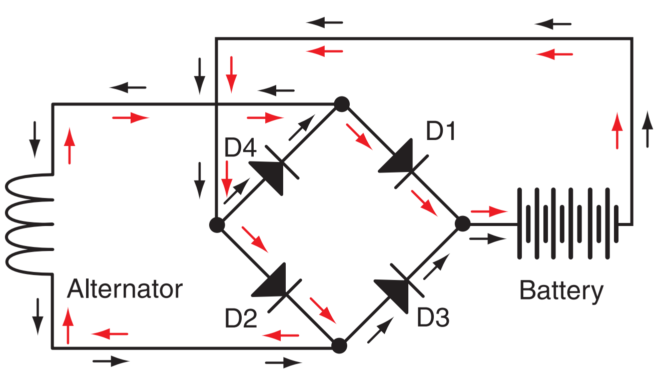


Figure 14-27 By using four diodes, both the upper and lower halves of the AC wave are used and a full-wave rectification system results.

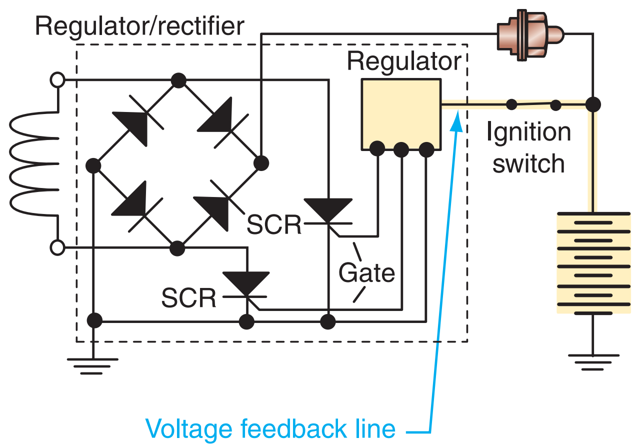


Figure 14-28 A full-wave charging system block diagram with a voltage regulator.

Three-Phase Permanent-Magnet Charging System

The three-phase permanent-magnet charging system is the most widely used system in power equipment engines, because of its large charging potential. This system uses permanent magnets, like the charging systems previously mentioned; however, the three-phase system uses three charging coils instead of one (Figure 14-29). The alternator for this type of charging system, just as in the previous two systems discussed, has the rotor mounted on the crankshaft and the stator mounted on the engine (Figure 14-30).

The rectifier in the three-phase system consists of six diodes and is connected to the alternator. The voltage regulation system is the same as in the full-wave system, except that it has the ability to change the charging system from three-phase system to a full-wave or a half-wave system, as the battery approaches its full charge. This is done by independently controlling the gates to the three SCRs, which short the alternator output to ground (Figure 14-31). The waveform created by a three-phase charging system (Figure 14-32) closely approximates that of a pure DC output, because three AC waves are produced in a single revolution of the alternator's rotor.

Three-Phase Excited-Field Electromagnet Charging System

The three-phase excited-field electromagnet charging system is used in many larger power equipment engines and in engines in which the

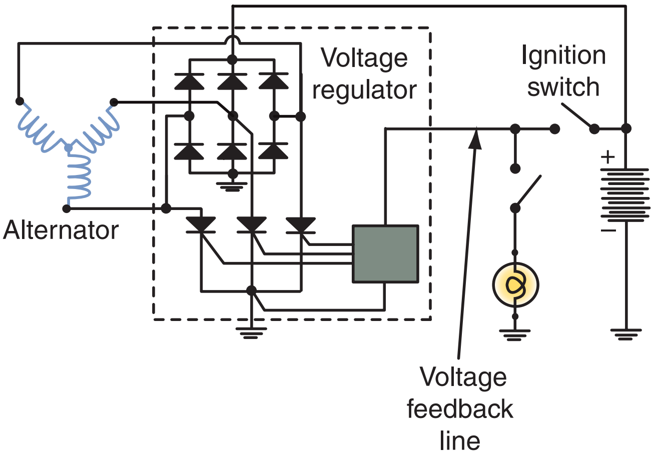


Figure 14-29 A three-phase permanent charging system has three coils of wire at the alternator instead of one, as found in the half-wave and full-wave systems.

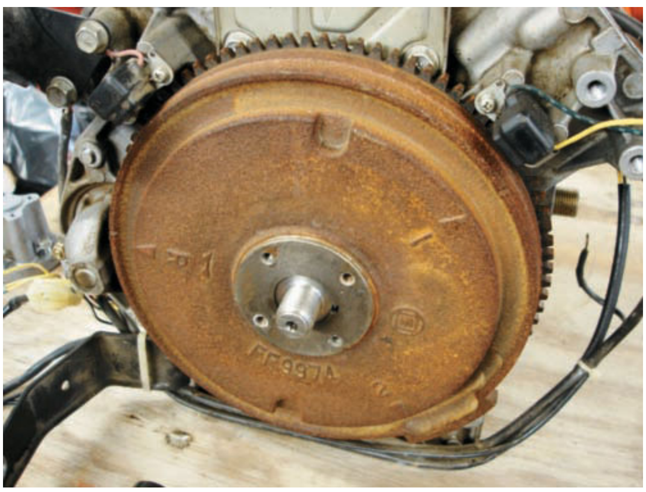


Figure 14-30 The alternator for the three-phase permanent-magnet charging system has the rotor mounted on the crankshaft. The stator is mounted on the crankcase.

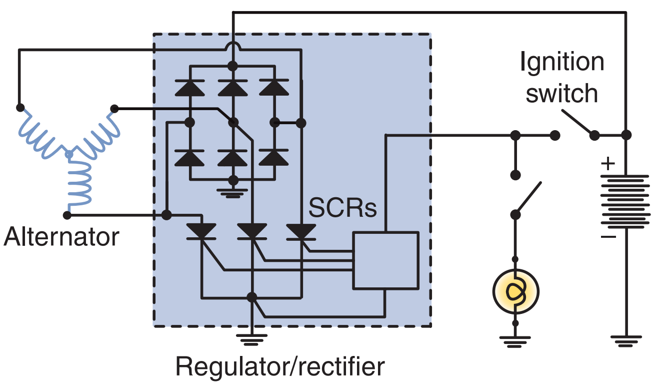


Figure 14-31 The regulator/rectifier in a three-phase charging system has six diodes and three SCRs.

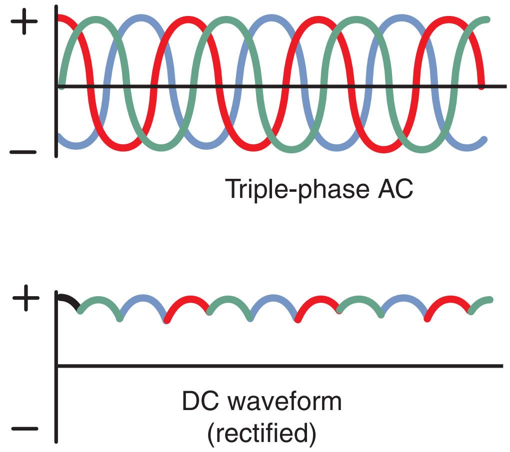


Figure 14-32 The waveform created by a three-phase charging system closely approximates that of a pure DC output, because three AC waves are produced in a single revolution of the alternator's rotor.

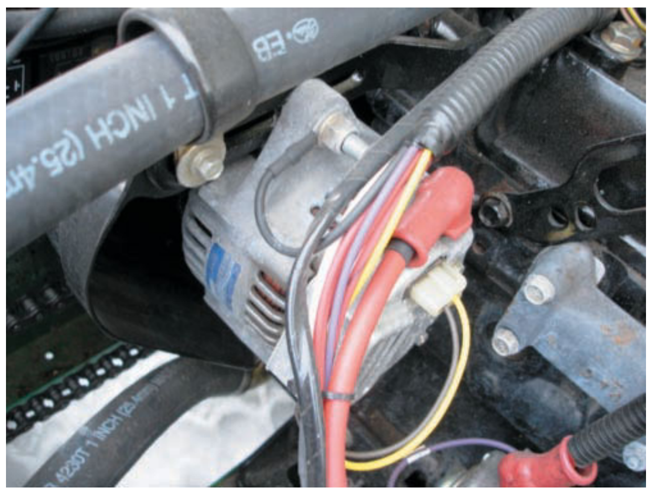


Figure 14-33 An excited-field charging system isn't generally located on the crankshaft, as seen here.

alternator isn't directly mounted on the crankshaft (Figure 14-33). The three-phase electromagnet system differs from the three-phase permanent-magnet system in that it uses an electromagnet in the alternator instead of a permanent magnet to produce the input AC, and also in most cases, it's completely self-contained (Figure 14-34). This means that all charging system components are housed within one unit. As mentioned previously, there are two types of excited-field systems: brush-type and brushless-type.

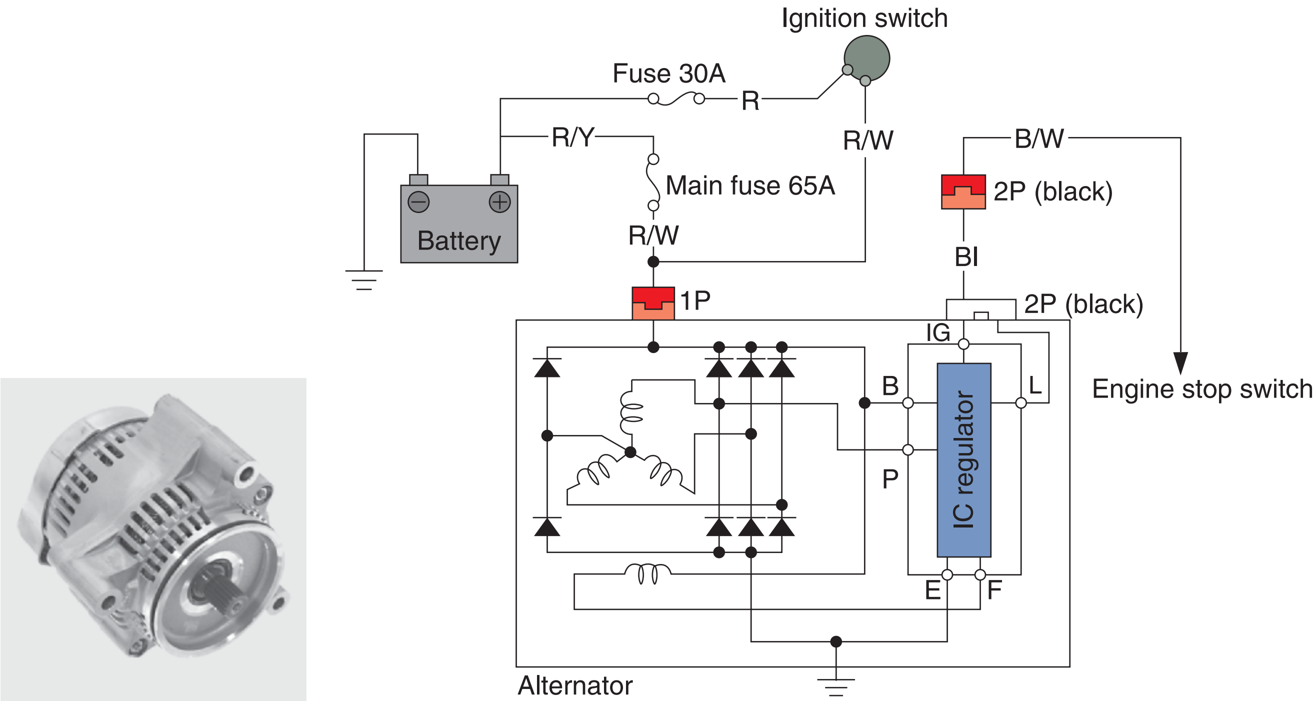


Figure 14-34 The three-phase electromagnet system differs from the three-phase permanent magnet system primarily because the former uses an electromagnet instead of a permanent magnet to produce AC. Also, in most cases, it's completely self-contained. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Voltage regulation in the three-phase electromagnet occurs by changing the field coil current to create a stronger or weaker electromagnet. By having more current pass through the field coil, a stronger electromagnetic field is created. Conversely, having less current pass through the field coil produces a weaker electromagnetic field.

The voltage regulator monitors the voltage at the battery and controls the base of the transistor. When the regulator turns the transistor on, the battery feeds current through the ignition switch, field coil, and transistor to ground. The field coils magnetize the rotor and the alternator generates AC as the engine rotates.

The charging system waveform created by the three-phase excited-field electromagnet charging system is the same as for the three-phase permanent-magnet system (see Figure 14-32).

CHARGING SYSTEM INSPECTION

Thus far in this chapter, we've discussed how to recognize the different components of a charging system in a power equipment engine. We're now going to combine that information and expand on it to help you understand how to inspect for problems found within a charging system.

Hand Tools for Electrical Work

The basic hand tools you'll need for most electrical repairs are as follows:

- Soldering gun (Figure 14-35)
- Cutting pliers (Figure 14-36)
- Needle nose pliers (Figure 14-37)
- Wire stripper/crimping pliers (Figure 14-38)
- Test light (Figure 14-39)
- Multi-meter (Figure 14-40)
- Hydrometer (Figure 14-41)

There are also other electrical system specialty tools that generally are manufacturer specific as well.

Figure 14-35 A typical soldering gun.

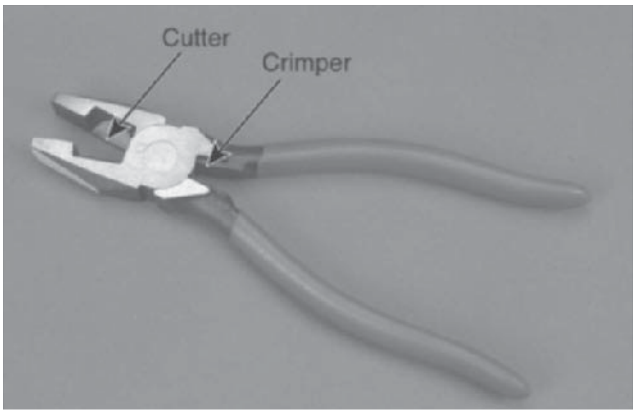


Figure 14-36 Cutting pliers with a wire crimper.

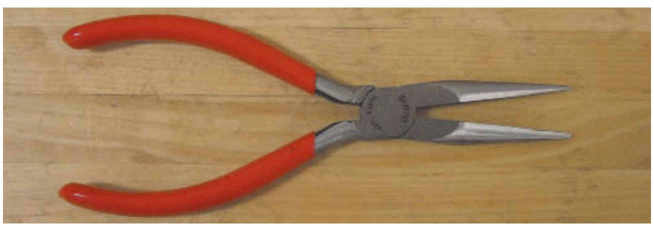


Figure 14-37 Needle nose pliers.

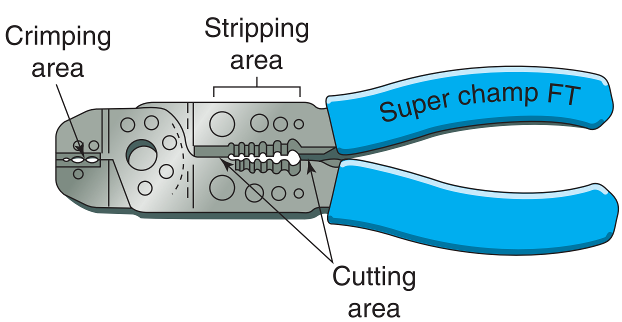


Figure 14-38 Wire striper/crimping pliers.

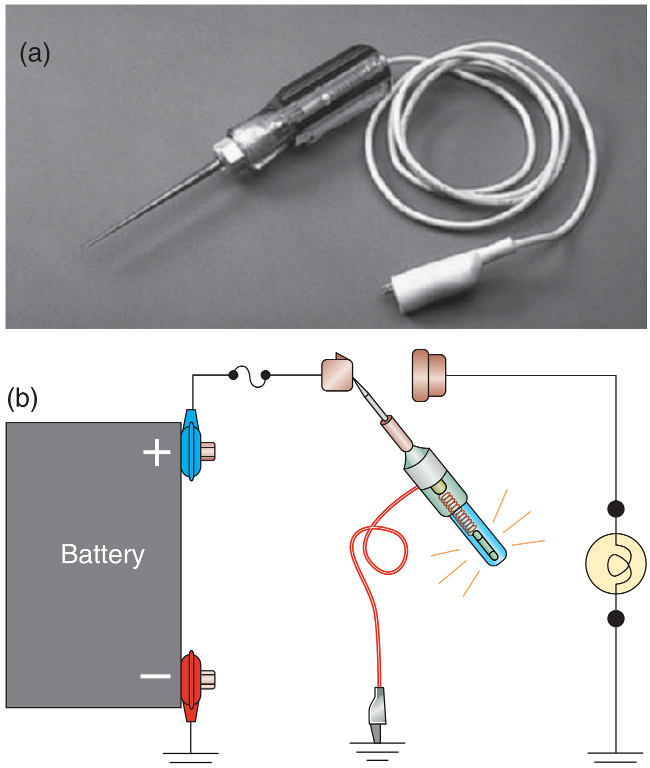


Figure 14-39 (a) A typical test light; (b) circuit diagram of a test light in use.

Figure 14-40 A typical digital multi-meter.

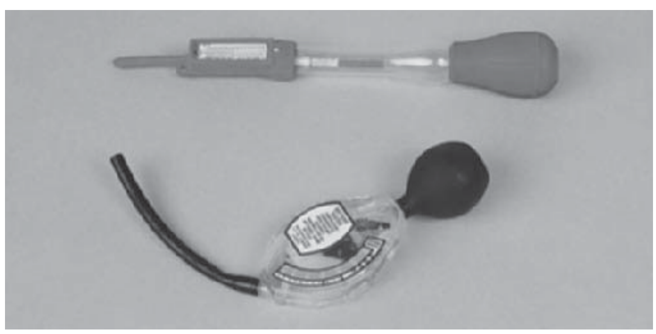


Figure 14-41 Two types of hydrometers. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Battery Inspection

First off, be careful when working with a battery. Always wear safety glasses and rubber gloves when working around batteries. Battery acid will destroy clothing, paint, and the like, and could also cause severe burns if it gets on your skin. If you accidentally spill some battery acid, the spill should be washed quickly using water and baking soda, which will help neutralize the acid. After handling battery acid, always wash your hands thoroughly.

Before checking, you should always visually inspect the battery. If there are cracks in the casing, broken terminals, bulging, or other signs of severe damage, such as heavy white lead sulfate on the internal plates, the battery should be replaced.

Next, check the battery cables and ensure they have good contact with the battery terminals. If the cables or terminals are corroded or loose, be sure to clean and tighten the connection. A bad battery connection can cause high resistance, which will interfere with the flow of electrical current. Clean the battery cables and terminals with a wire brush (Be sure to wear safety glasses!). The same goes for any cable connection pertaining to the battery, such as the starter solenoid and ground connectors. A smear of dielectric grease on the cables and terminals helps prevent corrosion.

The electrolyte in a battery is very caustic. The condition of a battery is determined by the specific gravity of the electrolyte. When working with a conventional battery, you can use a hydrometer (Figure 14-41), which is available from most automotive parts stores. When a battery is new or fully charged, you should get a specific gravity reading of 1.280–1.320 (depending on air temperature). As the battery is discharged, this reading will decrease.

A battery provides DC for operating the power equipment engine. One way of determining the amount of current that can be drawn out of a battery is to know its amp-hour capacity. For example, a 12-amp-hour battery will discharge fully if 1 amp of current is drawn out continuously for a 12-hour period.

Power equipment engine batteries are rated in amp hours. The larger the amp-hour number, the stronger the battery. The voltage does not change in relation to amp hours of the battery.

The battery amp-hour rating isn't always stated within the battery model number. To determine the amp-hour rating in most batteries, you must look on the battery cover. Some batteries will state the amp-hour rating right on the battery (Figure 14-42).

Most other MF battery amp-hour ratings will have to be determined using some good old-fashioned math! To determine what the amp-hour rating is on a particular battery, simply look at the standard charge rating (Figure 14-43), shown as "STD" imprinted on the battery and multiply that number by 10.

Batteries that are weak or have been out of service for a long time can be recharged using a battery charger. Note that there are two types of battery chargers available.

Power equipment engine manufacturers generally don't recommend the use of automotive-style battery chargers (Figure 14-44). Most automotive chargers are of the constant-voltage–variable-current type and are slow to charge a battery in a small power equipment engine. However, if you don't shut off the charger on time, a battery can overcharge. It can also be damaged if left connected to the incorrect battery charger for a long time. Remember that batteries produce hydrogen gas, which is explosive. Install the positive battery post first when installing a battery, and always charge a battery in a well-ventilated area.

Instead, most manufacturers recommend the more sophisticated constant-current battery charger–maintainer (Figure 14-45), which

Figure 14-42 In some batteries, the amp-hour rating may be easily determined by looking at the battery cover. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Figure 14-43 Some battery amp-hour ratings must be determined by locating the STD number. Multiply the STD number by 10 to determine the amp-hour rating. The STD rating may be shown on the front (top) of the battery or on the top of the battery (bottom).

Figure 14-44 Automotive-type constant voltage battery chargers are not usually recommended to charge smaller power equipment batteries.

(a)
(b)

Figure 14-45 Most battery manufacturers recommend a constant-current battery charger over the constant-voltage automotive type. These battery chargers can be purchased to charge (a) 1 or 2 batteries or (b) up to 10 at once!

Figure 14-46 Load testers are used to test a battery's ability to withstand high electrical loads. This particular unit shows that it's for motorcycles but is used on any type of battery that fits within its range.

has advanced features to recover, monitor, and maintain 12-volt batteries. A battery charger–maintainer shuts off the charging process, thereby preventing it from overcharging even if left on the charger for a long time.

In the past and in some cases even today, a battery would be tested for its ability to hold a charge by using a battery load tester (Figure 14-46). A load tester tests the battery under a heavy electrical load, such as an electric starter. This test is performed while the battery is disconnected from the implement it's meant to power.

The power equipment engine industry is now beginning to use a tool that has been used in the automotive industry for some time now to measure the health of a battery (Figure 14-47). A battery

Figure 14-47 A battery conductive analyzer describes the battery's ability to conduct current. This type of test is a more accurate way to determine the battery's internal condition compared to load testing.

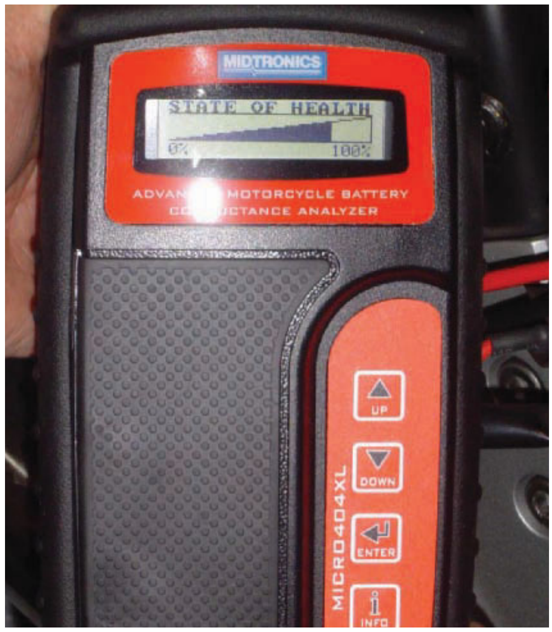


Figure 14-48 A battery conductive analyzer has the capability to test the state of health of a battery.

conductive analyzer describes the battery's ability to conduct current. It measures the battery plate surface available in a battery for chemical reaction. Measuring conductance provides a reliable indication of the battery's condition and is correlated to battery capacity. This type of tester can be used to detect cell defects, shorts, normal aging, and open circuits, which can cause battery failure.

A fully charged battery has a high conductance reading, up to 110% of its internal rating. As a battery ages, the plate surface sulfates or sheds active material, which lowers its capacity and conductance.

The conductance tester displays the service condition of the battery. It indicates if the battery is good, needs to be recharged and tested again, has failed, or will soon fail. As well as giving a state of charge, this type of tester also shows the overall battery condition, the "state of health" of the battery (Figure 14-48).

Once sulfation develops to an advanced state, permanent capacity loss or total failure of the battery occurs. Besides sulfation concerns, many other detrimental actions take place inside the battery while in a discharged condition. The corrosive effect on the lead plates and connections within the battery is greatly increased because of the reduced specific gravity of the electrolyte. The corrosion of the plates typically result in a gradual reduction in performance, followed by battery failure. The corrosion associated with the inter-cell connectors and the connecting welds in many instances result in sudden battery failure. A corroded connector may have sufficient integrity to support low-drain accessories, such as lights and instruments, but lack the necessary strength to provide the high-discharge current required to start the vehicle. This corrosive effect can also dissolve the lead into solution, which in turn may compromise the plate insulators and result in micro-shorts. Another condition that frequently occurs in a discharged battery is freezing, because the solution in a discharged battery has lower acid content and therefore higher water content.

Rectifier/Regulator Inspection

As we've mentioned, electronic voltage regulators and rectifiers have no internal moving parts and must be replaced if found defective. The main symptoms of a faulty voltage regulator are the following:

- The battery discharges.
- The battery becomes overcharged.
- The lights in the electrical system burn out quickly.

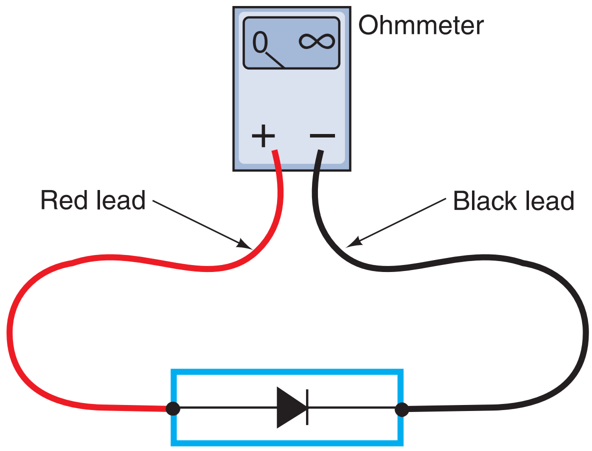


Figure 14-49 Testing a diode with an ohmmeter.

In most cases, to inspect a voltage regulator, you simply run the engine at the manufacturer's recommended engine speed and check for DC voltage at the battery. If the system is overcharging, the regulator is at fault and will require replacement. If the charging system is undercharging and all other charging system components have been proven to be in proper working order, the regulator is likely to be at fault.

Rectifiers are relatively easy to test. You can use an ohmmeter to test rectifiers (Figure 14-49). Simply connect the ohmmeter to the ends of each of the diodes and check the resistance in both directions. The resistance should be low in one direction and very high in the opposite direction. The specification will be given in the appropriate service manual. A general guideline for testing most diodes is to have 5–40 ohms of resistance in the forward bias direction (where current is allowed to flow) and infinite resistance in the reverse bias direction (where current isn't allowed to flow).

To test the three-phase six-diode rectifier shown in Figure 14-50, connect the black probe of the ohmmeter to the ground side of the rectifier (E) and the red probe to P1, P2, and P3. Record your measurements. Then swap the meter leads and take the three resistance readings again. You have now measured the ground side of the rectifier.

You can now test the battery side of the rectifier by connecting the meter probes to the battery (B) side of the rectifier and test the diodes in the same manner. When you have completed testing,

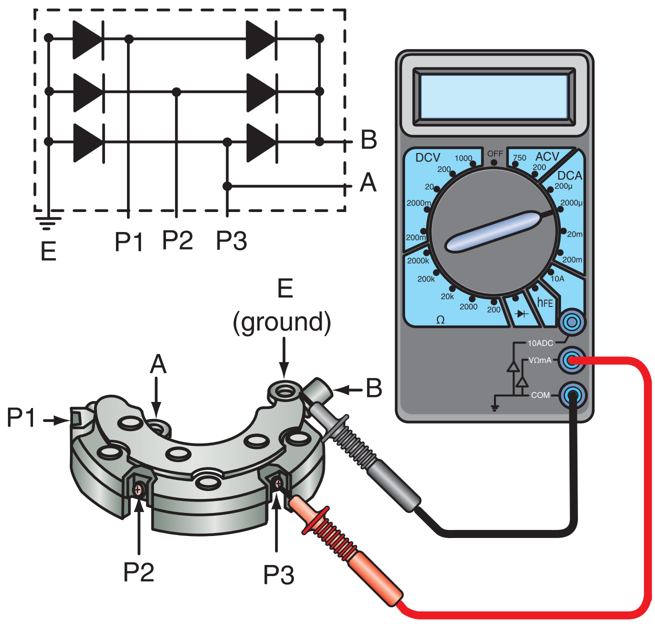


Figure 14-50 Testing a six-diode rectifier requires 12 individual tests.

you should have 12 readings consisting of forward and reverse bias measurements for each of the 6 diodes. In most cases, a diode will have between 5–40 ohms of resistance in the forward bias and show infinite resistance in the reverse bias.

Alternator Inspection and Testing

The function of the alternator is to produce electricity that can be used to charge the battery and supply current for other electrical system accessories such as lights. As you learned before, the principal parts of an alternator are the rotor and the stator. Permanent magnets or electromagnets are attached to the rotor and rotate when the crankshaft rotates. Rotors are positioned so that the magnets closely pass the stator coils. As the magnets pass the coils, electricity is induced in the coils.

Problems seldom occur with alternators because they have few moving parts. Servicing is generally not required except on brush-type excited-field alternators. If a problem does occur on an alternator, the problem may be due to a faulty stator coil. You should be aware of possible stator coil failures such as:

- **Open stator wire.** If the stator wire is open, there is no AC output; therefore, the battery will not charge. In this case, an ohmmeter will indicate no continuity (infinite resistance) between the terminals being tested.
- **Shorted circuit.** Diagnosis of a shorted circuit is a bit more difficult. The symptom may simply be poor AC output performance or low AC output when the engine is hot. Vibration or shock can be the cause of such problems.

Rotors

Rotors must not contact the stator coils as they turn. Therefore, care should be taken to ensure that the rotor is correctly positioned on the crankshaft. If the rotor is loose or crooked, it will wobble and damage the stator coils.

Rotors don't require service and rarely fail; however, care should be taken to prevent the loss of magnetism on permanent-magnet charging systems, which can be caused in several ways, such as:

- Dropping the rotor
- Hitting the rotor with a hammer (e.g., to remove it)
- Allowing the rotor to come into contact with another magnetic field

Heat and aging are other factors that can cause rotors to lose their magnetism. If the magnets on the rotor are weakened for any reason, you should replace the rotor. Keep in mind, however, that there are no specifications given to tell you how much magnetism a magnet should have. Therefore, you should be aware that low rotor magnetism is the cause of a weak charging system if all other tests indicate that the charging system is working properly and yet the battery does not come to its full charge.

Excited-Field Electromagnet Coil Inspection

Excited-field electromagnet coils can be inspected by measuring the field coil resistance. To measure the coil resistance, set an ohmmeter to the R1 range. Connect the test leads of the ohmmeter to the slip rings (Figure 14-51). If the meter doesn't read as specified in the service manual, replace the component. Coil resistance should normally be about 4 ohms. Also, check to make certain that there is no short to ground at the excited filed by testing the slip ring to the end of the rotor shaft (Figure 14-52).

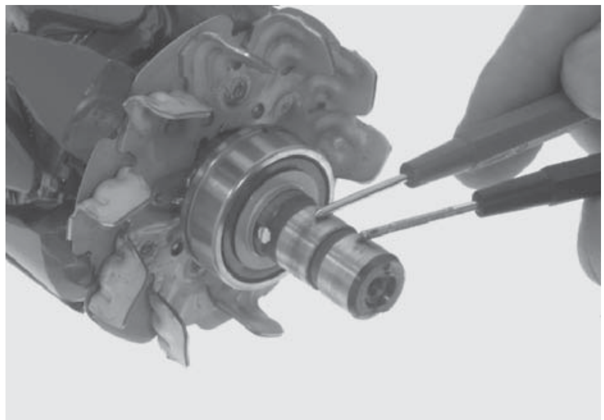


Figure 14-51 Testing the field coil resistance by measuring the resistance through the slip rings. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

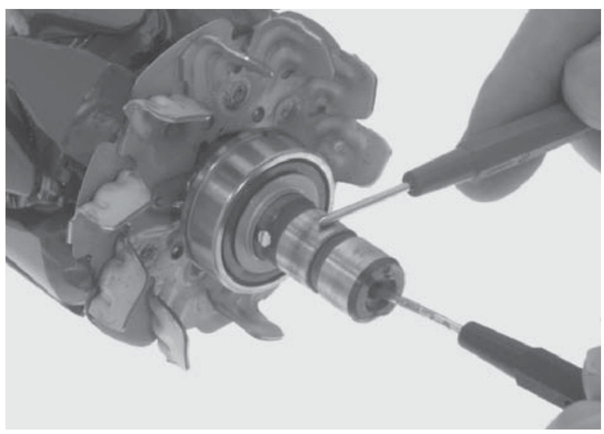


Figure 14-52 Checking for a short to ground. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Stator Inspection

The stator can be tested measuring the coil resistance. Set an ohmmeter to the R1 range and connect the test leads between each of the sets of stator coil wires (Figure 14-53). The stator coil resistance should be less than 1 ohm for each coil.

Next, verify that there are no shorts to ground by setting the ohmmeter to the highest range. Measure the resistance between the stator coil core and each coil winding. The reading should be infinity. If there's a short, the stator is defective and must be replaced.

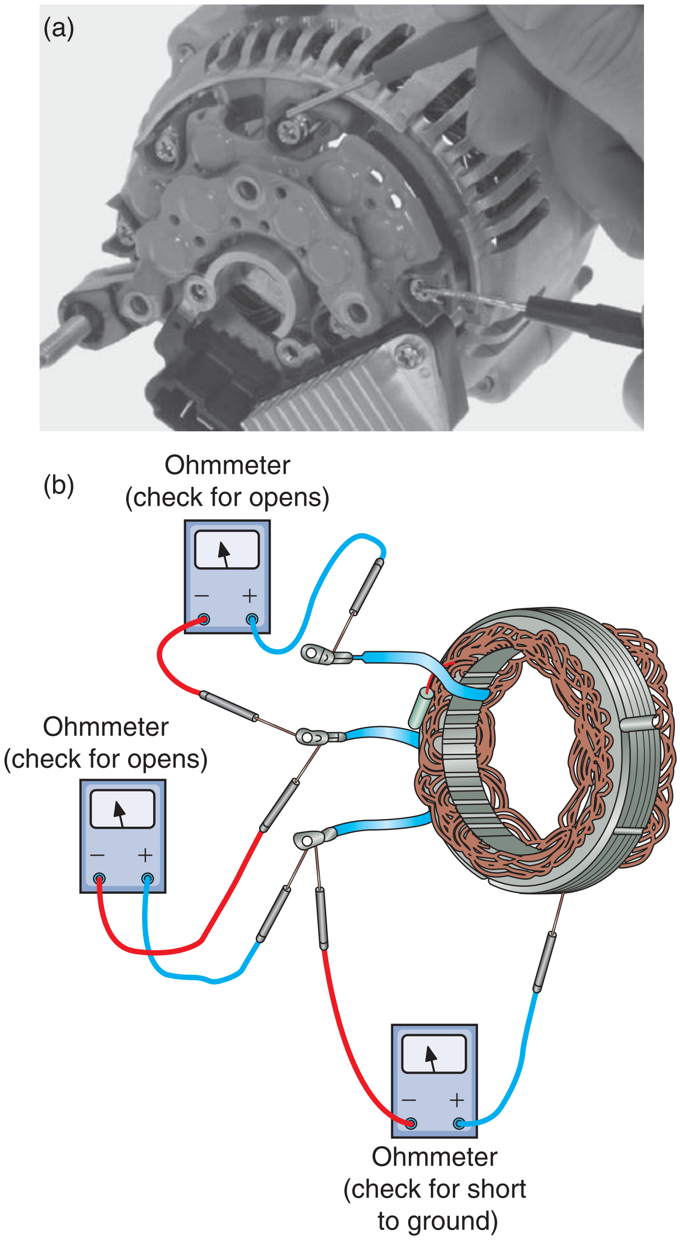


Figure 14-53 (a) Checking for stator resistance on an actual alternator and (b) an illustration of the main tests to verify that a stator is working well. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Figure 14-54 Testing the stator for AC voltage at the alternator with the stator disconnected from the rest of the electrical system.

Another test on the stator can be made with the engine running. Set your multi-meter to measure AC voltage and connect the meter to the output of the alternator (Figure 14-54). As the engine speed is increased, the AC voltage will increase generally to at least 20 volts AC at each connection point with the stator disconnected from the rest of the electrical system.

When checking the continuity of a stator, remember to isolate the stator from the rest of the electrical system by disconnecting it.

DC ELECTRICAL CIRCUITS

When electric current leaves the battery of an electrical system in a power equipment engine, it travels to various electrical components, both AC and DC. In this section, we're going to discuss the various DC electrical circuits found in power equipment engines. We'll give a brief description of each circuit and show how it can be thought of as a separate electrical subsystem. The systems that we're about to discuss have four properties in common:

- Each is powered by the battery.
- Each is operated by a switching device.
- Each must complete its circuit to operate.

- Each has a load device to create resistance in the system (lights, horn, etc.).

Switches

Switches are designed to open and close an electrical circuit. If a switch is defective, it must be replaced. You can check a switch using an ohmmeter. The ohmmeter should indicate continuity (a complete connection or 0 ohms) when the switch is in the On position and should indicate infinite resistance when the switch is in the Off position (Figure 14-55).

Some switches have more switch positions and leads than the simple on/off type of switch. These switches generally have a switch matrix shown in the power equipment engine electrical schematic, similar to that shown in Figure 14-56. A switch matrix shows you the switch positions and the switch leads that should have continuity for each position.

Figure 14-55 A properly working key switch will show a complete connection in one position and an open connection in the other.

	BAT1	IG1	BAT2	ACC	IG2	KEY
ACC			○	○		KEY ON
ON	○	○	○	○	○	KEY ON
OFF						KEY OFF
LOCK						KEY OFF LOCK PIN
COLOR	R	R/Bl	R	R/W	Bu/O	

Figure 14-56 Many switches have multiple uses for different positions. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Headlight Circuits

The headlight is turned on whenever the ignition switch is in the On position, but is sometimes momentarily turned off as the electric starter motor is activated. The purpose of this is to allow maximum current flow from the battery to the starting circuit. The headlight is momentarily turned off during starting by the starter switch. When the starter button is pressed or key is turned, the starter switch opens a set of contacts in the lighting circuit (Figure 14-57).

Turn-Signal and Hazard Relay Circuits

Turn signals and hazard lights would be found on larger implements such as tractors and

Engine stop switch

	IG	BAT
OFF		
RUN	○	○
COLOR	W	W/Bl

Starter switch

	ST	IG	BAT4	HL
FREE			○	○
PUSH	○	○		
COLOR	Y/R	Bl	Bl/R	Bu/W

Figure 14-57 In this illustration, the engine stop switch is connected when in the On position, and the (electric) starter switch creates an open to the headlight (HL) when it's being pushed. This allows maximum current to be available for the starter motor to start the engine. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

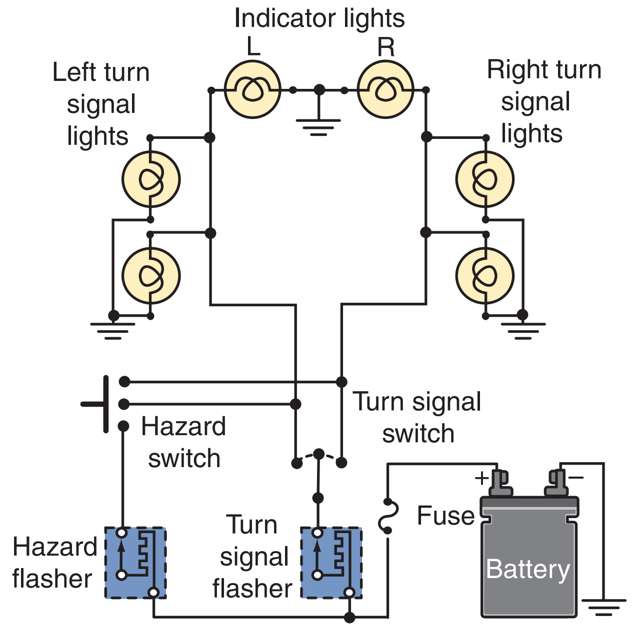


Figure 14-58 A typical turn-signal and hazard-lighting system block diagram.

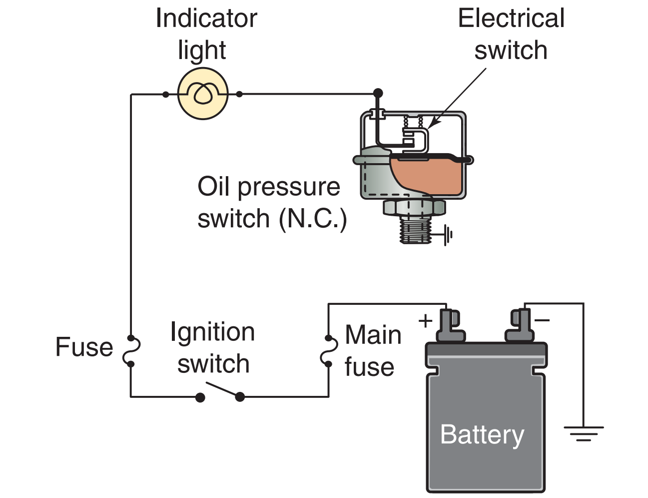


Figure 14-59 A typical oil-pressure warning light circuit.

machines that may need to be driven on highways at times. Figure 14-58 shows a typical turn-signal and hazard relay wiring diagram. The diagram illustrates the system as it would be with the turn-signal and hazard switches in the Off position.

When the turn-signal switch is turned on (either left or right), power flows from the battery, through the turn-signal relay, through the L (left) or R (right) switch contacts, and through the left or right indicator and signal lights to ground.

When the hazard switch is activated, power flows from the battery, through the hazard switch contacts, and through both the left and right indicator and signal lights to ground. The hazard relay and turn-signal relay are special circuits that open and close to make the lights flash.

Warning Lights

Figure 14-59 shows a typical oil-pressure warning-light system used in a four-stroke engine. If the engine oil pressure falls below a specified level, the oil-pressure switch "senses" it and turns on the warning light. When the oil pressure is too low, the switch provides a ground to turn on the indicator. When the oil pressure is satisfactory, the oil-pressure switch removes the ground connection and the light turns off. Oil-level indicators work in the same fashion by closing the circuit when the oil level is low, causing the warning light to come on. When there is enough oil in the engine, the circuit is open, which shuts the warning indicator light off.

Summary

- The purpose of a charging system is to replenish the voltage in a battery as it's used when the power equipment engine is running.
- The alternator generates AC voltage. The rectifier changes the AC into DC. The battery stores the DC voltage, and the voltage regulator controls the voltage being sent to the battery to prevent overcharging or undercharging of the battery.
- There are three basic types of charging systems used in power equipment engines: half wave, full wave, and three phase.
- There are three key requirements needed to produce AC voltage: a magnetic field, a conductor (coils of wire), and motion. An alternator is used to generate electricity in a power equipment engine and has two main components: the rotor and the

stator. The rotor has a series of magnets and rotates either inside or outside the stationary windings of the stator. The stator consists of sets of coils, which are used to produce power for the power equipment engines electrical circuits and to charge the battery.

- A rectifier is required to convert the AC from the alternator into DC that is needed to charge the battery. Depending on the type of charging system being used, the rectifier uses a diode or a group of diodes to convert the AC into DC by allowing AC to flow in only one direction.
- It's important to understand that block diagrams are often used to separate an electrical subsystem from the rest of the power equipment engine. This is done by drawing out the specific components in the system in question using the complete schematic as a starting point.

Chapter 14 Review Questions

1. What is used to generate AC in a power equipment engine?
   a. Alternator
   b. Rectifier
   c. Battery
   d. Thyristor
2. Resistance of an isolated component can be quickly checked using a(n)
   a. AC voltmeter.
   b. ammeter.
   c. DC voltmeter.
   d. ohmmeter.
3. In a permanent-magnet alternator, the magnets are attached to or are part of the
   a. countershaft.
   b. crankshaft body.
   c. rotor.
   d. stator.
4. What device is used to control the rate of charging to prevent undercharging or overcharging the battery?
   a. Diode
   b. Voltage regulator
   c. Resistor
   d. Rectifier
5. How many cells will a 12-volt power equipment engine conventional wet-cell battery have?
   a. 2
   b. 3
   c. 6
   d. 12
6. What device is used to convert AC into DC?
   a. Voltage regulator
   b. Resistor
   c. Rectifier
   d. Battery
7. A charging system that uses the complete AC waveform from a single charging coil is called a ____ charging system.
   a. half-wave
   b. three-phase permanent-magnet
   c. full-wave
   d. three-phase electromagnet
8. Which of the following is potentially the most powerful type of alternator?
   a. Excited-field electromagnet
   b. Alnico inner-rotor
   c. Permanent magnet
   d. Current limiter

9. What can be used on a battery acid spill to help neutralize it?
   a. Distilled water
   b. Motor oil
   c. Baking soda
   d. Sand
10. White crystal deposition on battery plates is known as
    a. chalking.
    b. sedimentation.
    c. cracking.
    d. sulfation.
11. When AC is changed to DC, it's known as
    a. rectification.
    b. mutual induction.
    c. electromagnetism.
    d. chemical reaction.
12. The two main components of an alternator are the
    a. rotor and flywheel.
    b. regulator and rectifier.
    c. rotor and stator.
    d. motor and starter.
13. Another term to describe a voltage regulator is
    a. current limiter.
    b. rectifier.
    c. inverter.
    d. thyristor.
14. What device is used to detect a short between a stator coil winding and the core?
    a. Ammeter
    b. Ohmmeter
    c. Converter
    d. Voltmeter

CHAPTER

15 Ignition and Electric Starting Systems

Learning Objectives

- Describe the three major functions of an ignition system
- Describe the common components found in all types of ignition systems
- Name the two major electrical circuits used in an ignition system
- Name the different types of ignition systems
- Describe how electric starter systems used in power equipment engines operate

Key Terms

Capacitor discharge ignition
Electronic ignition system
Firing order
Ignition coil
Ignition timing
Ignition timing advance
Spark plug
Spark plug reach
Starter clutch

INTRODUCTION

In Chapters 13 and 14, you learned the basics of electricity and charging systems. You also learned about battery-powered electrical circuits found in power equipment engines.

In this chapter, you'll learn about the different types of ignition systems. First, we'll explain basic ignition system operation and identify the main components in an ignition system. Then, we'll look at the different types of ignition systems and learn about ignition system timing. Finally, we'll discuss electric starting systems found in power equipment engines.

Do you remember the stages of operation in a two-stroke and a four-stroke engine? In each cylinder of the engine, the piston rises during the compression stage to compress the air–fuel mixture in the combustion chamber. Just before the piston reaches the top-dead center (TDC), a spark plug fires in the cylinder and ignites the compressed air–fuel mixture. The ignition of the air–fuel mixture forces the piston down in the cylinder, producing the power stage. The power produced by the ignition of the air–fuel mixture turns the crankshaft, which in turn keeps the piston moving and the engine running.

One of the requirements for an efficient engine is the correct amount of heat, delivered at the right time. This requirement is met by the ignition system. The ignition system supplies properly timed, high-voltage surges to the spark plug(s). These voltage surges cause combustion inside the cylinder.

The ignition system must create a spark, or current flow (Figure 15-1), across each pair of spark plug electrodes at the proper instant, under all engine operating conditions. This may sound relatively simple, but when one considers the number of spark plug firings required and the extreme variation in engine operating conditions, it's easy to understand why ignition systems are so complex.

Almost all ignition systems used in power equipment engines fire the spark plug once per revolution of the crankshaft. When this occurs on a four-stroke engine, it's known as a wasted spark, as the cylinder requires only one spark per every two revolutions of the crankshaft. These spark plug firings must also occur at the correct time and must generate the correct amount of heat. If the ignition system fails to perform these functions properly, fuel economy, engine performance, and emission levels are adversely affected.

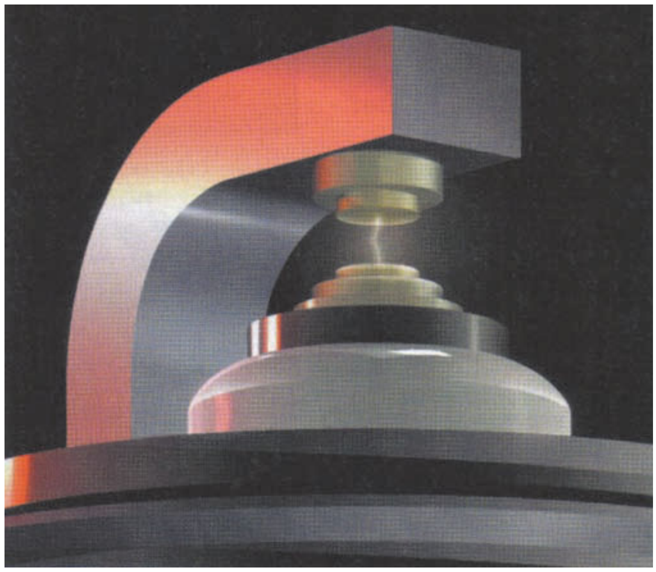


Figure 15-1 The sole purpose of an ignition system is to provide a spark that ignites the air–fuel mixture in the combustion chamber of an engine. Courtesy of Honeywell International Inc.

POWER EQUIPMENT ENGINE IGNITION SYSTEMS

The sole purpose of an ignition system is to provide a spark that will ignite the air–fuel mixture in the combustion chamber. The spark must be timed to occur at a precise point relative to the position of the piston as it reaches TDC on the engine's compression stroke. The difference between various ignition systems lies in how the spark is activated. In some of today's larger power equipment engines, ignition systems are used in unison with electronic fuel injection systems.

For each cylinder in an engine, the ignition system has the following three main functions:

- It must generate an electrical spark that has enough heat to ignite the air–fuel mixture in the combustion chamber.

- It must maintain that spark long enough to allow for the combustion of all the air and fuel in the cylinder.
- It must deliver a spark so that combustion can begin at the right time during each compression stroke of the piston.

When the combustion process is completed, a very high pressure is exerted against the top of the piston. This pressure pushes the piston down on its power stroke and this is the force that gives the engine power. For an engine to produce the maximum amount of power it can, the maximum pressure from combustion should be present when the piston is at 10–23° after top-dead center (ATDC). Because combustion of the air–fuel mixture within a cylinder takes a short period of time, usually measured in thousandths of a second (milliseconds), the combustion process must begin before the piston is on its power stroke. Therefore, the delivery of the spark must be timed to arrive at some point just before the piston reaches TDC.

Determining how much time before TDC the spark should begin is complicated. This is because even as the speed of the piston moving from its compression stroke to its power stroke increases, the time needed for combustion stays about the same. This means that, as the engine's speed increases, the spark should be delivered earlier (Figure 15-2). However, at high speeds, as the engine has to provide more power to do more work, the high load on the crankshaft tends to slow down the acceleration of the piston, in which case the spark needs to be accordingly delayed.

Figuring out when the spark should begin gets more complicated because the rate of combustion varies, depending on certain factors. Higher compression pressures tend to speed up combustion. A higher-octane gasoline ignites less easily and requires more burning time. Increased vaporization and turbulence tend to decrease combustion times. Other factors, including intake air temperature, humidity, and barometric pressure, also affect combustion. Because of all of these complications, delivering the spark at the right time is a difficult task.

How does an ignition system produce a spark, time it perfectly, and keep making sparks over and over again? Let's find out.

Ignition Timing

Ignition timing refers to the precise time spark occurs. It's specified by referring to the position of a manufacturer-determined piston (generally the No. 1 piston on the crankshaft in multicylinder engines) in relation to crankshaft rotation. Ignition timing reference marks are sometimes located on the engine's crankshaft flywheel/rotor to indicate the position of the

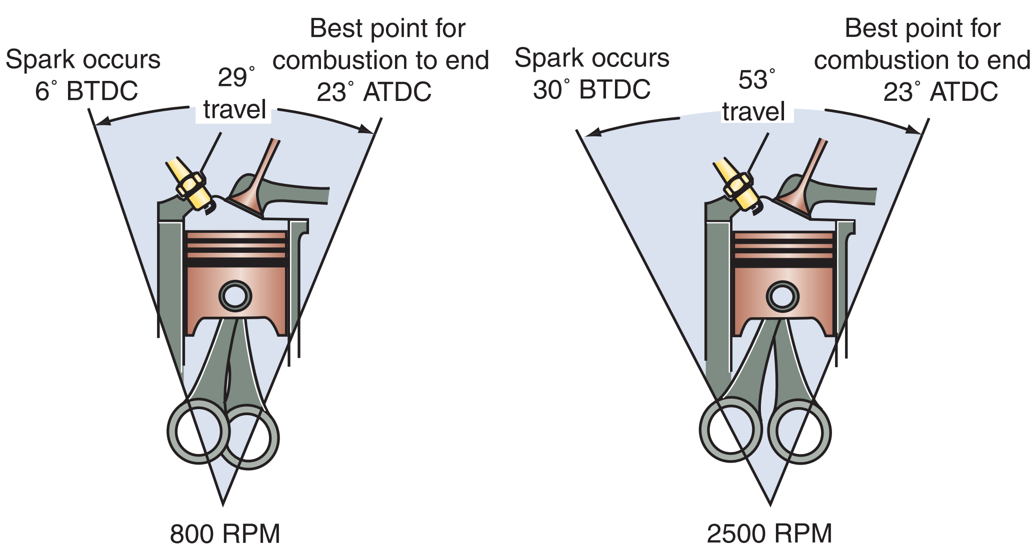


Figure 15-2 As an engine's speed increases, a spark must be delivered sooner to allow for complete combustion of the air–fuel mixture. This is known as ignition advance.

piston. Power equipment engine manufacturers specify initial or base ignition timing. Some engines don't require such markings because the ignition systems are fixed in one position and are not adjustable.

When the marks are aligned at TDC, the piston is at the TDC of the engine's stroke. Additional marks indicate the required number of degrees of crankshaft rotation before top-dead center (BTDC) or ATDC. In a majority of engines, the initial timing is specified at a point between TDC and 15° BTDC, depending on the manufacturer's predetermined specification.

Although most power equipment engines are designed to run over a relatively small engine rpm range (for instance, 500–3,600 rpm), if optimum engine performance is to be maintained, the ignition timing of the engine must change as the operating conditions of the engine change. These conditions affect the speed of the engine and the load on the engine. Therefore, all ignition timing changes are made in response to these primary factors.

Ignition Timing Advance

Power equipment engines generally run at relatively stable engine speeds, and so ignition advance isn't required. But in some engines, speed varies a lot and ignition timing needs to be varied accordingly. In such cases, it's necessary to advance or retard ignition in some engines. Two methods are used in power equipment engines to advance ignition.

Ignition systems in older power equipment engines that require **ignition timing advance** are equipped with centrifugal advance mechanisms (Figure 15-3), which advance or retard ignition timing in response to engine speed. Centrifugal advance uses a set of pivoted weights and springs connected to a shaft with the point cam (crankshaft or camshaft) attached to it. When engine speed increases, the weights move outward, shifting the plate where the triggering device is mounted. This shifting of the plate causes the triggering device to receive its signal earlier, causing an advance in the ignition timing.

Most all modern day power equipment engines that require advance use an electronic advance system to control the ignition. Electronic advance systems require no adjustment, have no mechanical parts, and therefore don't wear out. The design eliminates the need for maintenance. Electronic advance systems use multiple sensors to determine the correct timing advancement for any given condition. They offer a greater variety of timing choices for different engine running conditions instead of basically only two, as is case with centrifugal advance systems.

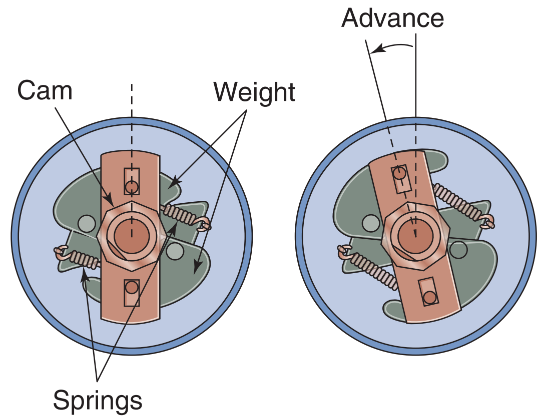


Figure 15-3 A centrifugal advancer uses a set of pivoted weights and springs connected to the shaft holding the triggering device attached to it (left). When engine speed increases, the weights move outward, shifting the plate where the triggering device is mounted (right). This shifting of the plate causes the triggering device its signal earlier, causing an advance in the ignition timing.

Engine rpm and Turbulence

At higher rpm, the crankshaft turns through more degrees in a given period of time. If combustion is to be completed by a particular number of degrees ATDC, ignition timing must occur sooner—or be advanced—by the use of a mechanical or electrical advancer. The advancer is generally attached on the crankshaft.

Another complication that arises at high rpm is the turbulence (swirling) of the air–fuel mixture, which increases with rpm. This causes the mixture inside the cylinder to turn faster. Increased turbulence requires that ignition must occur slightly later—or be slightly retarded—by the use of the advancer.

These two factors—high rpm and increased turbulence—must be balanced for optimum engine performance. Therefore, although ignition timing must be advanced as engine speed increases, the amount of advance must be decreased to compensate for the increased turbulence.

Engine Load

The load on an engine is related to the work it must do. For example, cutting deep grass or pulling extra weight increases engine load. At higher loads, there is greater resistance on the crankshaft; therefore, the piston has a harder time moving through their strokes.

Under light loads and with the throttle partially open, a high vacuum exists in the intake manifold. The amount of air–fuel mixture drawn into the manifold and cylinders is small. On compression, this thin mixture produces less combustion pressure, and combustion time is increased. To complete combustion by the desired degrees ATDC, ignition timing must be advanced.

Under heavy loads, when the throttle is open fully, a larger mass of air–fuel mixture is drawn in, and the vacuum in the manifold is low. High combustion pressure and rapid burning result. In such cases, ignition timing must be retarded to prevent completion of burning before the crankshaft has reached the desired degrees ATDC.

Firing Order in Multi-Cylinder Engines

Up to this point, we've focused primarily on ignition timing as it relates to any one cylinder. However, the function of an ignition system extends beyond timing the spark in a single cylinder. In multi-cylinder engines, it must perform this task for each cylinder of the engine in a specific sequence.

In the case of a multi-cylinder four-stroke engine, each cylinder of the engine must produce power once in every 720° of crankshaft rotation. Each cylinder must have a power stroke at its own appropriate time. To make this possible, the pistons and connecting rods are arranged in a precise fashion called the engine's **firing order.** The firing order is arranged to reduce rocking and imbalance problems. Because the potential for this rocking depends on the design and construction of the engine, the firing order varies from engine to engine. Engine manufacturers simplify cylinder identification by numbering each cylinder. Regardless of the firing order used, the No. 1 cylinder always starts the firing, with the rest of the cylinders following in a fixed sequence.

The ignition system must be able to "monitor" the rotation of the crankshaft and the relative position of each piston to determine which piston is on its compression stroke. It must also be able to deliver a high-voltage surge to each cylinder at the proper time during its compression stroke. How the ignition system does these things depends on the design of the system.

BASIC IGNITION SYSTEM COMPONENTS

Figure 15-4 shows a simplified drawing of a basic ignition system. The main components of the system are the following:

- Power source
- Ignition switch
- Ignition coil

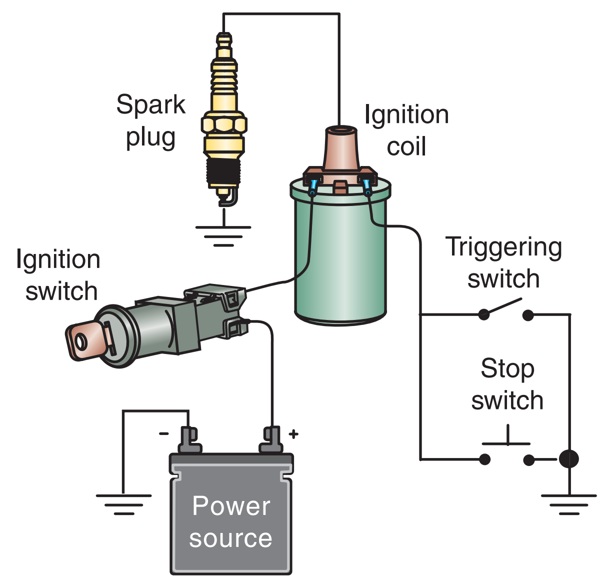


Figure 15-4 The basic components of an ignition system.

- Spark plug
- Triggering switch
- Stop switch

All ignition systems contain these components. The difference is how the components function. We'll take an in-depth look at each of these components, beginning with the power source.

Power Sources

In power equipment engine ignition systems, there are just two power source options. These power sources are the battery [for direct current (DC)] or the AC generator [for alternating current (AC)].

In a battery ignition system, a battery is connected to the ignition coil. A triggering switch device is used to alternately turn the DC voltage on and off for its operation.

AC generator power sources are far more common than battery systems for power equipment engines, and in most cases, they're designed to be run without a battery. The AC-powered ignition system uses the principles of magnetism to produce a voltage. In Chapter 13, we discussed magnetic induction and generators. Remember that when a conductor wire is moved through a magnetic field, a voltage is induced in the conductor. It's also true that if a magnet is moved near a conductor, a voltage is induced in the conductor. If this conductor wire is connected to a complete circuit, current will flow in the circuit.

In an AC ignition system, permanent magnets are installed in the engine's flywheel/rotor. As the flywheel/rotor turns, the moving magnets cause a voltage to be induced in the ignition coil.

We'll look at the design and operation of both the AC-powered system and the battery system in detail a little later in this chapter. For now, just keep in mind that the power source for a power equipment engine or ignition system can be provided by either AC power or a battery.

Advantages of the Battery Power Source System

Battery-type ignition systems have some advantages over AC ignition systems. First, the battery that powers an ignition system can also be used to run other devices, such as lights, accessories, and electric starter systems. In contrast, most AC-powered ignition systems supply power only to fire the spark plug. Second, because a battery can be used to run an electric starter system, implements that contain battery systems can be started with a simple turn or push of an electric starter switch. AC-powered ignition systems are generally activated by manually starting the engine with a pull-start device. Therefore, larger power equipment engines, such as those used in tractors, generally use battery systems, whereas smaller power equipment engines, such as lawnmowers, generally use AC-powered systems.

Advantages of the AC Generator Power Source System

The AC-powered ignition system has certain advantages over the battery as a power source. First, when a power equipment engine uses an AC generator, no onboard battery is needed. Batteries are heavy and inconvenient on implements such as lawnmowers and handheld blowers. Second, no separate charging system is required with an AC generator, whereas batteries require a charging system to keep them working.

Ignition Switch

The ignition switch allows the power source to provide electrical power to the ignition system. It's generally a key-type switch that also powers all components that use a power source, such as lights and accessories.

Ignition Coil

An **ignition coil** is essentially a transformer that consists of two wire windings wound around an iron core (Figure 15-5). The first winding is called the primary winding, and the second winding is called the secondary winding. The secondary winding has many more turns of wire than the primary winding.

In an ignition coil, one end of the coil's primary winding is always connected to a power

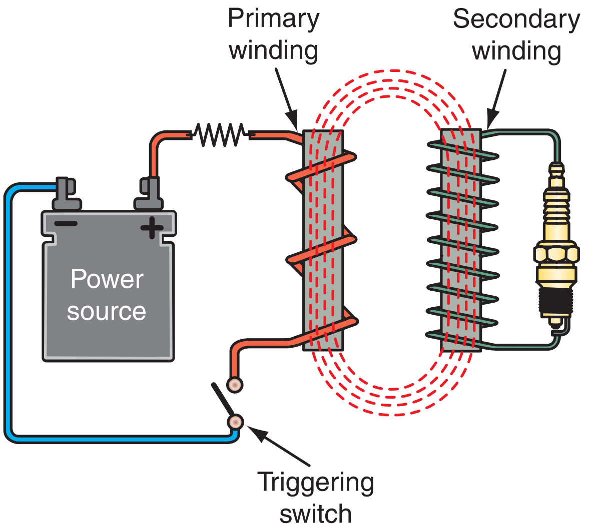


Figure 15-5 A basic transformer. When a voltage is applied to the primary winding, a voltage is induced into the secondary winding that's many times greater than the voltage in the primary winding.

source. Depending on the type of ignition system, the power source may be a battery (providing DC) or a flywheel/rotor with a permanent magnet (providing AC). Either type of power source can be used to apply a voltage to the primary winding of the coil.

When current passes through the primary winding of the coil, a magnetic field is created around the iron core. As the magnetic field expands, the magnetic lines of flux cut through the wires of the secondary winding and induce a voltage in the secondary winding. If the current in the primary winding is switched off, a voltage is again induced into the secondary winding by the magnetic lines of flux, which again cut through the secondary winding. The direction of current induced into the secondary winding is reversed each time the current in the primary is turned on and off. This is because the magnetic lines of force around the iron core cut through the secondary winding in opposite directions as the magnetic field expands and collapses.

Because the secondary winding of the coil has many more wire coils than the primary, the voltage produced in the secondary winding is much higher than the original voltage applied to the primary winding. In a typical power equipment engine ignition system, the power source supplies about 12 volts to the primary winding of the ignition coil. From this 12-volt input, the ignition coil produces 20,000–60,000 volts or even more at the secondary coil.

The secondary winding of the coil is always connected to the spark plug through the spark plug wire. Because the spark plug wire needs to carry the high voltage and prevent it from arcing to ground, it's heavily insulated.

When the magnetic field in the ignition coil expands or collapses (coils are designed to do one or the other), the high voltage in the secondary is applied to the spark plug and causes a spark to jump across the spark plug gap. The spark ignites the air–fuel mixture, enabling the power equipment engine to run.

It's important to remember that the high voltage in the secondary winding of the coil is produced each time the primary current is turned on or off. In a collapsing-field ignition system, the high voltage from the secondary winding is used when the current to the primary winding is switched off. In a rising-field ignition system, the high voltage from the secondary winding is used when the current to the primary winding is switched on. This means that all ignition systems need some type of a device that will keep turning the current from the power source on and off.

Spark Plug

The spark plug provides the crucial air gap across which the high voltage from the secondary coil causes an arc or spark. The main parts of a **spark plug** are a steel shell; a ceramic core or insulator, which acts as a heat conductor; and a pair of electrodes, one insulated in the core and the other grounded on the shell. The shell holds the ceramic core and electrodes in a gas-tight assembly and has threads for plug installation in the engine (Figure 15-6). The insulator is made of ceramic materials to provide for increased durability and strength. The shell may be coated with a corrosion-resistant material or materials that prevent the threads from seizing to the cylinder head. Most of today's spark plugs have a resistor (generally about 5,000 or 5K ohms) between the top terminal

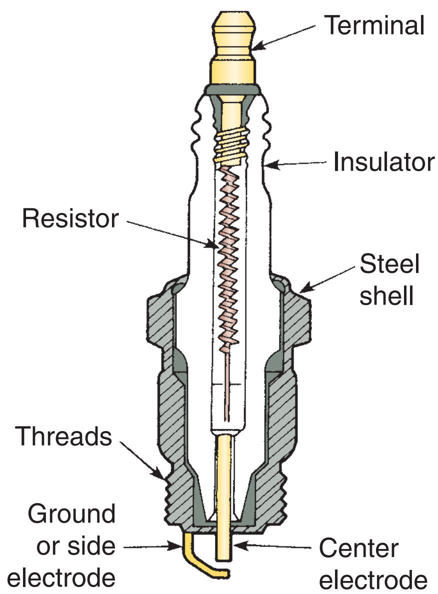


Figure 15-6 The parts of a typical spark plug.

and the center electrode. Some spark plugs use a semiconductor material to provide for this resistance. The resistor reduces radio frequency interference (RFI), which can interfere with, or damage, radios, computers, and other electronic accessories. If an engine is equipped with resistor plugs, the same should be installed when the originals are replaced.

The terminal post on top of the center electrode is the connecting point for the spark plug cable. Current flows through the center of the plug and arcs from the tip of the center electrode to the ground electrode. The center electrode is surrounded by the ceramic insulator and is sealed to the insulator with copper and glass seals. These seals prevent combustion gases from leaking out of the cylinder. Ribs on the insulator increase the distance between the terminal and the shell, to help prevent electric arcing on the outside of the insulator. The steel spark plug shell is crimped over the insulation, and a ground electrode, on the lower end of the shell, is positioned directly below the center electrode. There is an air gap between these two electrodes.

Spark plugs come in many sizes and designs to accommodate different engine designs.

Spark Plug Reach

One important design characteristic of spark plugs is spark plug reach (Figure 15-7). This refers to the length of the shell from the contact surface at the seat to the bottom of the plug. **Spark plug reach** is crucial because the plug's air gap must be placed properly in the combustion chamber to produce the correct amount of heat. If a plug's reach is too short, its electrodes are in a pocket and the arc is not able to adequately ignite the mixture. If the reach is too long, the exposed plug threads can hit the piston or get so hot they will ignite the air–fuel mixture at the wrong time and cause preignition. *Preignition*, as we know, is a term used to describe abnormal combustion, which is caused by something other than the heat of the spark.

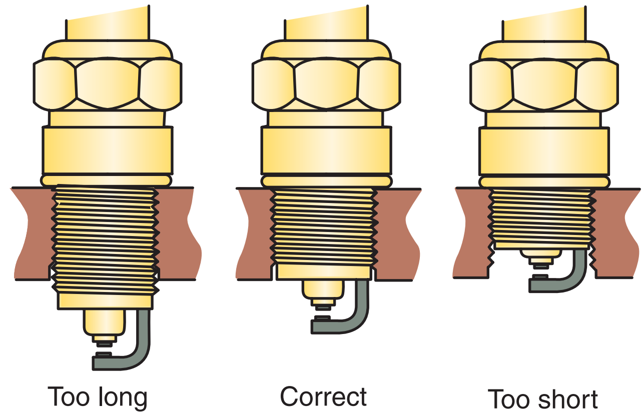


Figure 15-7 Spark plug reach is crucial because the plug's air gap must be properly placed in the combustion chamber to produce the correct amount of heat. If a plug's reach is too short, its electrodes are in a pocket, and the arc does not adequately ignite the mixture. If the plug's reach is too long, the exposed plug threads can hit the piston or get so hot they will ignite the air–fuel mixture at the wrong time.

Heat Range

When the engine is running, most of the spark plug's heat is concentrated on the center electrode. Heat is quickly dissipated from the ground electrode because it's attached to the shell, which is threaded into the cylinder head. In liquid-cooled engines, coolant circulating in the head absorbs the heat and moves it through the cooling system. In air-cooled engines, the heat is absorbed through the cylinder head. The heat path for heat in the center electrode is through the insulator into the shell and then

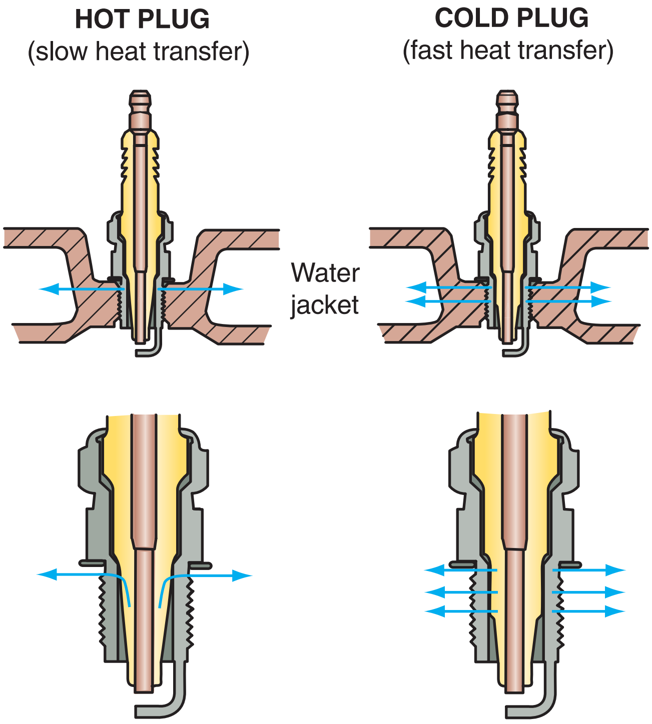


Figure 15-8 Spark plug heat range: hot versus cold.

to the cylinder head. The heat range of a spark plug is determined by the length of the insulator before it contacts the shell. In a cold spark plug, there is a short distance for the heat to travel up the insulator to the shell. This short path for heat means the electrode and insulator maintain little heat between firings (Figure 15-8).

In a hot spark plug, the heat travels farther up the insulator before it reaches the shell. This provides a longer heat path and the plug retains more heat. A spark plug needs to retain enough heat to clean itself between firings, but not so much that it damages itself or causes premature ignition of the air–fuel mixture in the cylinder.

The heat range is indicated by a code imprinted on the side of the spark plug, usually on the porcelain insulator.

Spark Plug Gap

Correct spark plug air gap (Figure 15-9) is essential for achieving optimum engine performance and long plug life. A gap that is too wide requires a higher voltage to jump the gap. If the required voltage is greater than what is available, misfiring results. Misfiring occurs because of the inability of voltage generated at

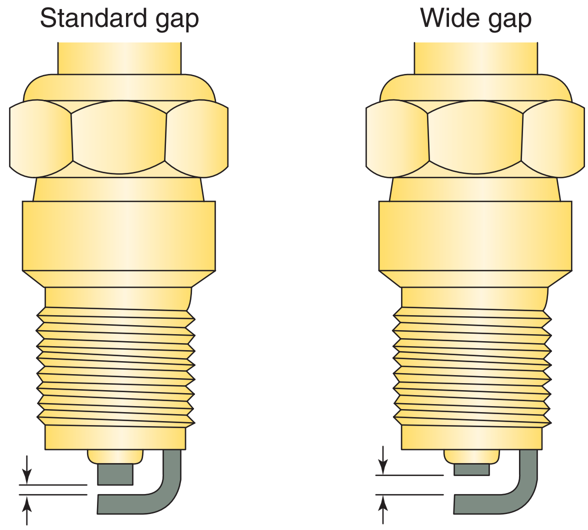


Figure 15-9 Spark plug gaps.

the secondary coils to jump the gap or maintain the spark. Alternatively, a gap that is too narrow requires lower voltages and can lead to rough idle and prematurely burned electrodes, due to higher current flow. Also, a misfire may occur if a spark plug terminal is loose.

Electrodes

The materials used in the construction of a spark plug's electrodes determine the longevity, power, and efficiency of the plug. The construction and shape of the tips of the electrodes are also important.

The electrodes of a standard spark plug are made out of copper, and some use a copper–nickel alloy. Copper is a good electrical conductor and offers resistance to corrosion.

Platinum electrodes are used to extend the life of a spark plug (Figure 15-10). Platinum has a much higher melting point than copper and is highly resistant to corrosion. Although platinum is an extremely durable material, it's an expensive precious metal; therefore, platinum spark plugs cost more than copper spark plugs. Also, platinum isn't as good a conductor as copper. Spark plugs are available with only the center electrode made of platinum (called single-platinum) and with the center and ground electrodes made of platinum (called double-platinum). Some platinum plugs have a very small center electrode combined with a sharp-pointed ground electrode designed for better performance.

Figure 15-10 A platinum-tipped spark plug. Courtesy of Bob Freudenberger.

Until recently, platinum was considered the best material to use for electrodes, because of its durability. However, another material with several advantages is iridium alloy. Iridium is six times harder, eight times stronger, and has a melting point that is 1,200° higher than that of platinum. Iridium is a precious, silver-white metal and one of the densest materials found on earth. A few spark plugs use an iridium alloy as the primary metal complemented by rhodium to increase oxidation wear resistance. This iridium alloy is so durable that it allows for an extremely small center electrode. A typical copper–nickel plug has a 2.5-mm-diameter center electrode, whereas a platinum plug has a diameter of 1.1 mm. An iridium plug can have a diameter as small as 0.4 mm (Figure 15-11), which means firing voltage requirements are decreased. Iridium is also used as an alloying material for platinum.

Electrode Designs Spark plugs are available with many shapes and numbers of electrodes. When trying to ascertain the advantages of each design, remember the spark is caused by electrons moving across an air gap. The electrons will always flow in the direction of least electrical resistance.

The shape of the ground electrode may also be altered. A flat, conventional electrode tends to crush the spark, and the overall volume of the flame front is smaller. A tapered ground electrode increases flame front expansion and

Figure 15-11 This spark plug has a small-diameter iridium center electrode and a grooved ground electrode. Courtesy of Denso Sales California, Inc.

reduces the heat lost to the electrode. Ground electrodes in many power equipment engine spark plugs have a U-groove machined into the side that faces the center electrode. The U-groove allows the flame front to fill the gap formed by the U-shape. This ball of fire develops a larger and hotter flame front, leading to a more complete combustion.

Triggering Switch Devices

Different types of ignition systems use different types of switching devices. There are two basic types of trigger switching devices used in power equipment engine ignition systems. Older ignition systems use a set of electrical contacts called breaker points and a condenser to do the switching. Although rarely used by any major manufacturer today, breaker points and condensers continue to be in use in millions of older power equipment engines. All modern power equipment engine systems, however, use electronic components to do the switching. In either system, the construction of the ignition coil and the spark plug remain the same.

Breaker Points and Condenser

Breaker points are mechanical contacts that are used to stop and start the flow of current through the primary windings of the ignition

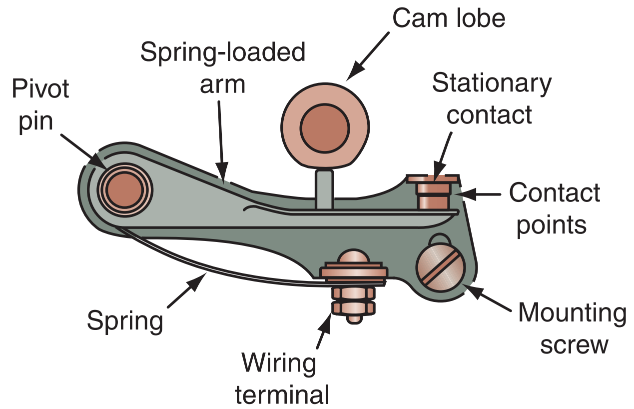


Figure 15-12 A set of breaker points.

coil. The points are usually made of tungsten, a very hard metal that has a high resistance to heat. One breaker point is stationary (fixed), and the other point is movable and insulated from the stationary point. The movable contact is mounted on a spring-loaded arm, which holds the points together. Figure 15-12 shows a simplified drawing of a set of breaker points.

When the two breaker points touch, the ignition circuit is complete and the primary winding of the ignition coil is energized. When the end of the spring-loaded movable breaker point is pressed, its contact end moves apart from the stationary breaker point. This opens the circuit and the flow of current stops. Each time the breaker points move apart, the spark plug fires. This action is shown in Figure 15-13.

The spring mounted under the movable point holds the movable breaker point against the cam. The movable breaker point is moved to the open position by a turning cam with a lobe. In most cases, the cam is located on the crankshaft. The lobe on the cam forces the movable breaker point away from the stationary point, and the spark plug fires.

Another important component of a breaker-points system is the condenser (also called a capacitor). Remember that each time the breaker points touch, current flows through them. Unless this current flow is controlled in some way, a spark or arc will occur across the breaker points as they move apart. If this sparking is allowed to occur, the breaker points will arc, burn, and fail to operate properly. The points would also

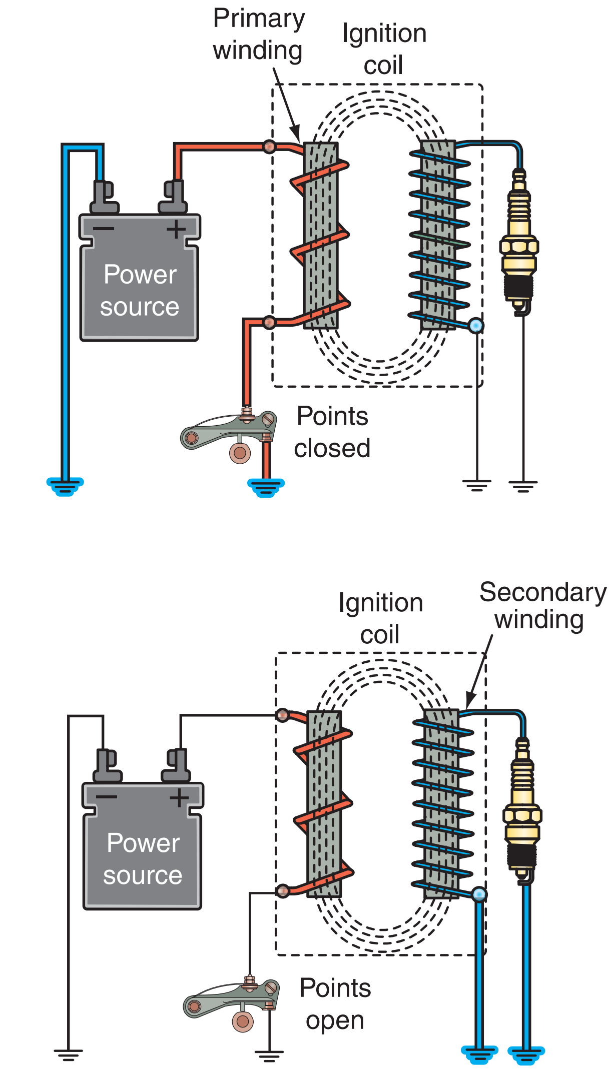


Figure 15-13 Shown is the action of breaker points in a simple ignition circuit. When the breaker points are closed, current flows through the ignition coil's primary winding. When the points open, the circuit is broken, and the magnetic field in the coil collapses, which induces a voltage into the coil secondary to fire the spark plug.

absorb the electrical energy and reduce the output voltage of the ignition coil.

For these reasons, a condenser is used to control the current as it flows through the breaker points. A condenser absorbs current and stores it, like a miniature battery. In an ignition circuit, the condenser is connected across—or parallel to—the breaker points. As the breaker points begin to separate, the condenser absorbs the current created by the collapsing magnetic

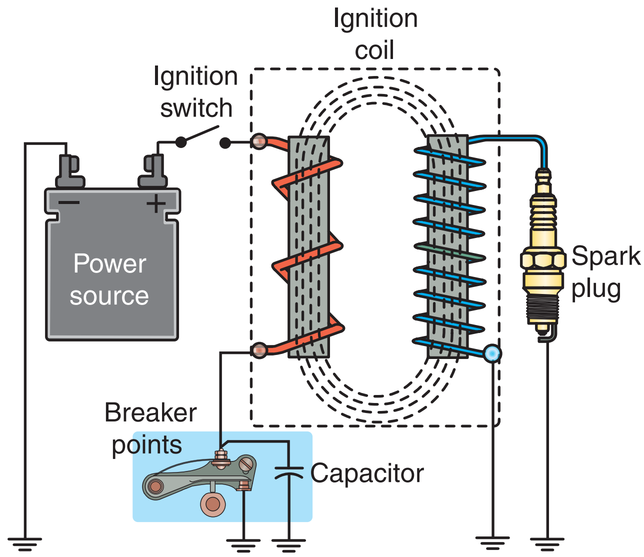


Figure 15-14 A typical battery-powered breaker point system.

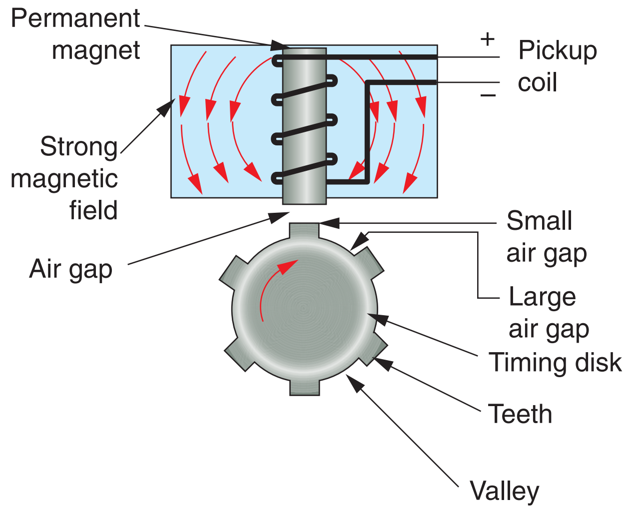


Figure 15-15 A magnetic-pulse generator is located near the engine's crankshaft or camshaft in most cases. It consists of two parts: a timing disc (also known as a reluctor) and a pickup coil.

field around the primary winding of the coil so that it can't jump between the points and make a spark.

The breaker-points-and-condenser switching system can be used in both AC and battery-powered ignition systems. Figure 15-14 shows a breaker-points system. Note the location of the breaker points and condenser in the circuit.

Electronic Trigger Devices

When an electronic ignition system is used in a power equipment engine, a sensor is used to monitor the position of the crankshaft and control the flow of current to the primary side of the ignition coil. These sensors primarily include magnetic-pulse generators and Hall-effect sensors. An electronic switch completely eliminates the need for breaker points and a condenser.

Magnetic-Pulse Generator A magnetic-pulse generator is located generally on the engine's crankshaft or camshaft and consists of two parts: a timing disc (also known as a reluctor) and a pickup coil (Figure 15-15). The pickup coil consists of a length of wire wrapped around a permanent magnet. The magnetic-pulse generator operates on the basic electromagnetic principle that voltage can be induced only when a conductor *moves* through a magnetic field. When the crankshaft or camshaft is turned, the timing disc moves through the magnetic field. As the timing disc teeth approach the pickup coil, a voltage is induced, and this is used to control the voltage to the primary side of the ignition coil, just as the opening and closing of the contact points in the breaker-points-and-condenser switching system. A specific, manufacturer-determined air gap is required to ensure that a signal of appropriate strength is being produced.

Hall-Effect Sensor The Hall-effect sensor or switch is the most commonly used engine position sensor used in a power equipment engine that uses an electronic ignition system. There are several reasons for this. Unlike the magnetic-pulse generator, the Hall-effect sensor produces an accurate voltage signal across the entire rpm range of the engine. Furthermore, a Hall-effect switch produces a square-wave pattern that is more compatible with the digital signals required by onboard computers.

Functionally, a Hall-effect switch performs the same tasks as a magnetic-pulse generator. But the Hall-effect switch's method of generating voltage is quite unique. It's based, as you may guess, on the Hall-effect principle. This states that if a current is allowed to flow through a thin conducting material and that material is exposed to a magnetic field, voltage is produced in the conductor. In essence, a Hall-effect switch is either on or off. It also uses a timing disc that is used to switch the power on and off as it passes by the sensor.

Stop Switch

Once an engine is started, it will keep running until it runs out of fuel or is put under a heavy-enough load to cause it to stall. The stop switch provides a convenient means to stop the engine.

Different types of stop switches are found in different types of ignition systems. In some power equipment engines, the stop switch interrupts the flow of electricity to the spark plug by giving the electrical current an easier path to ground. This type of switch consists of a button that grounds the ignition system (Figure 15-4).

In other engines, the stop switch is designed to prevent the flow of electricity through the primary winding of the ignition coil. This type of stop switch is connected in series with the primary side of the ignition coil. When you turn the switch to the Off position, the ignition circuit is made to open and the engine stops.

TYPES OF IGNITION SYSTEMS

Now that you understand how a basic ignition system in a power equipment engine operates, let's take a closer look at the construction of some types of ignition systems. The two general types are the:

- Breaker point ignition system
- Electronic ignition system

There are two types of breaker point systems. (1) The magneto breaker point ignition system is usually found in older machines, where a voltage is needed only to power the spark plug—not a starter system or lights. (2) The battery-and-points ignition system is found in most of the older power equipment engines that have electric starter systems and lights.

Electronic ignition systems of one type or another are found in virtually all modern day power equipment engines.

All types of ignition systems contain the same basic components. The magneto system and the battery system are similar, except that they use different power sources. **Electronic ignition systems** use electronic components to perform the switching function, but their power source can be either a battery or an AC generator. Finally, all ignition systems have a switch device to turn the ignition system on and off.

Magneto Ignition Systems

In magneto ignition systems in older power equipment engines without any lights or a battery, the AC source may have the sole function of operating the ignition system. In other models that include lighting systems, one AC generator coil may be used for ignition, and another for lighting. All magneto ignition systems operate without a battery, or are independent of the battery if one is used for the operation of other electrical functions.

The magneto ignition system uses permanent magnets installed on the engine's flywheel/rotor. Magnetos are classified as being one of three types:

- High tension
- Low tension
- Energy transfer

High-Tension Magneto Ignition System

High-tension magneto ignition systems (Figure 15-16) haven't been in use in power equipment engines for quite a few years, but they were once the most popular ignition system, found in small engines. With this ignition system, the ignition coil (magneto primary and secondary windings) is mounted in a stationary position near the flywheel/rotor. When the flywheel/rotor turns, the magnets induce a voltage in the primary winding of the ignition coil.

The position of the magnets on the flywheel/rotor is important. To generate the voltage at the exact time needed, the magnets in the

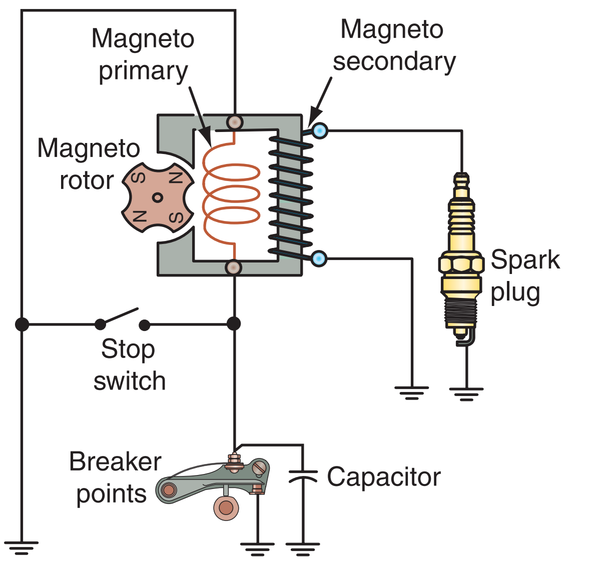


Figure 15-16 A high-tension magneto system.

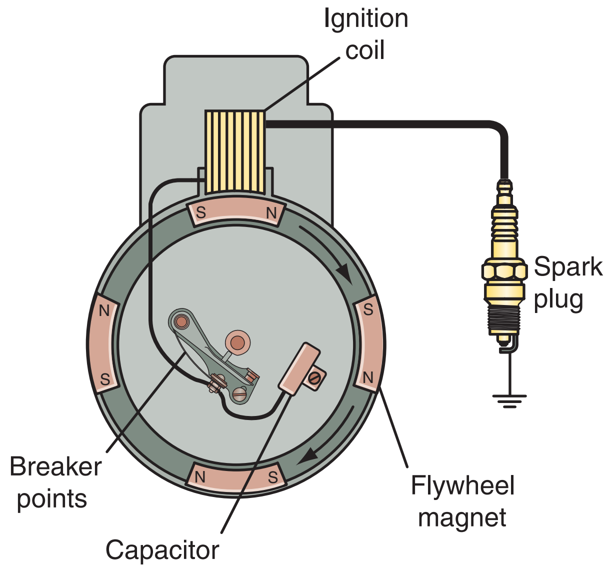


Figure 15-17 A high-tension magneto ignition system. A permanent magnet is mounted near the edge of the flywheel. As the flywheel turns, the magnet passes near the ignition coil and induces a voltage in the primary winding.

flywheel/rotor must be properly aligned. This means that the flywheel/rotor must be located exactly in the position required on the crankshaft. The flywheel/rotor is held in position on the crankshaft by a flywheel/rotor key, which is inserted into matching slots that are cut into the crankshaft and flywheel/rotor.

The gap between the edge of the flywheel/rotor and the iron core of the ignition coil is an important specification in a high-tension magneto ignition system. The engine manufacturer's specification for this gap is of the order of thousandths of an inch or hundredths of a millimeter. This is one of the specifications that must be checked when you're servicing a high-tension magneto ignition system.

Now, let's take a closer look at the operation of a high-tension magneto system. Figure 15-17 illustrates a simplified drawing of a high-tension magneto system in operation. You can see the breaker points at the center of the flywheel/rotor. In actual practice, the breaker points are located underneath the flywheel/rotor.

Remember that the ignition coil is basically a transformer and contains a primary winding and a secondary winding. In a typical high-tension magneto ignition coil, the primary winding comprises about 150 turns of fairly heavy copper wire, and the secondary winding comprises about 20,000 turns of very fine copper wire. This difference in the windings is what causes the voltage to be multiplied as it's induced by the primary to the secondary.

As the flywheel/rotor turns, the permanent magnets mounted near the edge of the flywheel/rotor move past the ignition coil. This movement magnetizes the soft iron core (coil armature) and induces a current in the primary winding of the ignition coil. The magnetic field produced by the primary winding induces a voltage in the secondary winding. However, the buildup and collapse of the magnetic field by this action isn't fast enough to induce the voltage strong enough to fire the spark plug.

This is when the condenser comes in handy. The primary winding, as can be seen in Figure 15-17, is connected to the breaker points. When the breaker points are closed, a complete circuit is formed, and a current flows through the primary winding to produce a magnetic field. The eccentric egg-shaped cam that is located on the crankshaft is timed to open the breaker points just as the magnetic field in the primary begins to collapse. This interrupts the current flow in the primary circuit, causing the magnetic field around the primary winding to rapidly collapse. At the same time, the condenser (which also protects the breaker points from burning) releases its charge back through the primary winding to hasten the collapse of the magnetic field. This action helps to increase the voltage induced in the secondary winding to the required high strength.

The high voltage induced in the secondary winding causes a current to flow through the spark plug wire and arc across the spark plug gap. After the high voltage in the secondary winding is released as a spark, the flywheel/rotor continues to turn until the magnet positions itself by the ignition coil again, and the process repeats itself.

Low-Tension Magneto Ignition System

Not found often in power equipment engines, the low-tension magneto system is similar in operation to the high-tension magneto system. The main difference is that the low-tension system uses a separate ignition coil. The breaker points in both the high- and low-tension magneto ignition systems are connected in series with the primary circuit. When the breaker points are closed in the low-tension magneto system, the primary circuit is completed (Figure 15-18). As the magneto rotor turns, AC is generated in the magneto windings and flows through the ignition coil primary winding. The primary winding in the ignition coil produces a magnetic field in the ignition coil.

Energy-Transfer Ignition System

The energy-transfer ignition system (Figure 15-19) is another type of magneto ignition system found in power equipment engines. The primary difference between the energy-transfer system and the magneto systems is that the breaker points are connected in parallel with the primary circuit instead of in series. By having the points wired in parallel, the primary winding in the ignition coil induces voltage into the secondary windings by using a rapid buildup of a magnetic field instead of a rapid collapse of the field.

Battery-and-Points Ignition Systems

Now, let's look at a battery-and-points ignition system. Remember that battery ignition systems were used in older street-type power equipment engines. In a battery-and-points ignition system, a battery is used to provide power to the ignition coil instead of a magneto; however, the remainder of the system is similar to the magneto systems we've discussed. The battery-and-points system (Figure 15-20) uses the same type of breaker points, condenser, and spark plug as magneto-type ignition systems.

The battery used in this type of system is the lead acid storage battery (see Chapter 14). Besides providing electricity to power the

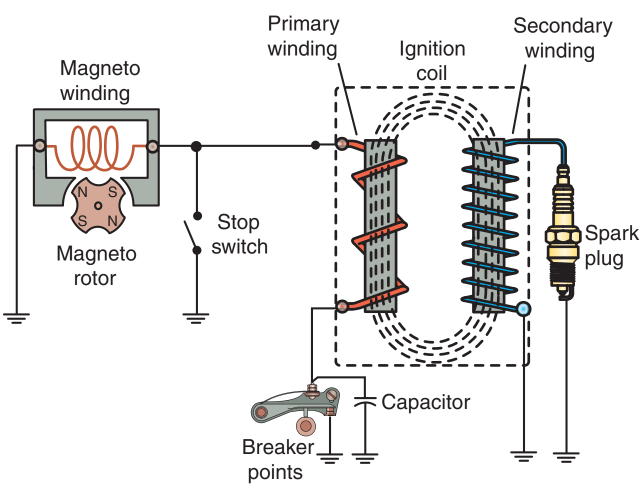


Figure 15-18 A low-tension magneto ignition system.

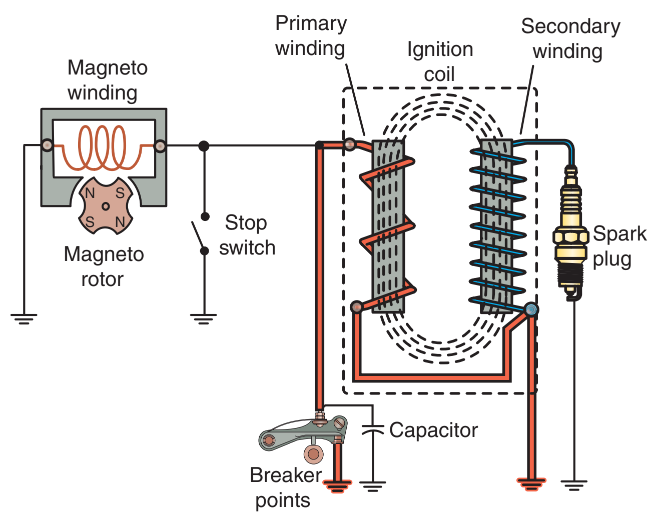


Figure 15-19 An energy-transfer ignition system.

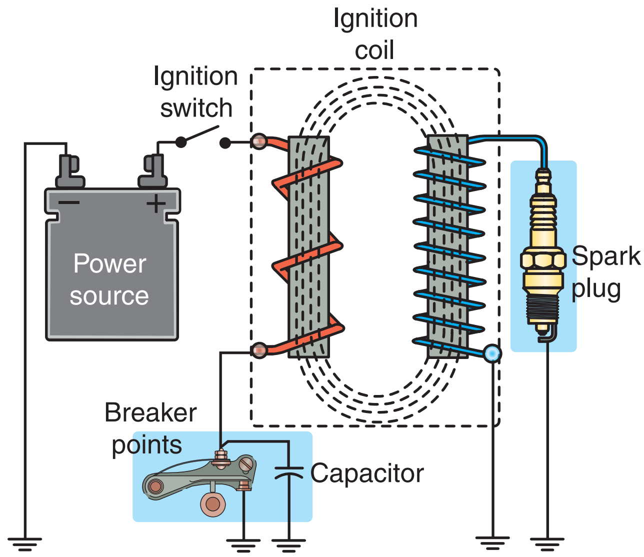


Figure 15-20 The battery-and-points system uses the same type of breaker points, condenser, and spark plug as the magneto-type ignition system, the primary difference being the source of electrical power.

ignition coil, the battery may also be used to power lights, electric starter systems, and other accessories.

The battery-and-points ignition system uses breaker points to trigger the ignition. The battery provides the voltage to energize the primary winding of the ignition coil. The voltage to the ignition coil is controlled by a key-operated ignition switch. When the ignition switch is turned on, power from the battery passes through the ignition switch to the primary winding of the ignition coil. The opposite end of the primary winding is connected to the breaker points and condenser. The breaker points, the secondary winding, and the spark plug operate in exactly the same manner as in the high- and low-tension magneto systems. The contact points are opened by the breaker-point cam at the specified time. As the points open, the primary magnetic field rapidly collapses, causing a high voltage to be induced into the secondary windings. The only difference between this ignition system and the magneto ignition system is that DC (from the battery) is used to energize the primary winding of the ignition coil in the former, instead of the AC.

When the ignition switch is turned off, the switch contacts open, and the flow of power from the battery to the primary winding of the ignition coil is stopped. As a result, the engine stops running.

Electronic Pointless Ignition Systems

Breaker-points-and-condenser ignition systems have been in use for many years, but you may see these types of ignition systems only in older power equipment engines. Newer power equipment engines come with electronic ignition systems. The reason for this is that mechanical breaker points eventually wear out and fail. The result is poor engine performance at first and ultimately, total ignition failure. Electronic ignition systems are durable because they use permanent magnets, electronic sensors, diodes, transistors, and SCRs in place of mechanical switching components.

Except for the breaker points and condenser, electronic ignition systems use the same basic components that we've discussed. In place of the breaker points and condenser, the electronic ignition system uses an electronic ignition control module (ICM or ECM). This module is a sealed, non-repairable unit that's generally mounted on a bracket on the chassis or can also be part of the ignition coil. The unit is frequently black in color, which has led to the term *black box* often being used for this module.

Other than the rotor and its magnets, electronic ignition systems have no moving parts; so the performance of the system doesn't decline through operation. ICMs are resistant to moisture, oil, and dirt. Although resistant to outside conditions, water can get into modules and cause interruptions or failure to the ignition system. However, in general, they're reliable, don't require adjustments, and have long life spans. An electronic ignition system provides easy starting and smooth, consistent power during the operation of the power equipment engine.

Although there are many variations, there are three basic types of electronic ignition configurations that we'll discuss:

- Capacitor discharge ignition
- Transistorized ignition
- Digitally controlled transistorized ignition

Capacitor Discharge Ignition Systems

The electronic ignition system most often used in small power equipment engines is the CDI system. The basic components of a **capacitor discharge ignition** (CDI) system may be configured in several ways. Although various CDI systems may have different arrangements of wiring and parts, they all operate in much the same way.

Figure 15-21 shows how the components of a CDI system are arranged in a typical power equipment engine. Note that the CDI system contains two coils (windings) that are triggered by magnets in the flywheel/rotor or AC generator. The larger coil is called the charging or exciter coil, and the smaller coil is called the trigger coil. The trigger coil controls the timing of the ignition spark and essentially replaces the breaker points.

As the flywheel/rotor rotates past the exciter coil, the AC produced by the exciter winding is rectified (changed to DC) by the diode in the CDI unit. The capacitor in the CDI unit stores this energy until it's needed to fire the spark plug (Figure 15-22). As the flywheel/rotor magnet rotates past the trigger coil, a low-voltage signal is in the trigger coil, which activates the electronic switch (SCR) in the CDI unit (Figure 15-23). The SCR acts as the power source to the primary side of the circuit. This completes the primary circuit, to allow the energy stored by the capacitor to pass through the primary winding of the ignition coil. The transformer action of the ignition coil causes a high voltage to be induced in the secondary of the ignition coil, which fires the spark plug (Figure 15-24).

Another type of CDI ignition system found in some power equipment engines is one that

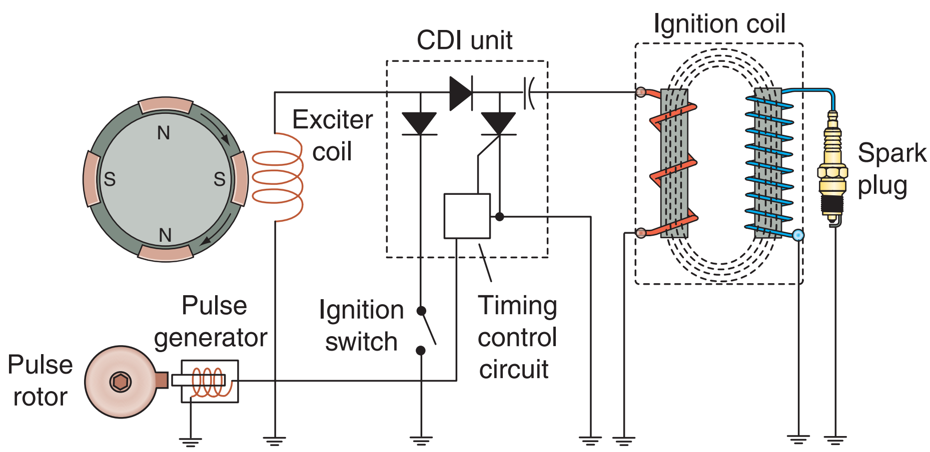


Figure 15-21 A typical capacitor discharge ignition (CDI) system.

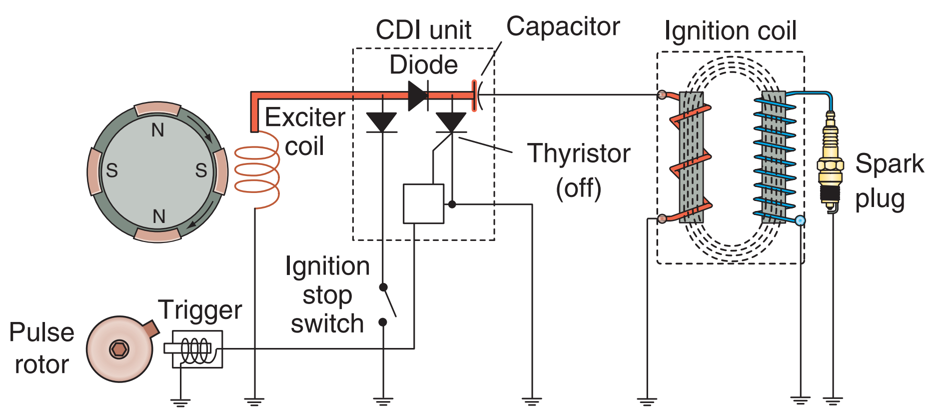


Figure 15-22 The capacitor in the CDI unit stores the diode-rectified DC until it's needed to fire the spark plug.

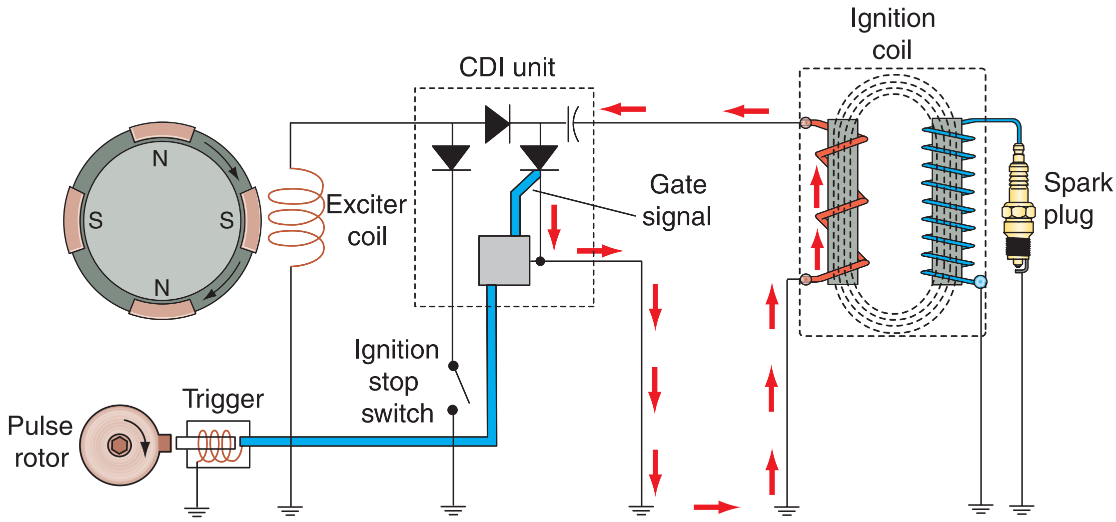


Figure 15-23 A low-voltage signal induced in the trigger coil activates the electronic switch (SCR) in the CDI unit. This completes the primary circuit, which enables the capacitor to discharge through the primary winding of the ignition coil.

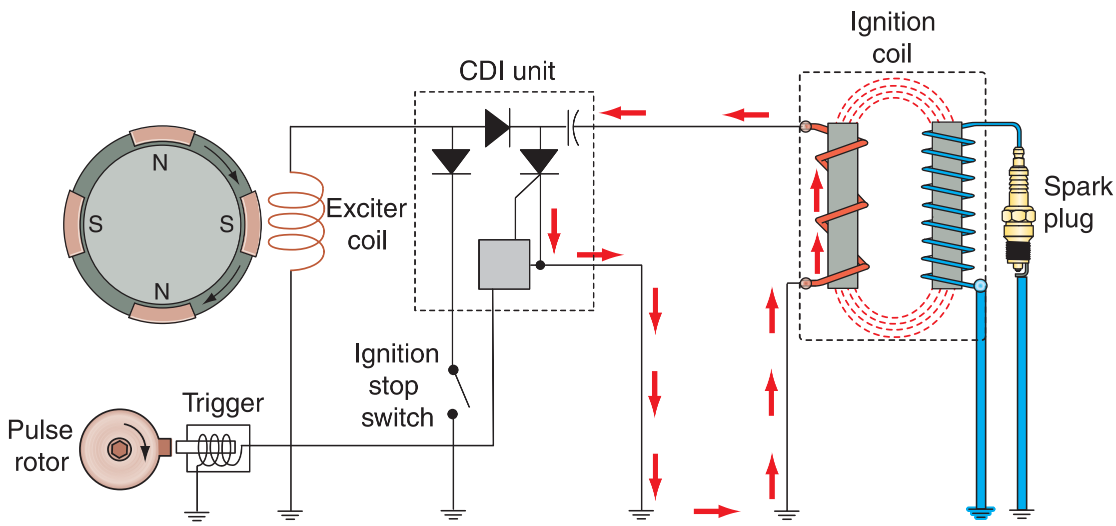


Figure 15-24 The transformer action of the ignition coil causes a high voltage to be induced in the secondary of the ignition coil, which fires the spark plug.

uses DC from a battery as its source of voltage, with a voltage booster placed in the CDI unit, instead of the AC generator and an exciter coil (Figure 15-25). The voltage booster amplifies the battery voltage to over 200 volts. This type of CDI system uses the same components we've just discussed and operates in the same fashion.

Transistorized Ignition Systems

Not popular but still used in some power equipment engines, the transistorized ignition system (Figure 15-26) operates by controlling the flow of electricity to the primary coil of the ignition. With this type of ignition system, transistors are contained within the ICM and are used to supply electricity to the primary coil. When the voltage level in the primary reaches a certain level, a second transistor turns off the first transistor. This causes the magnetic field around the primary coil to collapse, which creates the high voltage across the secondary coil. The high voltage is then discharged across the spark plug.

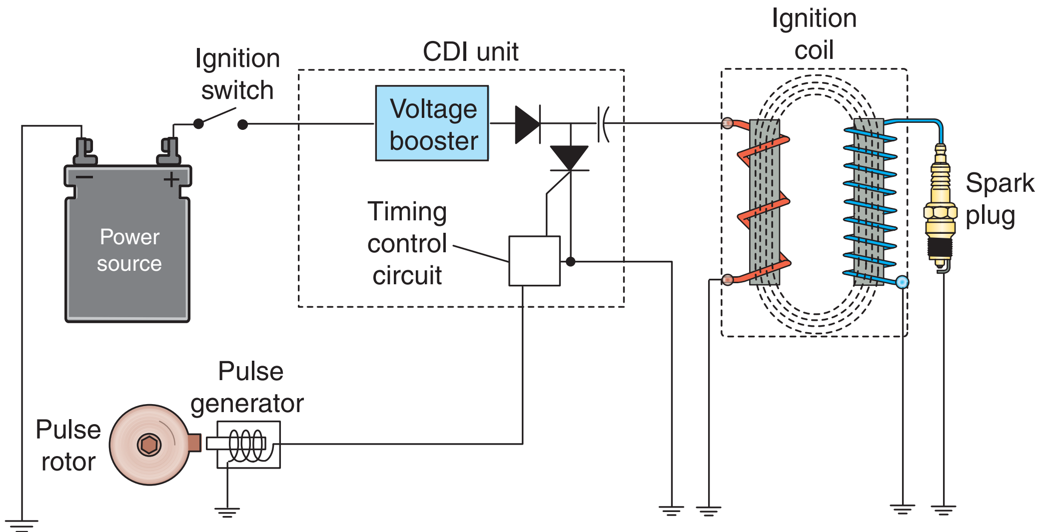


Figure 15-25 A simplified DC CDI system.

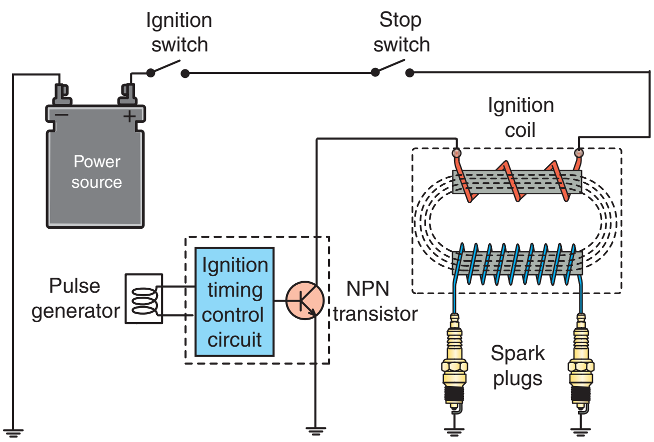


Figure 15-26 A transistorized ignition system.

Digitally Controlled Transistorized Ignition Systems

The digitally controlled transistorized ignition system is a type of transistorized pointless ignition (TPI) that's found in most power equipment engine applications today. The electronic components of a digitally controlled ignition system are contained in one unit that can be mounted directly to the power equipment engine. In this type of system, a transistor and a microcomputer are used to perform the trigger switching function.

The digitally controlled transistorized ignition system digitally controls ignition timing using a microcomputer inside the ICM (Figure 15-27). The microcomputer calculates the ideal ignition timing at all engine speeds. The microcomputer also has a fail-safe mechanism, which cuts off power to the ignition coil in case the ignition timing becomes abnormal. These ignition systems can also have built-in rev-limiters.

The generator rotor has projections, known as reluctors, that rotate past the ignition pulse generator, producing electronic pulses. The pulses are sent to the ICM. The engine rpm and crankshaft position of the cylinder are detected by the relative positions of the projections that are located on the rotor.

The ICM consists of a power distributor, a signal receiver, and a microcomputer. The power distributor distributes battery voltage to the ICM when the ignition switch is turned to the On position and the engine stop switch is in the Run position. The signal receiver uses the electronic pulse from the ignition pulse generator and converts the pulse signal to a digital signal. The digital signal is sent to the microcomputer, which has a memory unit and an arithmetic unit. The memory unit stores predetermined characteristics of the timing for different engine speeds and crankshaft positions. It then determines when to turn the transistor on and off to achieve the correct spark plug firing time.

When the transistor is turned on, the primary winding of the ignition coil is fully energized. The microcomputer turns the transistor

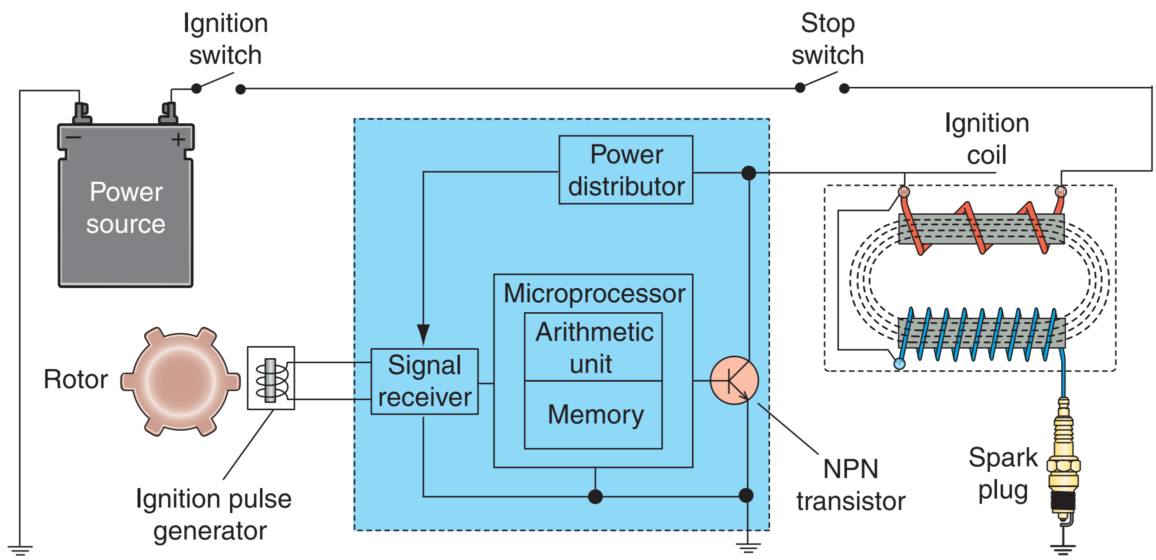


Figure 15-27 A digitally controlled transistorized ignition system.

off when it's time to fire the spark plug. This collapses the magnetic field and induces a high voltage in the ignition coil secondary winding to fire the spark plug.

Visually, both the standard TPI system and the digital TPI system look similar. The primary visual difference between these two popular ignition systems is the ignition pulse generator rotor. When used on a standard TPI, the pulse generator rotor has only one reluctor to signal the pulse generator. On the digital TPI system, there are several reluctors to "inform" the microcomputer of the engine's rpm and crankshaft position.

ELECTRIC STARTER SYSTEMS

Electric starting systems found in power equipment engines use a DC motor that converts the battery's electrical energy into mechanical energy, which turns the engine's crankshaft quick enough to start the engine. Because the current required for a starting system is very high, a starter solenoid (also known as an electromagnetic switch) and heavy-gauge electrical leads are used to make the connection between the battery and starter motor. When the starter motor electrical circuit is completed, it engages a starter drive clutch that in turn engages, directly or indirectly, the engine's crankshaft. Reduction gears between the starter motor and starter clutch are used to multiply the starter motor's torque output. There are numerous safety features found in electric starting circuits to ensure that the engine can't be started under certain circumstances, such as not being on the seat of the implement or having to place pressure on the brake and/or clutch pedal (Figure 15-28).

DC Motor Operating Principle

The electric starter motor uses the operating principle of the DC motor. As we've discussed in Chapters 13 and 14, when an electric current flows through a conductor wire, magnetic lines of force encircle the wire. If the current-carrying wire is placed between the north and south poles of a magnet, a reaction occurs between the magnetic field encircling the wire and the magnetic field between the magnets.

From Figure 15-29, we can see that the magnetic lines of force (of the current-carrying wire and of the magnet) reinforce each other below the wire, where they run in the same direction, and tend to cancel each other out above the wire, where they run in opposite directions. This causes the wire to be forced upward. The current-carrying wire is always pushed away from the side having the stronger magnetic field. If the electrical current through the wire was reversed, just the opposite reaction would occur, and the wire would be forced downward.

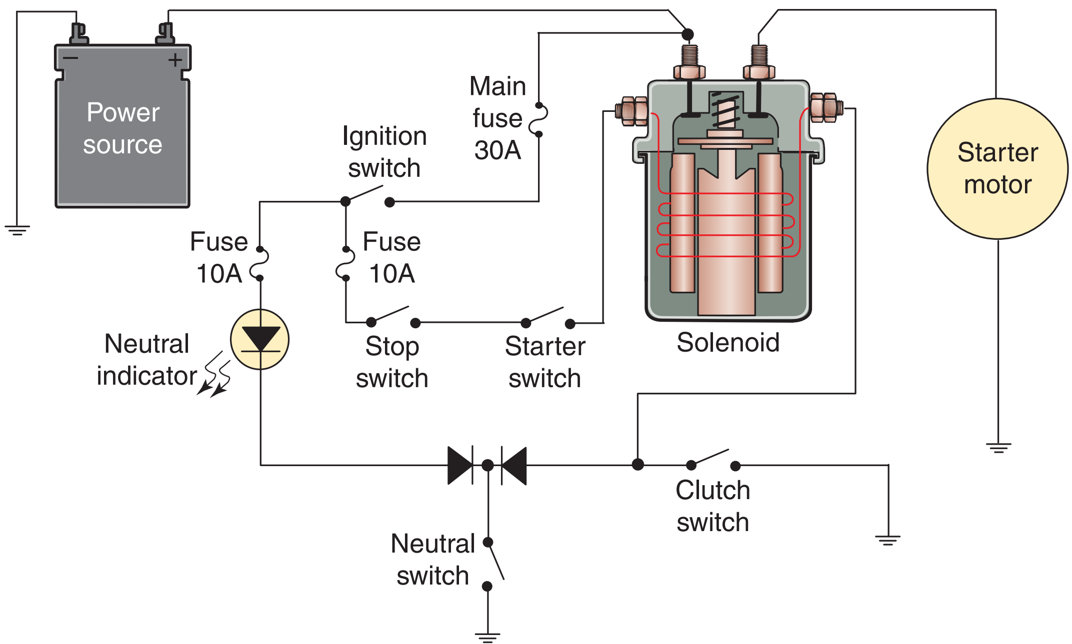


Figure 15-28 A basic electric starting circuit.

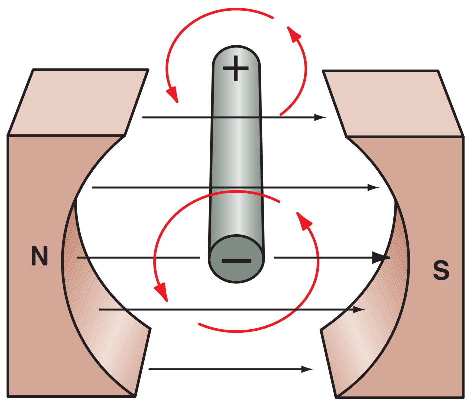


Figure 15-29 A current-carrying conductor placed in a magnetic field causes motion.

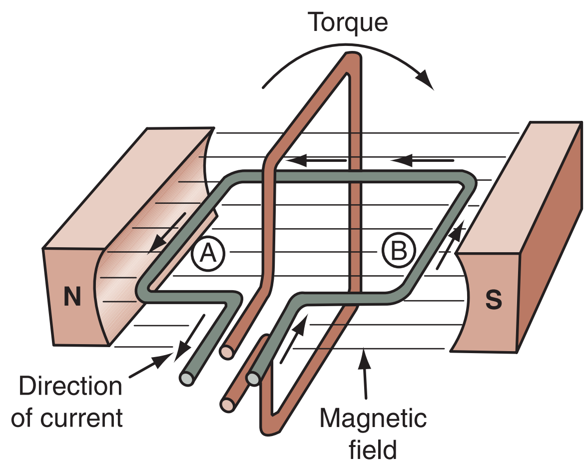


Figure 15-30 A loop of current-carrying conductor placed in a magnetic field causes a rotary motion.

If a loop of current-carrying wire is placed between the north and south poles of a magnet, as seen in Figure 15-30, the direction of the current flow (and therefore the direction of the magnetic field encircling the wire) in the loop at A is opposite to the direction of current flow (and magnetic field) in the other side of the loop at B. Therefore, Side A of the loop is forced upward while Side B is forced downward. This causes the black-colored loop in the figure to rotate in a clockwise direction until it stands perpendicular to the lines of magnetic force between the magnetic poles.

If both the brown and grey wires in Figure 15-30 are fixed so that they rotate together, the grey-colored wire would be in the horizontal position when the brown-colored wire is vertical. Now, if we pass a current through the grey wire, as we did for the brown wire when it was in the horizontal position, the grey wire will be forced to turn in the same (clockwise) direction. This continues the rotary motion of the wires. As the grey wire is turned to the vertical position, the brown wire is returned to the horizontal position. However, to make the motor continue to rotate in the same direction, the current in the brown wire must now be reversed.

The reversal of current flow is accomplished by a commutator-and-brush arrangement, as shown in Figure 15-31. The battery is connected to carbon brushes, which slide against commutator segments. Each commutator segment is connected to one end of a wire loop. The commutator segments rotate with the wire loops. As the segments turn, each brush slides from one commutator segment to the next. The direction of current flowing through each wire loop is reversed when the brushes contact opposite commutator segments, allowing the loop to continue rotating as long as there's battery current being sent to the brushes.

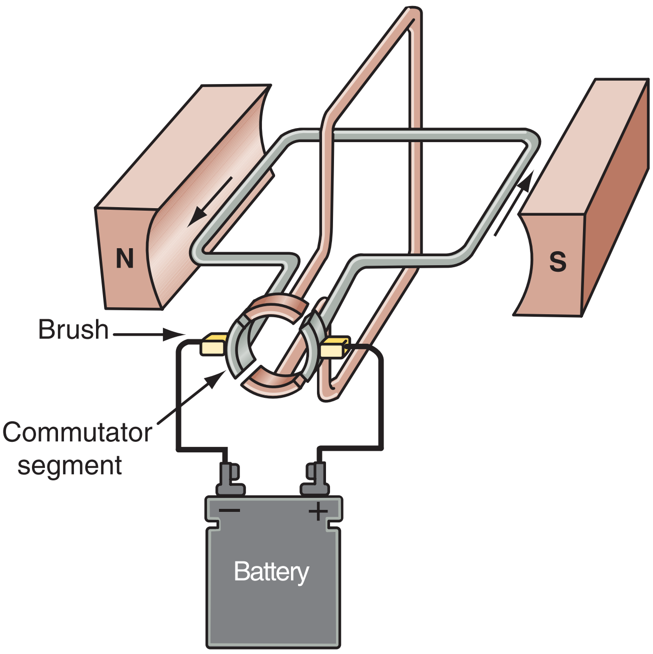


Figure 15-31 The operation of a commutator and brushes in a DC motor.

The DC motor we've described has been greatly simplified to illustrate the basic principles of the DC motor. In an actual DC motor, many loops of wire, called armature windings, are used to make the DC motor run more smoothly and develop more power. Also, some starter motors use electromagnets rather than the permanent magnets shown in our simple illustration.

Starter Motor Construction

Figure 15-32 shows a cutaway of a typical starter motor. The motor contains coils of wire wound around a laminated-iron armature core. At one end of the armature, there are copper commutator segments, which directly correspond to the number of armature coils of wire. Each of the commutator segments is insulated from the others. The armature coils are spaced in such a manner that, for any position of the armature, there will be coils near the poles of the field magnets. This makes the torque both continuous and strong. Electromagnets are used in many starter motors instead of permanent magnets because they can be made to provide a stronger magnetic field.

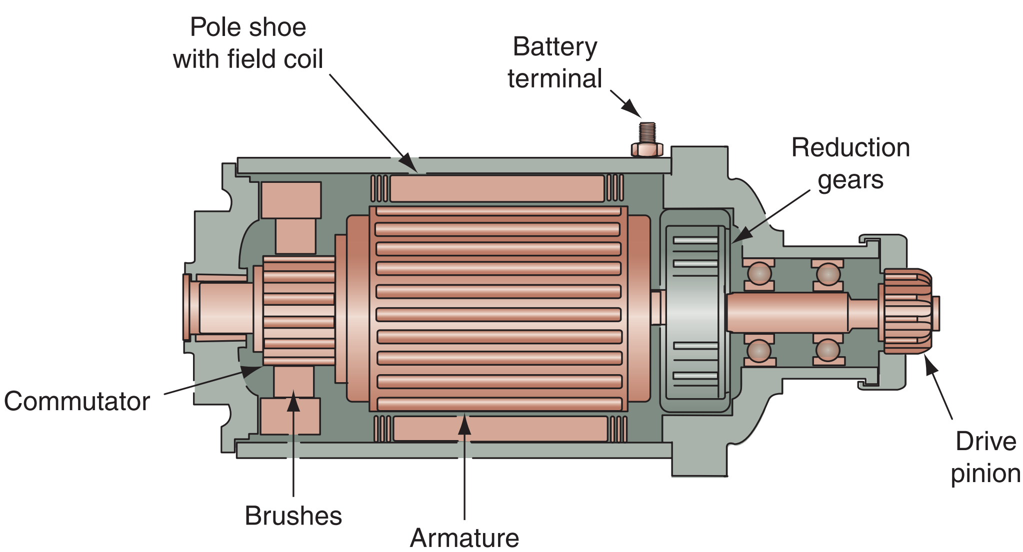


Figure 15-32 An electric starter motor.

Brushes are made out of carbon, because of which they have a long service life and cause minimum commutator wear. Springs are used to hold the brushes firmly against the commutator (Figure 15-33). The brushes and commutator connect the field coil windings with the armature windings in series. Therefore, any increase in current strengthens the magnetism of both the field and the armature. DC motors produce high starting torque, which is necessary in a starter motor. The brushes have a specification for length, as they can wear with time (Figure 15-34).

The armature shaft is connected to a gear reduction system, which multiplies the motor's torque. This enables the starter to turn the engine over easily under compression. The gear reduction system may be contained in the engine crankcase or built into the starter motor housing, depending on the engine design.

Figure 15-33 The end cap of this starter motor has been removed to show its brushes, brush springs, and commutator. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

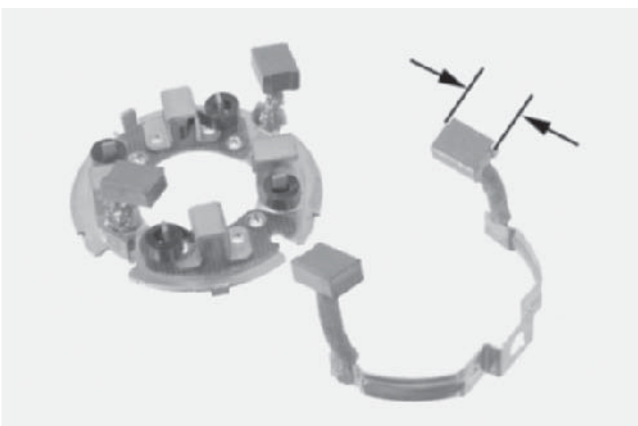


Figure 15-34 Because contact brushes on starter motors are made out of carbon and wear with time, manufacturers have a length specification to measure wear. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

Starter Solenoids

A starter motor can draw in excess of 120 amperes of current when cranking the engine. A heavy electrical cable and a heavy-duty switch are required to properly handle this high current flow. It would seem obvious that it wouldn't be practical to run heavy cables up to the handlebar and install a large, heavy-duty switch there. Therefore, instead, a small key or push-button switch on the implement activates an electromagnetic starter solenoid switch, as shown in Figure 15-35. The starter solenoid connects the battery to the starter motor. You'll generally find the solenoid mounted near the battery.

When the main switch is turned on and the starter button is pressed, the starter solenoid primary circuit is completed. DC flows from the battery through an electromagnet in the solenoid. The electromagnet pushes the plunger into contact with the starter switch terminals, completing the circuit between the battery and the starter motor.

Starter Clutches

The **starter clutch** is a mechanism that allows the starter motor to engage only while the starter motor is operating to start the engine. Starter clutches are also known as sprag clutches (Figure 15-36).

When the engine starts, the engine's increased speed automatically disengages the starter motor. Figure 15-37 shows a starter clutch. This particular starter clutch would be installed on the crankshaft and is chain driven.

The starter-clutch housing is attached to the engine's crankshaft. Starter engagement is achieved by locking the gears of the starter motor to those of the starter-clutch housing, and disengagement is achieved by unlocking these parts. Spring-loaded rollers in the clutch housing perform the locking and unlocking functions.

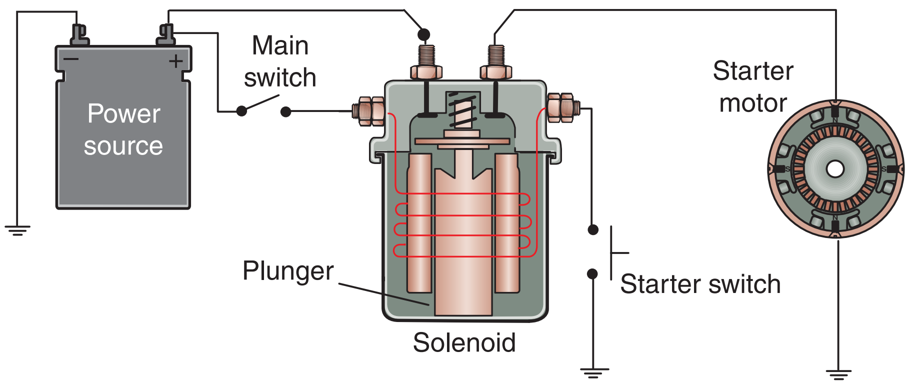


Figure 15-35 An electromagnetic starter switch and solenoid.

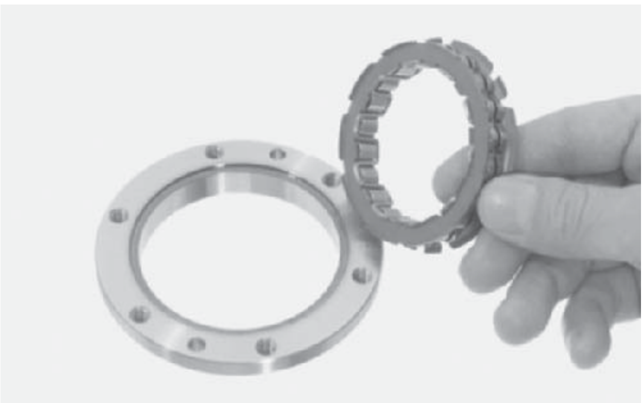


Figure 15-36 A one-way starter clutch. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

The rollers ride on ramps within the starter-clutch housing. When extended, the rollers wedge the hub tightly against the clutch housing. When the rollers are retracted, the sprocket hub and clutch housing are no longer locked together.

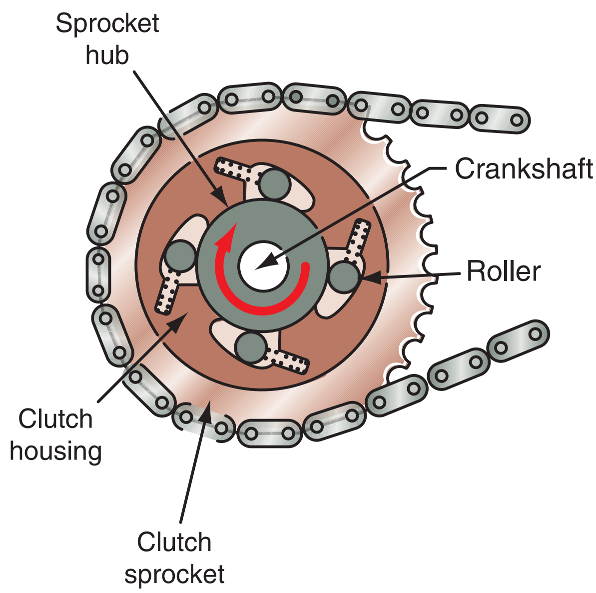


Figure 15-37 A typical chain-drive starter clutch.

Summary

- The ignition system has three main functions. First, it must generate an electrical spark that has enough heat to ignite the air–fuel mixture in the combustion chamber. Second, it must maintain that spark long enough to allow for the combustion of all the air and fuel in the cylinder. Lastly, it must deliver a spark to the cylinder so combustion can begin at the right time during each compression stroke of the piston.
- The main components of an ignition system are the power source, ignition switch, ignition coil, spark plug, triggering switch, and stop switch.
- All ignition systems use a primary coil and a secondary coil. The current in the primary coil induces a relatively large voltage in the secondary, to create a high output voltage to the spark plug.
- There are two general types of ignition systems: breaker point and electronic ignition. There are four types of breaker point systems: high-tension magneto, low-tension magneto, energy transfer, and battery point. There are three basic types of electronic ignition systems: capacitive discharge, transistorized, and digitally controlled transistorized systems.

- Electric starting systems found in power equipment engines use a DC motor to transform the battery's electrical energy into mechanical energy, which turns the engine's crankshaft quick enough to start the engine. The current required for a starting system is very high. Therefore, a starter solenoid and heavy-gauge electrical leads are used to make the connection between the battery and starter motor.

Chapter 15 Review Questions

1. The side electrode of a spark plug is also called the ______.
2. A spark plug that can easily transfer combustion heat from the firing end to the shell and then to the cylinder head is called a ______ plug.
3. Correct spark plug ______ is essential for achieving optimum engine performance and long plug life.
4. The ______ winding of an ignition coil uses relatively few turns of heavy copper wire in relation to the ______ winding.
5. A capacitor discharge ignition system has fewer moving parts than an energy-transfer ignition system. (True/False)
6. The power source in a power equipment engine ignition system is connected directly to the secondary winding of the ignition coil. (True/False)
7. The electromagnetic switch that's used to activate the starter motor is known as a ______.
8. Electric starters are used to transform the battery's electrical energy into ______ energy to turn over the engine's crankshaft.
9. In a CDI ignition system, which one of the following components stores the energy to fire the spark plug?

   a. Capacitor c. Charging coil
   b. Diode d. SCR

10. The function of the condenser in a breaker points ignition system is to

    a. advance the engine timing at high rpm.
    b. induce a voltage in the primary coil.
    c. delay the opening of the points.
    d. prevent electricity from arcing across the points.

11. The length of the metal threads at the end of a spark plug is called the

    a. ground. c. insulator.
    b. reach. d. shell.

12. Which of the following is an ignition component requiring no adjustment?

    a. Contact breaker points
    b. Mechanical advancer
    c. Electronic advancer
    d. Voltage regulator

13. The flywheel/rotor and the crankshaft are held together in alignment by the

    a. armature coil.
    b. woodruff key.
    c. cylinder head.
    d. magneto.

14. Which of the following statements about the ignition coil in a power equipment engine ignition system is correct?

    a. The coil will be found only in an ignition system that's powered by a magneto.
    b. The coil's iron core is called the primary winding.
    c. The secondary winding is connected to the spark plug wire.
    d. The secondary winding contains fewer coils of wire than the primary winding.

15. An electric starter system uses a ______ to carry the high current from the battery to the starter.

    a. condenser.
    b. magneto.
    c. capacitor.
    d. solenoid.

CHAPTER

16 Power Equipment Engine Maintenance

Learning Objectives

- Understand the importance of performing various engine maintenance procedures
- Describe procedures for storing a power equipment engine

Key Terms

Dip-stick
Timing light
Tune-up
Scheduled maintenance

INTRODUCTION

In this chapter, you'll learn the importance of scheduled maintenance as well as engine maintenance procedures. What are the benefits to having power equipment engines serviced and maintained on a regular basis? Technicians are frequently asked this question. Peak performance from a power equipment engine requires that each part be correctly adjusted and in good working condition. An experienced technician knows that if a part isn't functioning correctly, it can affect the performance of other related parts and the performance of the machine or implement. For example, a spark plug that doesn't fire when it should affects the power output of the engine. Spark plug failures can be caused by normal wear, an electrical system malfunction, or fuel system problems. Scheduled servicing ensures that marginal and out-of-tolerance parts are routinely corrected.

Many service shops use the word *tune-up* when referring to particular service procedures in maintenance of power equipment engines. You'll find that it means different things to different people. Some power equipment engine owners assume that certain items will be serviced during a routine **tune-up**, when in fact a tune-up may not include that level of service. A fairly common customer misconception is that a tune-up automatically includes carburetor overhaul service. Some shops may include this in a tune-up, but most don't. Again, some service shops adjust valves in a four-stroke engine during a tune-up, whereas others don't include this in a tune-up. Most shops consider this level of repair to be a separate service. The difference in what shops provide during a tune-up is one of the main reasons that you'll find a wide range of prices for maintenance service.

There's an important point that requires emphasis. You, as a power equipment engine technician, should encourage users to adopt a policy of routine periodic service inspections for their engines. **Scheduled maintenance** ensures trouble-free operation of the engine and the machine it's powering, as is a complete pre-run inspection each time the engine is used.

MAINTENANCE INTERVALS

All manufacturers recommend that power equipment engines be serviced at specific time intervals. The suggested maintenance intervals are listed in the owner's manual to help remind owners and in the service manual to help technicians set up a realistic and appropriate maintenance schedule. Many power equipment engine owners have a vehicle tune-up every spring, even though it may not be necessary. This is because if a power equipment engine owner had had a full scheduled maintenance completed in spring but used the engine only a couple of times over the year, the engine won't need a full maintenance the following spring.

To ensure maximum performance, a technician should check parts for wear and perform needed adjustments during specific service inspections. This allows technicians to alert owners if minor or even major repair work is required. If caught in time, this process can potentially eliminate many serious mechanical failures, benefiting both the owner and the technician.

In a service environment, it'll be important for you to convey to engine owners the results and findings of a routine service inspection in a way that generates confidence in your ability. If, for example, during the inspection, you find a defective part, you should be able to provide the owner with an accurate assessment of the problem and an estimate of what it will cost to correct.

Tables 16-1 through 16-3 provide examples of typical engine maintenance intervals as they would appear in an owner's manual. You should note that the maintenance schedules you'll see in many manuals are based on average-use conditions. Machines that are subjected to severe usage would require more frequent servicing than what is listed in the service or owner's manual.

As you can see from these suggested maintenance intervals, different procedures are recommended at different times. Always keep in mind that if a machine is being used under harsh conditions, such as extreme heat or dust, you'll need to perform certain maintenance procedures more frequently.

Table 16-1: Maintenance Schedule

Item (1)	Action	Each Use or 5 Hrs.	First Month or 5 Hrs.	Every Season or 25 Hrs.	Every Season or 50 Hrs.	Every 100 Hrs.	Every 150 Hrs.	Page
Engine oil	Check	0						7
	Charge		0		0(3)			7
Air cleaner	Check	0			0			7
	Clear			0(2)				
	Replace						0 (200 Hrs.)	
Spark plug	Check-Adjust				0			8
	Replace						0 (200 Hrs.)	
Blade brake clutch	Check					0		*
Flywheel brake pad	Check				0			8
Spark arrester	Clean					0		8
Idle speed	Adjust						0(4)	Shop manual
Fuel tank and fiiter	Check					0(4)		Shop manual
Fuel line	Check	Every 2 years (4)						Shop manual
Valve clearance	Check-Adjust					0(4)		Shop manual
Combustion charrber	Clean	After every 250 hours (4)						Shop manual

(1) For commercial use. log hours of operation to determine proper maintenance intervals.
(2) Service more frequently when used in dusty areas.
(3) Change engine oil every 25 hours when used under heavy load or in higl ambient temperatures.
(4) These items should be serviced by an authorized Honda servicing dealer, unless you have the proper tools and are mechanically proficient. Refer to the Honda shop manual for service procedures.

* See your equipment manual or Honda engine shop manual.

Failure to follow this maintenance schedule could result in non-warrantable failures ______

Table 16-2: Typical Engine-Maintenance Schedule

Daily or before starting engine

- Fill fuel tank
- Check oil level
- Check air cleaner, clean as necessary
- Check air intake and cooling areas, clean as necessary

Every 2 months or 25 hours

- Service air cleaner element (if not equipped with precleaner)
- Change oil and filter
- Remove blower housing and clean cooling areas
- Check all fasteners are in place and components are properly secured
- Replace fuel filter

Annually or every 100 hours

- Replace fuel filter

Every 2 years or 200 hours

- Check spark plug condition and gap
- Have Bendix starter drive serviced

Every 200 hours

- Have valve lash checked/adjusted

Table 16-3: Typical Engine-Maintenance Schedule

Procedure	Interval
Change oil	After first 2 hours (when engine is warm)
Check oil level	Every 5 hours or before each use
Clean cooling fins	Every 5 hours or before each use
Change oil	Every 25 hours or 3 months
Clean foam pre-filter	Every 25 hours or 3 months
Replace paper filter	Every 100 hours or seasonally
Check spark plug	Every 100 hours or seasonally
Replace spark plug	Every 200 hours or seasonally

Maintenance Process Order

The adjustments and repairs related to power equipment engine maintenance can be completed in any order the technician chooses. However, you'll find that a standard routine, applicable to servicing every type of engine, will help you do the job more efficiently.

All technicians will adopt and practice a routine or system that works best for them. It's best that you adopt a structured approach that fits your unique requirements. The important thing is to get into a fixed routine so that your service technique isn't "hit or miss" but structured and complete.

POWER EQUIPMENT ENGINE MAINTENANCE

As a power equipment engine technician, you'll need to perform engine service and maintenance, including cleaning, adjusting, and replacing parts. This will ensure that parts meet the manufacturer's specifications. Although it's likely that the engine will be attached to some sort of machine, we are concentrating only on the engine here. In addition, certain tests may need to be performed, such as compression and leak-down tests, to ensure that the engine internals are operating properly. Shown in the following list is maintenance of parts and systems that are subject to dirt, wear, and/or vibration. They should be carefully inspected (and replaced or adjusted as necessary) when you're performing an engine service.

- Oil and oil filter replacement
- Cooling system inspection
- Valve inspection and adjustment (four-stroke engines)
- Spark plug inspection and replacement
- Battery inspection
- Ignition system inspection and adjustment
- Idle and fuel screw adjustment
- Air filter inspection and cleaning

Good Maintenance Begins with a Clean Machine

The first step in performing quality maintenance on any power equipment engine is to start with a clean vehicle. It's important that dirt and other foreign material don't contaminate the internal working parts of the engine. Use soap and water or a commercially available degreaser to clean the exterior of the engine. Clean power equipment engines are also easier to work on and look better. Always wipe down the external parts of the machine after you have worked on it to remove any fingerprints that may have been left behind. You can be assured that customers will notice and appreciate the fact that they have received their machine back after a service cleaner than when it came into the service shop.

Oil and Oil Filter Inspection and Replacement

In the case of four-stroke engines, engine oil changes are among the most frequent services provided at any power equipment engine repair facility. In the case of two-stroke engines, maintenance is required with the upper-engine lubrication system, although the only requirement here is to be certain that there's a correct ratio of oil to fuel with the premix-type lubrication system. For an oil-injection lubrication system, you must verify if there's an adequate supply of two-stroke oil in the oil reservoir.

Four-Stroke Oils and Oil Filters

Four-stroke power equipment engines use the same oil to lubricate all of the engine's internal components. These engines usually have only one drain plug for removing the oil from the engine's crankcase (Figure 16-1). In many small power equipment engines, the oil is drained out the oil fill hole by simply tipping the engine up onto its side.

Many larger engines have an oil filter that should also be replaced when the engine oil is changed. Paying close attention to the oil filter is just as important as changing the engine oil. The oil filter traps and contains most of the dirt and contaminants that the engine has released

Figure 16-1 The drain plug for a four-stroke engine is generally at the bottom of the engine crankcase.

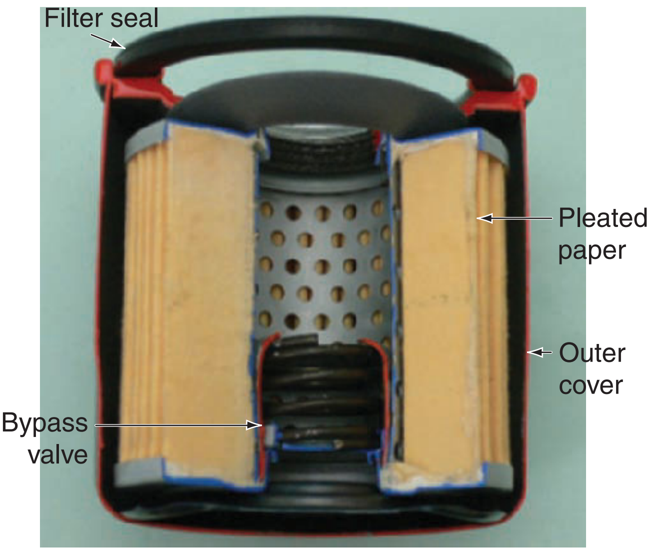


Figure 16-2 A cutaway view of a cartridge-type oil filter.

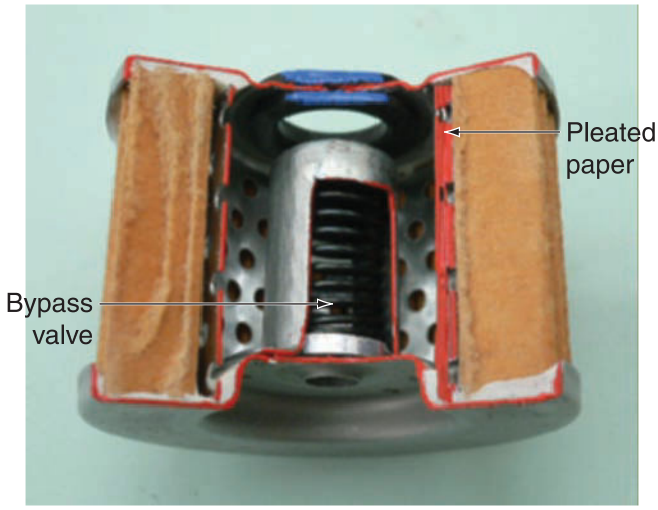


Figure 16-3 A cutaway view of an element-type paper oil filter.

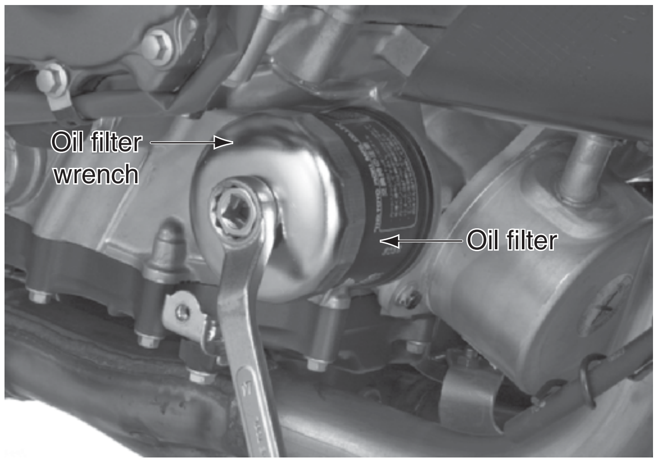


Figure 16-4 A typical oil filter wrench being used to remove a cartridge-type filter. Copyright by American Honda Motor Co., Inc. and reprinted with permission.

into the engine oil. If the engine oil is replaced without replacing the oil filter, the engine will filter new oil through a dirty filter, which may contaminate the oil and cause it to lose its effectiveness much sooner than it would have had a new filter been installed.

The most common types of power equipment engine oil filters are the cartridge-type paper filter (Figure 16-2) and the element-type paper filter (Figure 16-3). Both filter types use an oil pressure bypass valve to allow oil to pass through the filter even if the filter itself is so dirty that oil can't pass through it. The idea behind the use of a bypass valve is that dirty oil is better than no oil at all!

The cartridge-type filter is removed and installed using an oil-filter wrench. The wrench is designed to grasp the outside of this type of filter, as shown in Figure 16-4.

The element-type filter is removed by first removing a filter cover (Figure 16-5). Then, the oil filter is removed. Reference the service manual for the specific model you're working on for the proper assembly procedure. It's critically important that you correctly install the new oil filter, springs, washers, and seals. If installed incorrectly, this type of oil filter will not provide proper engine oil filtering. In a worst-case scenario, the filter could prevent the oil from reaching the engine components, which would cause major engine damage.

Checking the Oil Level

When you're checking the oil level of a power equipment engine, be sure the unit is in an upright position, on level ground. If the oil is checked incorrectly, the oil may appear to be low or high because of the tilt of the engine.

Generally speaking, the most popular method of checking the oil level uses a dip-stick (Figure 16-6). This method is similar to that in

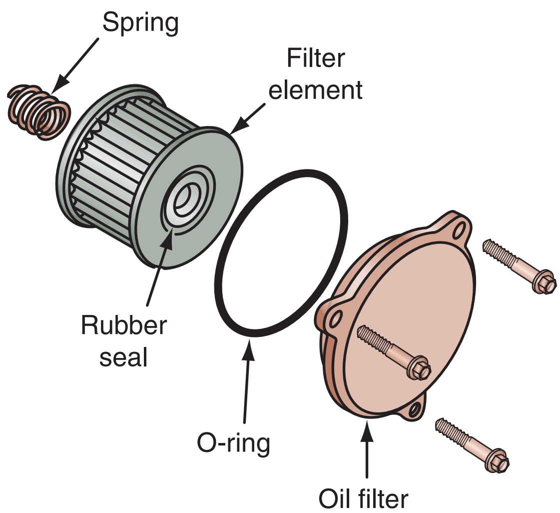


Figure 16-5 An element-type paper filter is held in place by a filter cover.

Figure 16-6 Generally speaking, the most popular method of checking the oil level in power equipment engines is by use of a screw-in dip-stick.

an automobile. In most cases, the **dip-stick** has a screw attachment. Check the manufacturer's recommendations for checking the oil level with a screw-in type of dip-stick. Also note that incorrect use of the screw-in type of dip-stick may yield an incorrect reading (Figure 16-7). Another method of checking the level of oil in smaller engines involves checking if the oil level is up to the filler cap on the engine.

Cooling System Inspection

Liquid-cooled power equipment engines can be pressure tested for leaks with a cooling system pressure tester (Figure 16-8) to ensure that the system holds the test pressure for a specified length of time.

Each manufacturer provides specifications for cooling-system pressure capabilities. If the system fails the pressure test, you should check hoses, pipe connections, the radiator, and the water pump for leaks. The water pump has a mechanical seal to separate the engine oil and the coolant. This seal is a common cause of failures in a liquid-cooled system. Most water pumps have a "telltale hole" on the bottom of

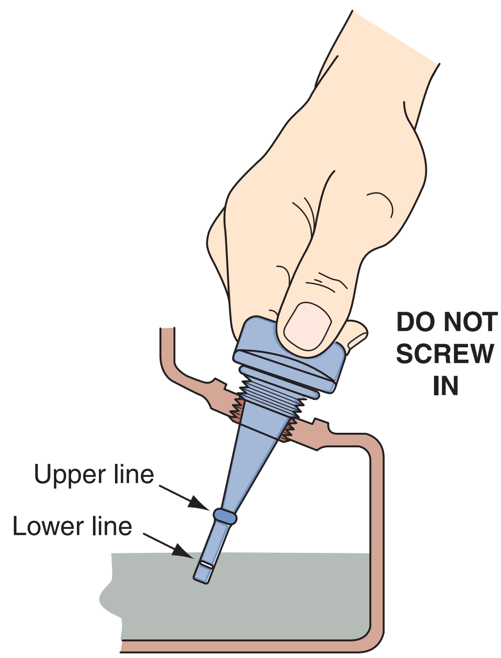


Figure 16-7 As you can see in this illustration, if you were to check the oil level incorrectly with a screw-in dip-stick, the oil level may appear to be incorrect.

Figure 16-8 A typical cooling system pressure tester. This tool checks for leaks in hoses, pipe connections, radiator, and water pump.

Figure 16-9 A hydrometer is used to check if the mixture of coolant and water is correct.

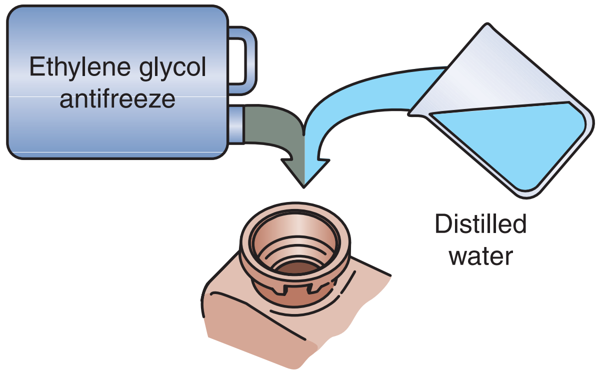


Figure 16-10 A 50:50 mixture of the manufacturer's recommended coolant and distilled water should be used in all power equipment engines that use liquid cooling.

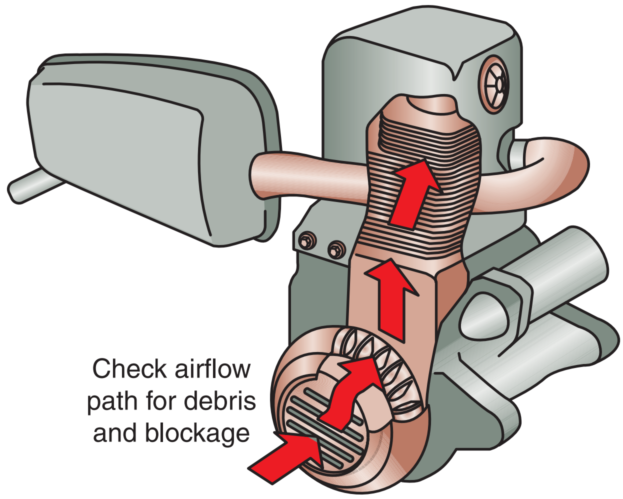


Figure 16-11 An air-cooled engine must have its cooling fins open to air. In most power equipment engines, cooling fins must be checked regularly, especially when the engine powers implements such as a lawn mower.

the pump. Coolant will leak out of this hole when the mechanical seal has failed, which will require that the pump be replaced. When checking the cooling system, the coolant should be checked with a hydrometer (Figure 16-9) to verify that it has a correct mixture of coolant and distilled water (Figure 16-10). Cooling systems should also be serviced on a periodic basis, which is provided by the manufacturer. Most agree that liquid-cooling systems should be flushed once every 24 months. Flushing a cooling system consists of draining the coolant, running water through it, and filling it with the correct mixture of coolant and distilled water.

Air-cooled engines need to have clean cooling fins. The forced-air cooling systems used in most power equipment engines should be inspected on a regular basis (and also after any long-term storage) as debris can build up under the engine shrouds (Figure 16-11) and cause overheating. Field mice and other small rodents have been known to build their winter homes inside these types of engine housings!

Compression and Leak-Down Tests

Compression and leak-down tests provide a good indication of the general condition of an engine's piston, rings, and cylinder area.

Compression tests are performed on both two-stroke and four-stroke engines.

Compression Test

A compression test ensures that the engine compression is high enough to heat the fuel–air mixture to a combustible level inside the engine's combustion chamber. To perform a compression test, remove the spark plug(s); then, using the compression gauge (Figure 16-12), measure the compression of each cylinder while the engine's crankshaft is being rotated rapidly by the starting device (electric starter or the pull starter). The recommended compression reading will be found in the appropriate manufacturer service manual. It should be noted that some engines have compression releases to aid in starting and may give a lower reading than when not activated. Manufacturers will inform you through their service manuals if there are different specifications for compression readings, or if compression releases should be removed when checking for compression.

If the compression is below recommendations, there may be possible worn parts within. Always remember to hold the throttle control in the wide-open position when checking engine compression, to allow the maximum amount of air to be drawn into the engine. If the throttle isn't held open, the compression reading will almost always read too low.

Figure 16-12 A typical compression gauge attached to a cylinder.

Unfortunately, the results of a compression test can be deceiving. For example, if you don't turn the engine fast enough, or if the testing procedures aren't correctly followed, the compression test may indicate that the engine should be disassembled and rebuilt, when the engine is actually in good working condition.

When the compression test has been performed correctly and compression appears to be outside specification, you'll need to consider other factors. If the compression readings are all below the service limit but the readings for all cylinders are relatively close and the engine isn't smoking and is running okay, the compression test by itself is seldom a good reason to disassemble the engine and do an expensive engine rebuild. However, if the compression readings for the cylinders of a multi-cylinder engine vary more than 15%, there's a good possibility that the engine has a problem that will need extensive repair work.

Leak-Down Test

Leak-down tests are performed on four-stroke engines. A leak-down tester consists of a calibrated pressure gauge that's connected to a pressure regulator, a pressure source, and a flow restrictor (Figure 16-13). As a general rule, a leak-down test provides a better indication of any internal engine problems than a compression test. Leak-down tests are obtained by pressurizing the cylinder with compressed air when the piston is at top-dead center (TDC) on the compression stroke. When this is done, a measurement of the rate at which the air escapes past the rings, piston, and valves is completed. A range of acceptable percentages of air loss is provided by the leak-down tester's manufacturer. Note that the crankshaft will rotate when performing a leak-down test, and caution should be taken when holding the crankshaft from turning.

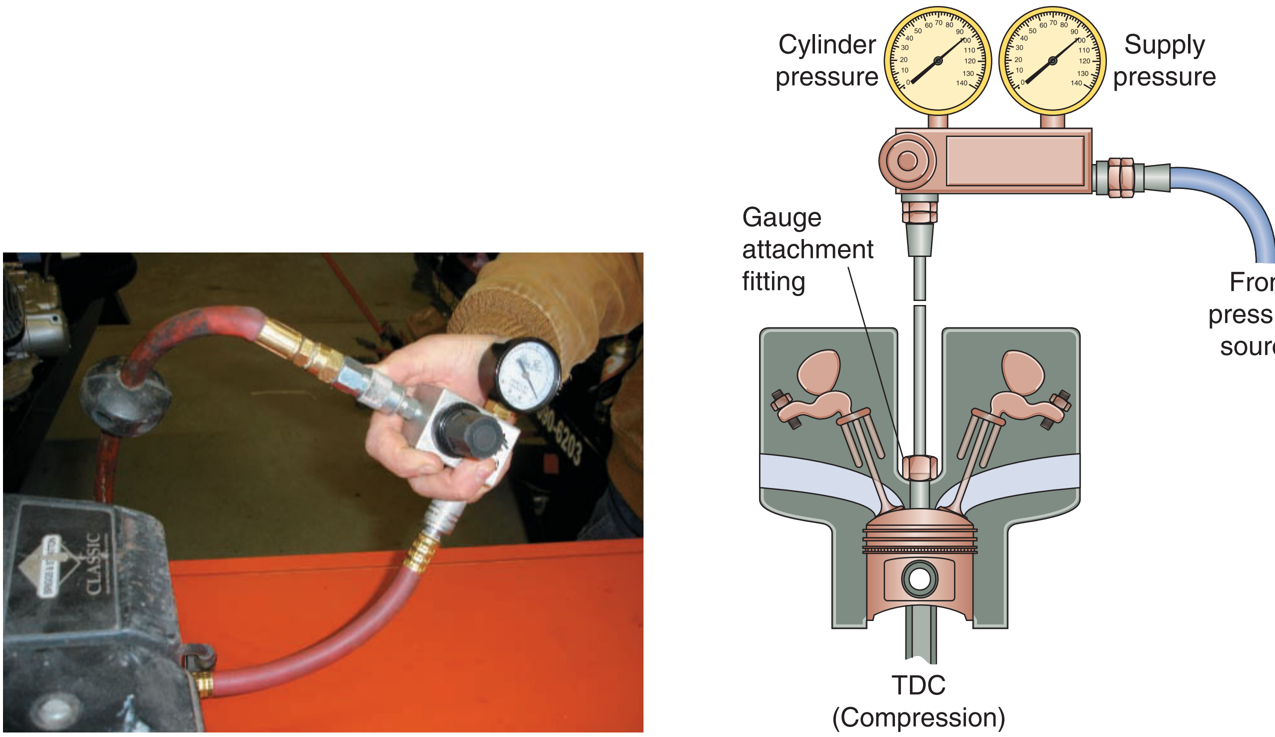
A key benefit of using a leak-down tester is that it tells you not only that there is a problem but also where the problem is located. By listening for escaping air at the air filter, the exhaust system, and engine crankcase filler-cap, you can determine if the problem is being caused by the intake valves, exhaust valves, or the piston and rings. Leak-down testers are available at most quality automotive tool suppliers.

Valve Adjustment (Four-Stroke Engines)

Nowadays, power equipment engines generally have a four-stroke engine. The valves in four-stroke engines should be inspected for proper adjustment at specific intervals. Valve clearance (lash) is necessary to allow for proper valve sealing. When valves aren't properly adjusted, engine performance may be affected. In most cases, the manufacturer will require that the valves be inspected for correct clearance when the engine is at room temperature.

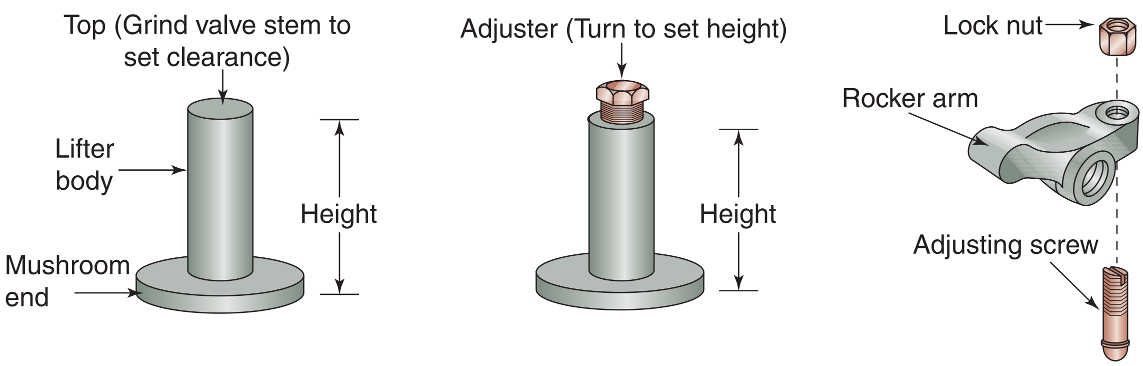
Valve Adjustment Methods

There are different ways in which manufacturers adjust valves in a four-stroke power equipment engine (Figure 16-14). Note that the piston



(a) (b)

Figure 16-13 When used correctly, leak-down testers can give the technician a good understanding of any internal engine problems.



(a) (b) (c)

Figure 16-14 The most common types of valve adjustment methods.

associated with the valves must be at top-dead center on the compression stroke (TDCC) in order to correctly inspect valves for proper clearance.

- The screw and lock nut uses a screw that can be turned in or out to change the clearance. After the adjustment has been made, a lock nut holds the screw in place. The screw and lock nut may be located on the rocker arm, on a push rod, or on a valve lifter.
- Some valves (generally in L-head designs) are adjusted by grinding the tip to allow for more clearance.

Some larger power equipment engines may use hydraulic-valve lash adjusters that automatically adjust for proper valve clearances by using oil pressure to maintain zero lash at all engine temperatures and rpm. Such hydraulic valves require no maintenance.

Valve Adjustment Specifications

The service manual has the manufacturer's recommended specifications for valve adjustments. Do yourself a favor: Don't try to remember these specifications, and refer to the manual each time they're needed. There are too many different engines for you to remember the specifications of each one. You may easily confuse the specifications of one model with those of another.

Spark Plug Inspection and Replacement

In some engines, the spark plug is one of the easiest components to access during maintenance, whereas in others, it may be among the most difficult components to access. The spark plug is generally located in the center of the cylinder head combustion chamber.

Spark Plug Removal

Before you remove the spark plug, be sure to always remove any loose dirt or debris on the cylinder head, near or around the spark plug. It's important to prevent any dirt from getting into the engine through the threaded hole in the cylinder head. If the engine had been in operation just before spark-plug removal, always allow the engine to cool before attempting to remove the spark plug. Engine heat causes the cylinder head and the spark plug shell to expand. If you try to remove the spark plug before the engine has cooled, it may seize, and removing it could damage the cylinder-head threads. When the engine and spark plug have cooled sufficiently, the plug will be much easier to remove and there's less chance of damaging the cylinder head.

To remove the spark plug, use the correct-sized spark-plug socket. We had mentioned in an earlier chapter that a spark-plug socket is a special socket wrench that's specifically designed for removing and installing spark plugs (Figure 16-15). The spark-plug socket has rubber inserts that protect the spark plug's ceramic insulator. The depth of the socket allows it to fit over the top of the spark plug to reach the hexagonal area of the shell. If a spark plug is tightly mounted on the cylinder head, the plug must be carefully removed to prevent it from breaking.

Spark Plug Inspection

After the spark plug has been removed, inspect it to determine its condition. The condition of a spark plug can tell you much about how an engine is operating. Many experienced power equipment engine technicians begin their troubleshooting process by removing and inspecting the spark plug(s).

When inspecting a spark plug, be sure to check the condition of the ceramic insulator. A damaged insulator can cause a spark plug to fail intermittently. This type of intermittent misfiring problem can be difficult to diagnose. It's a good idea to start with the spark plugs

Figure 16-15 A spark-plug socket is a special socket wrench that's specifically designed for removing and installing spark plugs.

Figure 16-16 A spark plug in normal condition. Note that the bottom surface of the center electrode is flat and the surfaces of the lower electrode are squared. Courtesy of Federal-Mogul Corporation.

Figure 16-17 Oil fouling causes the plug to be saturated with shiny oil deposits. Courtesy of Federal-Mogul Corporation.

when you're trying to isolate an intermittent problem. You should also check for the following issues.

You should first verify that the spark plug is the correct type for the engine. You can do this by referring to the service manual for the engine you're working on. After you've determined that the plug is correct, you should check the condition of the electrodes. Let's take a look at some of the most common spark plug conditions.

Normal Spark Plug Figure 16-16 shows a used spark plug in normal condition removed from a properly operating engine. Note that the bottom surface of the center electrode is flat and the surfaces of the lower electrode are squared. The electrodes are an ashy gray or light tan color, from normal fuel combustion. Note also that there is no buildup of contamination on or around the electrodes.

Oil-Fouled Spark Plug Figure 16-17 shows an oil-fouled spark plug. Oil fouling causes the plug to be saturated with shiny oil deposits. In a four-stroke engine, an oil-fouled plug may indicate that the piston rings are not sealing the cylinder properly, or that the oil may be passing through the intake valve stem. A clogged crankcase breather can also cause oil-fouled plugs. Remember that a breather is a vent in the crankcase. Thus, a clogged breather prevents the crankcase from venting properly. Pressure builds up in the crankcase, which can cause oil to be forced up past the piston rings and into the combustion chamber. Any oil in the combustion chamber can foul the spark plug, especially if the compression in the cylinder is below specifications. Oil-fouled spark plugs are more common in two-stroke engines. Remember that in a two-stroke engine, the fuel and oil are premixed in the crankcase. Thus, oil fouling is a potential problem in any two-stroke engine.

Fuel-Fouled Spark Plug Figure 16-18 shows a spark plug fouled by excessive fuel. Fuel fouling is indicated by dry, black, fluffy carbon deposits on the spark plug electrodes. Fuel fouling is most often caused by prolonged operation with a fuel–air mixture that is too rich. This is usually caused by a fuel system problem, such as a dirty air filter. A blocked or faulty exhaust valve can also cause fuel fouling. An engine with the choke that's left on for too long an interval can also cause fuel-fouled spark plugs.

Bridged-Gap Spark Plug Both oil fouling and fuel fouling can cause a spark plug condition known as a bridged gap (Figure 16-19). In this situation, carbon or oil deposits build up in the spark plug electrode gap until the gap

Figure 16-18 A fuel-fouled spark plug has dry, black, fluffy carbon deposits on the plug electrodes. Courtesy of Federal-Mogul Corporation.

Figure 16-19 A bridged gap is caused by carbon or oil deposit buildup in the spark plug electrode gap until the gap is closed. Courtesy of Federal-Mogul Corporation.

ceases to exist. A bridged gap prevents the spark plug from firing, resulting in an engine that won't start. Debris passing through the air filter and into intake port can also cause a bridged-gap.

Electrode-Eroded Spark Plug After many hours of use, a spark plug electrode begins to erode. This is a normal condition of wear. When erosion occurs, the center electrode appears rounded and the side electrode has a curve on the inside surface (Figure 16-20). Because the gap in such a spark plug is too high, the spark plug may not fire. In comparison, a new spark plug has electrodes with flat sharp surfaces.

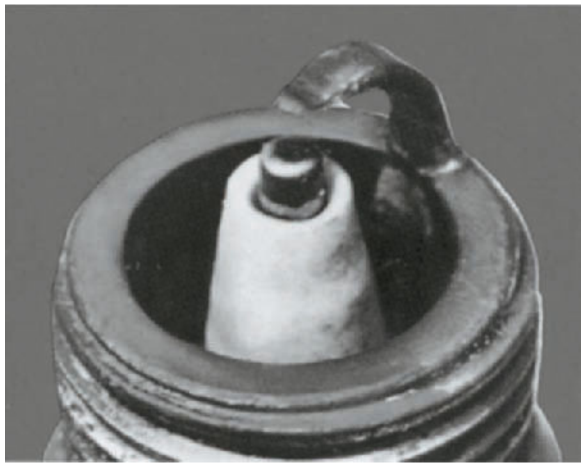


Figure 16-20 A spark plug with an eroded electrode from normal long-term wear. Courtesy of Federal-Mogul Corporation.

Figure 16-21 Measuring spark plug end gap using a wired-end spark plug gap tool.

Spark Plug Gap

The gap between the electrodes of a spark plug must be correct to ensure proper operation. Before you install a spark plug, you should measure the gap between the electrodes. The service or owner's manual for the engine gives the specified spark plug gap. The spark plug gap can be checked by using a wired-end spark plug gap tool (Figure 16-21).

Spark Plug Cleaning

Never sand or file a spark plug electrode and then reinstall the spark plug in an engine. Using sandpaper or a file leaves tiny grooves on the electrodes. These grooves will either burn off or will collect deposits when the engine is operated. Sanding and filing also leave tiny particles of sand or metal on the electrodes. These particles can get into the engine's cylinder and cause serious damage.

Some spark plug manufacturers have produced small sandblasting machines designed to clean their spark plugs. However, there are power equipment engine manufacturers who strongly recommend against using these sandblasters, for the reasons we've just discussed. If you're ever in doubt about a spark plug's condition, simply replace it.

Spark Plug Installation

To reinstall a spark plug, hold the plug with your fingers and gently screw the plug into the threaded cylinder head opening (Figure 16-22). Don't force the spark plug. The plug should turn at least three full turns into the cylinder head before it shows any signs of resistance. When the resistance point has been reached, use a spark-plug socket to tighten the plug into the cylinder head. Be sure to tighten the spark plug with a torque wrench to the manufacturer's specifications.

Battery Inspection

While you should wear safety glasses anytime you're working on an engine, when it comes to batteries, you must take extra precaution. Battery acid can cause severe burns if it contacts

Figure 16-22 To reinstall a spark plug, don't force it into the hole; hold the plug with your fingers or with the correct spark plug socket, and gently screw the plug into the threaded cylinder head opening.

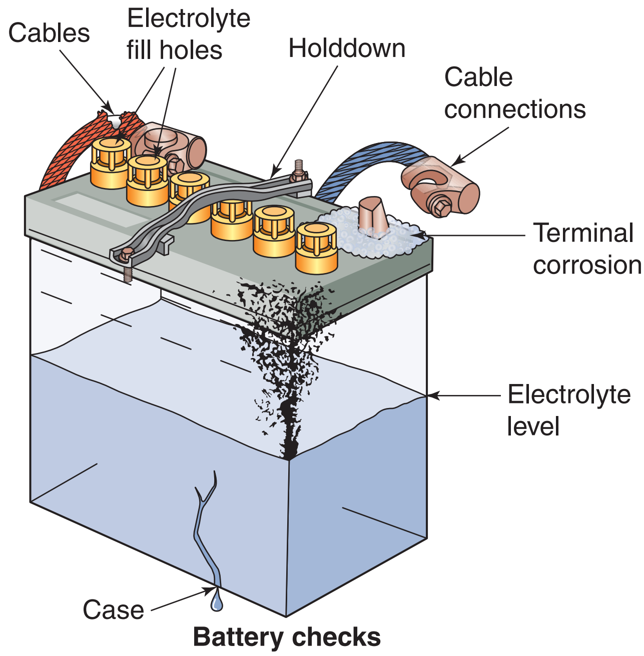


Figure 16-23 A conventional battery with filler caps. When inspecting a battery, look for typical battery conditions, such as ones illustrated here. Note that maintenance-free batteries don't require electrolyte level inspection.

your skin, and it damages clothing. If you accidentally spill any battery acid, the spill should be cleaned up immediately. Use a water-and-baking-soda solution to clean the spill area. This combination helps neutralize the acid.

First, a battery should be inspected for cracks in its casing, broken terminals, or other signs of physical damage (Figure 16-23). This includes checking for sulfation or warping on the internal plates if the battery has a transparent outer casing. If any of these conditions is found, the battery should be replaced. You should also ensure that the battery cable connectors make good contact with the battery terminals. If the cable connectors or terminals are corroded or loose, clean and tighten the connections. Application of dielectric grease on the cable connectors and battery terminals helps prevent corrosion.

Conventional Battery Electrolyte Testing

With conventional batteries, the condition of the battery is determined by measuring the specific gravity of the electrolyte. The specific gravity is measured with a hydrometer, as with a cooling system (Figure 16-24). The electrolyte

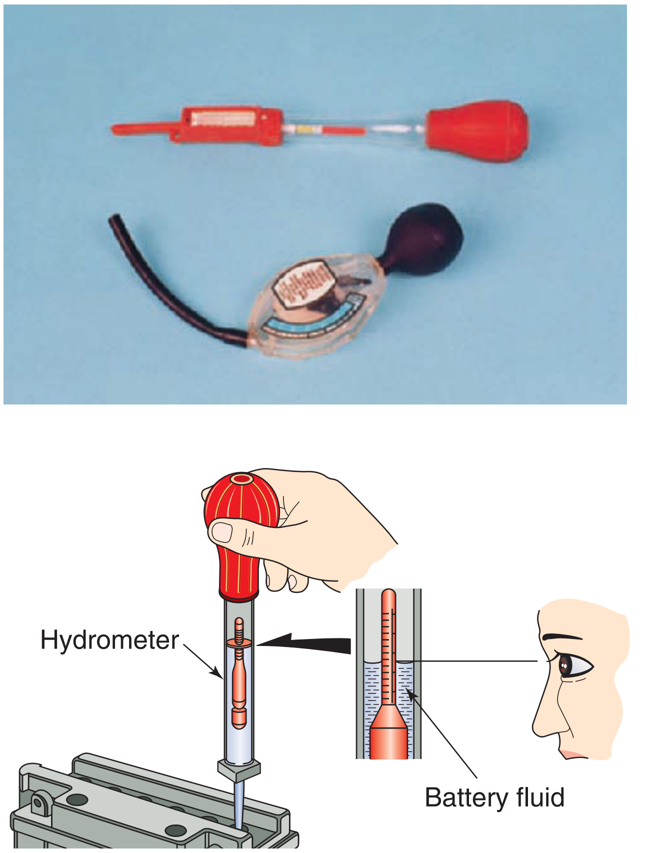


Figure 16-24 Two types of hydrometers (top) and the way a hydrometer is used (bottom).

Figure 16-25 If water level in a battery is low, replace with distilled water only, and fill each cell to the upper level. Distilled water has all of impurities removed and does not contaminate the sulfuric acid or the lead plates in the battery. Distilled water can be purchased at any grocery store.

Figure 16-26 A maintenance-free battery has no filler caps, and some, like the one shown here, come from the factory pre-filled with acid.

should have a specific gravity of 1.280–1.320 (depending on the temperature). As the battery becomes discharged, the specific gravity of its electrolyte decreases.

Conventional Battery Water Level Remember that conventional batteries are filled with a sulfuric acid electrolyte solution. The acid is absorbed into the battery plates during operation, but the remaining water can evaporate. Look on the outside of the battery for the level in a conventional battery, if it has a transparent casing. If it has been determined that it's necessary to add water to a battery with a low electrolyte level, add only distilled water (Figure 16-25). Distilled water should be used to prevent minerals and other impurities from contaminating the sulfuric acid and the lead plates in the battery.

Maintenance-Free Batteries

Many modern power equipment engines have MF batteries (Figure 16-26). This type of battery does not require fluid level checks because the battery is sealed. If this type of battery fails to hold a charge, you may replace it. Before replacing a maintenance-free battery, however, the charging and regulating circuits should be thoroughly tested.

Battery Testing

Due to the high quality of today's batteries and the technology that's built into them, in most cases, a battery should not be tested unless a specific request to do so was made or an issue was reported that may be battery related. In the past, and even in some cases today, a battery would be tested for its ability to hold a charge by using a battery load tester (Figure 16-27). A load tester tests the battery under a heavy electrical load condition (such as an electric starter) while it's out of the power equipment engine.

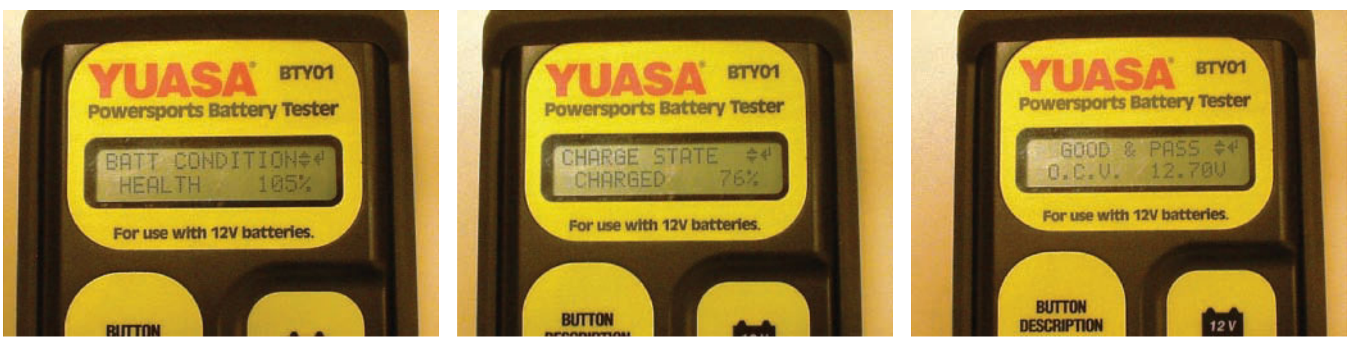
As we've discussed earlier, the power equipment engine industry is now beginning to use a tool that has been used in the automotive industry for some time now to measure the health of a battery (Figure 16-28). A battery conductive analyzer determines a battery's ability to conduct current. It measures the battery plate surface available in a battery for chemical reaction. Measuring conductance provides a reliable indication of the battery's condition and is correlated to battery capacity. This type of tester can be used to detect cell defects, shorts, normal aging, and open circuits in a battery, all of which can cause the battery to fail.

A fully charged battery has a high conductance reading, up to 110% of its internal rating. As a battery ages, the plate surface sulfates or sheds active material, which lowers its capacity and conductance.

The conductance tester displays the service condition of the battery. It indicates if the battery is good, needs to be recharged and tested again, has failed, or will soon fail. In addition to giving a state of charge, this type of tester shows a state of health as well. (Figure 16-29).

Figure 16-27 A battery load tester places a load on a battery to check its ability to withstand current flow through it.

Figure 16-28 Battery conductance analyzers are becoming more popular in the motorcycle industry due to their ability to more accurately tell us the condition of the battery.



(a) (b) (c)

Figure 16-29 A conductance battery tester gives information such as (a) the state of health of the battery, (b) the battery's state of charge, and (c) if battery condition is good or bad.

Ignition System Inspection and Adjustment

Ignition of fuel must occur at the proper time during the compression cycle for an engine to develop full power. Because the fuel takes some time to start burning, the spark must occur shortly before the piston starts the power stroke. In virtually every engine, the ignition spark occurs when the piston is still moving upward on the compression stroke. Power equipment engines have an optimum ignition timing setting that's determined by the manufacturer. This ignition timing setting is listed in the service manual for the engine. If the ignition timing differs from this optimum setting, the engine potentially loses its rated efficiency and power.

Most modern power equipment engines use non-adjustable electronic ignition systems. These systems have the correct timing configured into the electronic components, which are fixed in one place on the engine. In some engines, a **timing light**, though not much used nowadays, may be used to verify proper ignition operation (Figure 16-30). When it's attached to a spark plug, the timing light produces a flash of light each time the spark plug fires. The strobe effect of the timing light freezes the rotating timing marks. This allows you to observe and accurately adjust the timing of the ignition system. However, in most cases, either the ignition system timing is correct or the electronic ignition system won't function at all. In these cases, component replacement is required to correct the problem. Because most electronic ignition systems use no moving parts, a timing problem is a rare occurrence with them. Older engines were designed with breaker-point ignition systems (discussed in Chapter 15), which allowed adjustment of the ignition timing as the points wore over time (Figure 16-31). Engines with breaker points are adjusted with a feeler gauge. Note that some engine manufacturers require the use of a dial indicator to properly locate the piston at a specific point before top-dead center (BTDC), in order to set the points.

Figure 16-30 A tool that isn't often used any longer due to the advent of electronic ignition systems; the timing light can be used to verify the correct ignition timing of an engine, by pointing its flashing light at the flywheel while the engine is running.

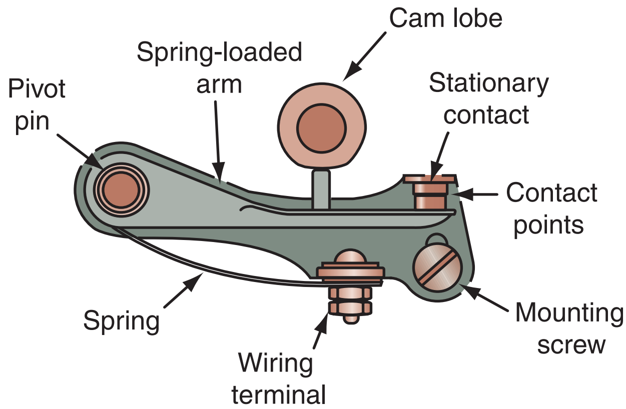


Figure 16-31 In older engines, adjustable points are used to signal the spark of the ignition system. As the crankshaft turns, a cam lobe opens and closes the point contact. A slot behind the mounting screw allows for adjustment as the points wear over time.

Idle and Fuel Screw Adjustment

Most power equipment engines have a manual idle speed adjustment (Figure 16-32), which uses a lever directly mounted on or attached to (by means of a cable) a control arm that controls the throttle plate (Figure 16-33). The latter allows for setting the engine idle speed (engine rpm) on the carburetor. Setting the fuel mixture screw(s) (Figure 16-34) is also a critical adjustment to ensure that the engine runs optimally.

The base settings for these screws will be provided by the engine manufacturer and will be published in the appropriate service manual.

Air Filter Inspection

Proper maintenance of the power equipment engine air filter is important. The air filter extends the life expectancy of the engine. If dirt and other contaminants are allowed to flow through the intake system, the engine's internal parts will be damaged. Air filters are made of various types of materials.

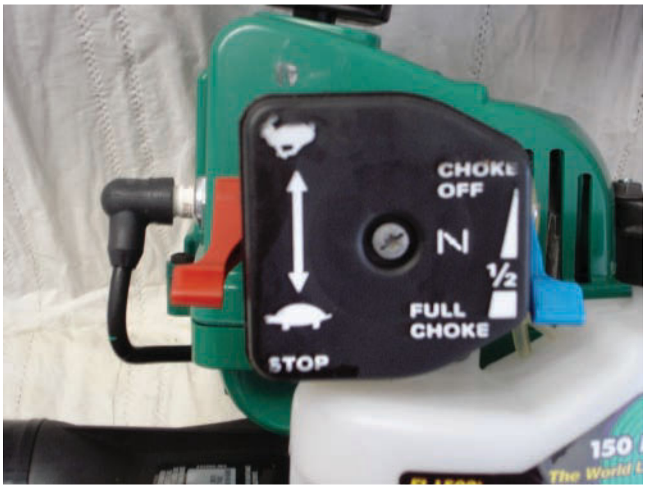


Figure 16-32 Engine speed in many power equipment engines is controlled by a manually adjusted lever.

Paper Air Filters

The paper filter consists of laminated paper fibers that are sealed at the ends or sides of the filter. Some paper air filters include supporting inner or outer metal screen shells. The paper used in these air filters is generally molded into a "W" pattern, as shown in Figure 16-35. This molded "W" is designed to increase the surface area and to decrease the restriction of air passing through the filter.

The paper air filter must be kept dry and free of oil. If it becomes excessively dirty or contaminated with oil, it must be replaced. Don't try to clean a paper air filter with soap and water because this will damage the paper fibers and cause the filter to fail. Some manufacturers suggest tapping the paper air filter on a head surface to dislodge any loose debris or using compressed air to clean the filter, provided it's not excessively dirty (Figure 16-36).

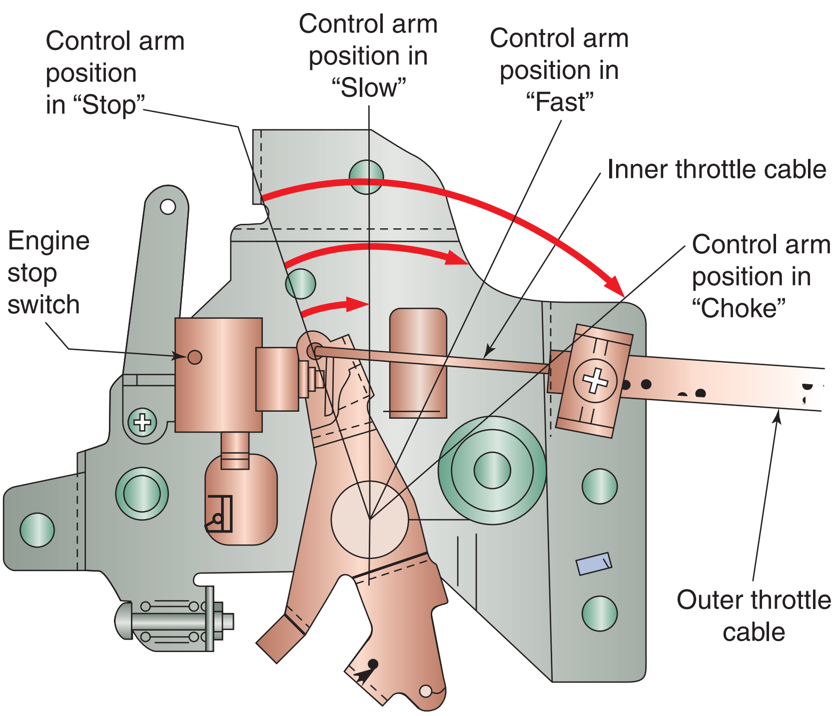


Figure 16-33 A cable-operated control arm and its various positions.

(a)

(b)

Figure 16-34 Fuel mixture setting screws. (a) The low speed adjustment and (b) the high speed control, which is handled by the screw under the carburetor. These screws may be located on different parts of a carburetor, depending on the type being used. Be sure to verify which screw does what by using the appropriate manufacturer's service manual.

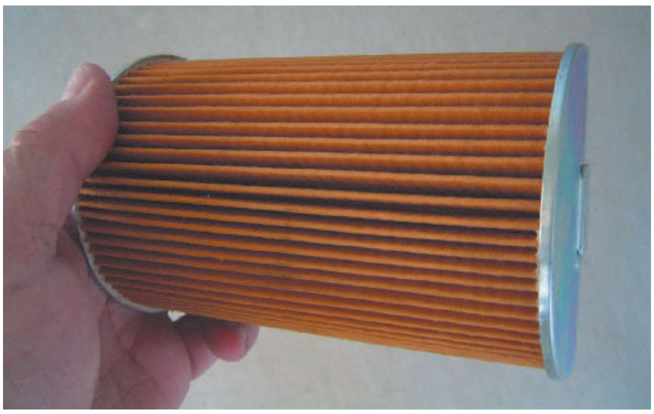


Figure 16-35 A typical paper-type air filter with a pleated "W" pattern.

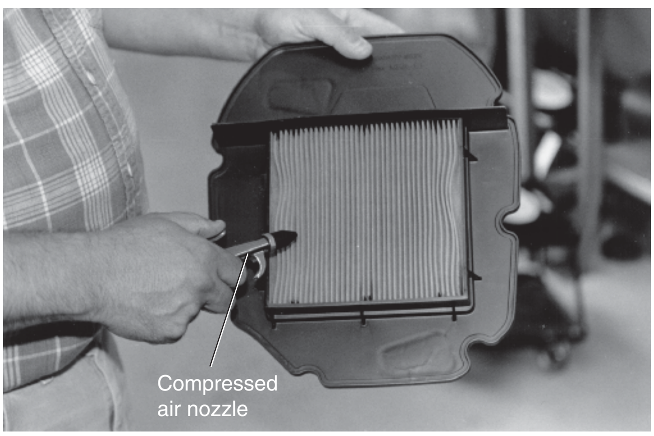


Figure 16-36 Cleaning a paper filter with compressed air.

Figure 16-37 Foam air filters are commonly found in power equipment engines.

Foam Air Filters

Figure 16-37 shows a foam-type air filter. It uses a special foam and oil to trap dirt and other contaminants. Clean this filter in a warm, soapy water solution; then rinse and dry it (Figure 16-38). When the filter has dried, apply oil specifically made for foam air filters. The excess oil is then squeezed out of the filter before use. In some cases, foam filters are used in conjunction with paper air filters as a pre-filtering device (Figure 16-39).

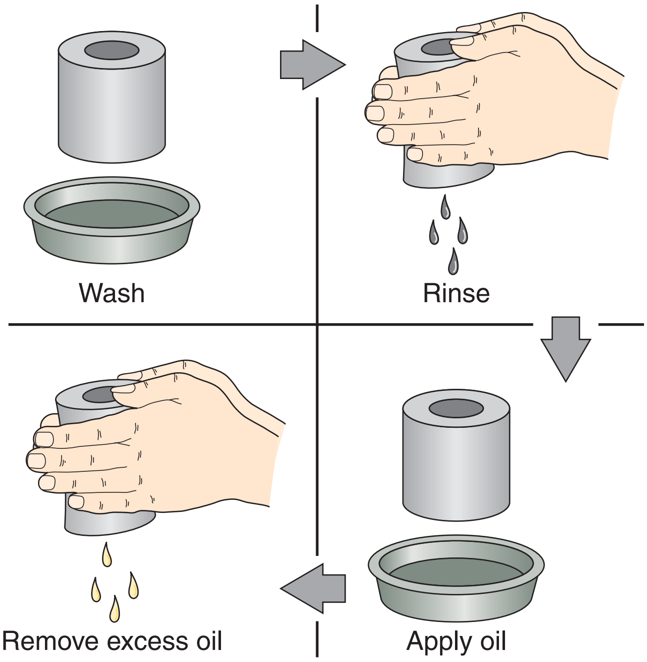


Figure 16-38 The process of cleaning a foam air filter.

Figure 16-39 In some cases, foam filters are used in conjunction with paper air filters as a pre-filtering device.

Figure 16-40 An oil bath air filter directs incoming engine air over an oil sump that catches dirt particles. This filter can be seen in older engines.

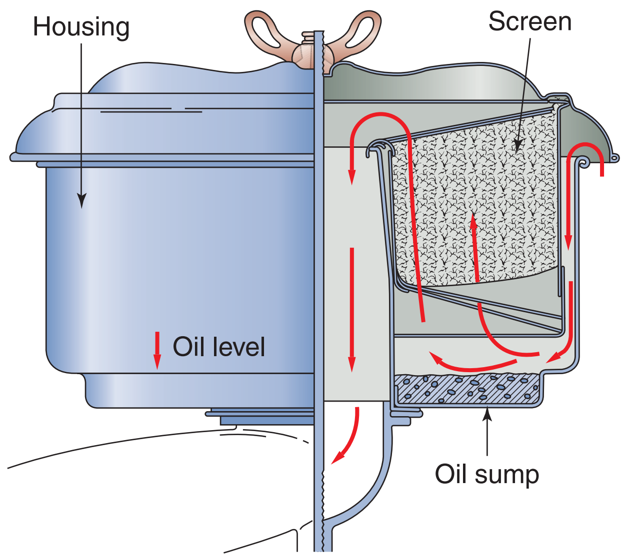


Figure 16-41 The path that air takes to get into the engine when an oil bath filter is used. Oil bath air filters are not used in newer engines as the oil in the housing requires frequent service and the complicated air routing inside the housing has very low air flow into the engine, which limits engine power. Courtesy of Kohler Co.

Oil Bath Air Filters

The oil bath air cleaner is a common type of air filter used in very old engines. An oil bath air filter directs incoming engine air over an oil sump that catches dirt particles (Figure 16-40). Like other air filters, the oil-bath-type filter is mounted on the carburetor. All the air going into the carburetor must go through the filter first (Figure 16-41). The housing is the main part of the oil bath air filter. The housing has air passages that direct the incoming air. Incoming dirty air comes on the top of the housing. It's then directed down the inside of the housing. The housing passages cause the air to change direction and start back up the housing.

There is a small oil sump in the bottom of the housing. The air entering the housing is made to change direction over the oil. Dirt in the air is too heavy to make the quick turn; so it keeps going straight into the oil. The oil traps the dirt and the filtered air goes through an oiled screen. Any dirt left in the air sticks to the oiled screen. Filtered air then goes down the center of the housing and into the carburetor.

The oil bath air filters are not used on newer engines. The oil in the housing requires frequent service. The complicated air routing inside the housing limits the air flow into the engine, which limits engine power.

POWER EQUIPMENT ENGINE STORAGE PROCEDURES

When a power equipment engine is going to be stored for an extended period of time, you should take certain steps to reduce the chances of having storage-related problems. The need for proper engine storage needs to be emphasized to customers because one of the key issues that service shops see is improperly stored engines. When not properly prepared for storage, the fuel can go bad and prevent combustion. When this occurs, fuel system cleaning is required, which can be expensive.

Preparing an Engine for Storage

To prepare a power equipment engine for storage, you should do the following:

1. Replace the engine oil and filter.
2. If the power equipment engine is liquid cooled, be sure that the cooling system is filled with the correct antifreeze solution. This prevents freezing of the cooling-system components.
3. Fill the fuel tank with fuel and add a fuel stabilizer. The fuel stabilizer prevents the fuel tank from rusting and the fuel from deteriorating during storage. Also, while you're servicing the fuel system, turn off the fuel petcock, if the engine has one. This will prevent fuel seepage into the engine during storage.
4. Drain the carburetor. To verify that all of the fuel is out of the carburetor float bowls, start the engine (choke in the On position) after the bowls have been drained. The engine will run for a brief interval as it consumes any remaining fuel. Fuel-injected power equipment engines don't need draining.
5. To prevent rusting in the cylinder, you need to remove the spark plug from each cylinder, pour a teaspoon of clean engine oil into the cylinder, and cover the spark plug hole with a piece of cloth. Crank the engine several times slowly to disperse the oil in the cylinders. Reinstall the spark plug.
6. Remove the battery and verify that it's fully charged. Store the battery in an area that's protected from freezing and direct sunlight. You should put the battery on a maintenance charger while it's in storage to prevent the battery from discharging.
7. Wash and dry the machine, including the engine, and then wax all of the painted surfaces. This will protect the vehicle while it's in storage, and will provide a clean, polished appearance when the vehicle is brought out of storage.
8. Cover the machine with a suitable cover and store it in an area that's free of excessive dampness, dust, and chemical fumes.

Removing an Engine from Storage

When you bring a machine out of storage, you should do the following:

1. Uncover and clean the machine.
2. Change the engine oil if the machine was stored for more than 4 months. This should be done even if the engine oil was changed prior to storing the engine, as it can break down over time when sitting in an engine.
3. Charge and reinstall the battery as appropriate.
4. Start the engine and run it at a low rpm to verify that everything is operating correctly.

Summary

- Understanding the importance of scheduled maintenance intervals for an engine is important to be a successful power equipment engine technician. Peak performance from an engine requires that each part be in good working condition and correctly adjusted.
- As a technician, you'll perform engine service, including cleaning, adjusting, and replacing parts to ensure that parts meet the manufacturer's specifications.
- When a power equipment engine is going to be stored for an extended period of time, proper storage procedures should be followed. This reduces the chances of having any problems when the machine is removed from storage.

Chapter 16 Review Questions

1. If you should accidentally spill battery acid, what should you use to neutralize it?
   a. A nonflammable household cleaner
   b. A water and baking soda solution
   c. Water
   d. Baking soda
2. What type of test will provide the best indication of any internal engine problems?
   a. Compression test
   b. Leak-down test
   c. Load test
   d. Bench test
3. Which type of air filter is least commonly used in modern power equipment engines?
   a. The foam air filter
   b. The oil-bath-type air filter
   c. The gauze-type air filter
   d. The paper-type air filter
4. A spark plug with carbon or oil deposits that block the gap between the center and the side electrodes is known as having a _____.
5. Power equipment engine manufacturers recommend that their machines be
   a. serviced at specific time intervals.
   b. serviced every 4 months.
   c. serviced when they no longer run properly.
   d. tuned-up at least once a year.
6. What is used to replenish a low conventional battery?
   a. Tap water
   b. Baking soda
   c. Sulfuric acid
   d. Distilled water
7. All four-stroke power equipment engines *must* have at least one yearly tune-up that includes adjusting the valves. (True/False)
8. Which of the following is used to test a cooling system for the correct mixture of coolant and water?
   a. Barometer
   b. Manometer
   c. Hydrometer
   d. Thermometer
9. A water pump has a mechanical seal to separate the engine oil and coolant. (True/False)
10. Paper-type air filters can be cleaned. (True/False)

CHAPTER

17 Power Equipment Engine Troubleshooting

Learning Objectives

- Understand how to systematically approach problems when working on power equipment engines
- Understand troubleshooting procedures for the following conditions: engine problems, fuel system problems, electrical-system problems, and abnormal noise problems

Key Terms

Constant failure

Improper-service failure

Intermittent failure

INTRODUCTION

The ability to quickly and correctly troubleshoot power equipment engine problems is a sign of a competent technician. Proper diagnosis of a malfunction makes disassembly, repair, and reassembly much easier. If a malfunction has been improperly diagnosed, the repair process will become long and tedious, or even seemingly impossible. Therefore, in order to be a successful technician, you must possess proficient troubleshooting skills. First and foremost, troubleshooting begins with a thorough knowledge of the

- Components of a power equipment engine
- Function of each component
- Effect each component has on the overall operation of the power equipment engine
- Types of failure symptoms that a defective component will cause

The previous chapters in this textbook were designed to help you to learn about these important areas pertaining to a working engine. Once you've gained this knowledge, troubleshooting becomes systematic and controlled. You must understand that this knowledge does not always come easily. You must accept that you're bound to make mistakes along the way, when diagnosing and repairing a power equipment engine. But make sure you understand what you did incorrectly in those situations, and learn from those mistakes. It's true that *everyone* makes mistakes, *including* those who design and create the engines used in today's world. The key is to learn from our mistakes to gain a better understanding of what we are doing.

When troubleshooting, you'll need to

- Gather all available information about the malfunction
- Analyze the symptoms related to the problem
- Pinpoint the most likely cause of the problem

The repair process shouldn't begin until after you've gotten a clear picture of what's causing the problem. For this, you'll have to mentally divide the power equipment engine into sections (fuel, engine, and electrical systems):

- Picture each component of every section
- Picture what each component does
- Picture each component and its relationship with the other components and decide if each part is functioning properly

For example, suppose a spark plug isn't firing correctly. You must envision the operation of the spark plug in relation to that of other power equipment engine systems. After doing this, you'll have a variety of possible problems identified, besides the obvious conclusion that the spark plug is bad. The problem could be due to a dirty air filter that's creating an excessively rich fuel mixture.

It's imperative that you understand what you're trying to repair before disassembling a machine. Once you begin the disassembly process, the troubleshooting process is over. In our spark plug example, cleaning and replacing parts in the fuel system won't solve the problem because the cause is a faulty ignition. Therefore, ensure that you've isolated the problem before beginning any repair.

Because it's impossible to cover every type of power equipment engine problem, we'll discuss basic diagnostic and troubleshooting techniques and concepts that you can apply to many situations. Each topic in this chapter contains tables that can be used as a guide when troubleshooting. To get the most from this chapter, focus your attention on the basic concepts presented.

Learning from the information in this chapter will allow you to begin to build a solid foundation for developing your own troubleshooting expertise. This chapter comprises a set of tables that cover virtually every aspect of troubleshooting. Although you'll feel there are many tables here, they by no means contain every possible cause for each problem listed. These tables are intended to aid you in troubleshooting problems by giving you some of the more common causes of the problems listed.

SYSTEMATIC APPROACHES TO SOLVING PROBLEMS

It's important to understand that there are techniques that will expedite the process of troubleshooting power equipment engine problems. Developing a systematic approach to solving problems will help you perfect your skills as you gain more experience.

Types of Problems

A symptom is an indication of an abnormal condition that you can recognize and identify. An example of a symptom would be a power equipment engine that's making a ticking sound when it's idling. The symptom helps you determine the cause of the problem. The following paragraphs cover three types of failures that you may encounter.

Constant Failures

A **constant failure** yields a symptom that is always present. For instance, a properly functioning power equipment engine stops without warning, the engine fails, and the crankshaft locks up and will no longer turn. The locked crankshaft is considered a constant failure.

Intermittent Failures

An **intermittent failure** is one that isn't always present. This type of failure increases the difficulty of the troubleshooting process. The following example illustrates an intermittent failure. A lawn mower's engine functions properly, with the exception of occasionally shutting off when mowing uphill. The user restarts the engine and it runs trouble free until another hill is encountered. This intermittent problem could be caused by multiple factors. Therefore, a systematic approach to troubleshooting the problem is required. A systematic approach allows the problem (performance, electrical, mechanical, or fuel) to be diagnosed in a reasonable amount of time with a high degree of accuracy.

Improper-Service Failures

An **improper-service failure,** as the name implies, is caused by a mistake during the servicing of the machine. Suppose a customer brings a power equipment engine to your service department for a general service and the technician servicing the machine fails to properly tighten the engine drain bolt. After the customer gets the engine back and uses it, this mistake causes the drain bolt to come out while the engine is running. The problem will likely cause major engine failure. Fortunately, most failures caused by improper service aren't this dramatic. It's important not to overlook problems resulting from incorrect service when you're troubleshooting an engine.

The Troubleshooting Process

The proper method of diagnostic troubleshooting consists of four steps that must be followed in the proper sequence. Following these steps will ensure a foolproof approach to the troubleshooting and repair process.

1. Verify the problem
2. Isolate the problem
3. Repair the problem
4. Verify the repair

When troubleshooting, you must observe the failure and verify that all the information you've received is accurate and guides you to the problem area. After you've verified the condition, you're ready to isolate the problem.

Isolating a problem begins with the easiest and most obvious solution to the problem. If simple solutions fail to correct the problem, more involved and difficult checks are needed in a step-by-step manner. The most common diagnostic mistake is to overlook the obvious or easiest possible cause of a failure. Let's look at the following example. A power equipment engine was functioning properly, then stalled, and wouldn't restart. The owner took the power equipment engine to a service shop. The technician removed and checked the spark plugs, checked the air filter, and performed compression and leak-down tests. When all was said and done, the problem was an empty fuel tank! Believe it or not, this situation isn't uncommon and results from poor troubleshooting skills (not starting with the simplest solutions first).

The symptoms of a problem guide you to the specific system you should troubleshoot, provided you have an understanding of how each system works and what it's responsible for. For example:

- If the battery won't turn the engine over and just clicks when you turn the key, you can assume that the machine has a discharged battery and possibly a charging system that's failing to provide a proper charge to the battery.
- If gasoline is leaking from the carburetor overflow tube, you can assume that there's an internal carburetor problem that's causing excessive amounts of gasoline to enter the system.

As the severity of problems increases, the knowledge required to isolate problems increases. An example of this is poor engine performance. A performance problem could be caused by an ignition system failure, a mechanical engine problem, or even a fuel-related problem. It's imperative to use all available resources and any information you can gather from your customer to assist you in identifying which system is responsible for the problem.

After you've isolated the problem, you can then repair the problem. In order to repair the problem, you must refer to the specific service manual for the particular engine you're servicing.

When you complete the repair, it's important to verify the repair. If you can't verify if that the repair was successful and the problem is still present, you must repeat the troubleshooting process, beginning with the verification stage.

Troubleshooting Guides

Virtually all manufacturers' service manuals contain troubleshooting checklists and/or tables of possible operating troubles along with their probable causes. These items are designed to aid the technician in troubleshooting and problem solving. All possibilities should be carefully checked because multiple factors may be causing the overall problem. Throughout the tables provided in this chapter, examples of typical problems and possible solutions are provided. These tables have been derived from current service manuals and technical guides to create a generic point of view. You should note that the tables provided in this chapter as well as in manufacturers' service manuals are intended only as a guide to diagnosing problems. Always read the detailed information in the specific chapters of the appropriate service manual before performing service work on any system or major component. Remember to adhere to all cautions and warnings.

As you learn more about various power equipment engine systems, you may develop a tendency to troubleshoot problems based on your personal experience. This approach can be a gamble that may save you time; but if you guess wrong, it could cost you time and money. Don't be afraid to apply your experience to a good troubleshooting routine, but don't underestimate repairs only because the failure looks familiar.

Locating and fixing a problem is very self-rewarding, provided you use good troubleshooting techniques. Furthermore, the more difficult the problem, the greater the satisfaction when you've solved it. To be successful, the most important barrier to overcome is the lack of self-confidence required to perform the job. Here are some points to keep in mind when you're troubleshooting a problem:

- Always think the problem through
- Never overlook the obvious
- Never assume anything
- Never take shortcuts
- Never make more than one change or adjustment at a time
- Always use the appropriate service manual(s) for all removals, replacements, and adjustments
- Remember to always *verify* the problem, *isolate* the problem, *repair* the problem, and most important, *verify the repair*

ENGINE PROBLEM TROUBLESHOOTING

There are various problems that require troubleshooting. These cover a wide spectrum of problems, from an engine that does not start to engine overheating. You must have a thorough knowledge of all components of the engine before you can begin troubleshooting. You must know what parts are used, understand how they work, and be aware of their relation to one another.

Refer to the following tables as a guide to the conditions listed.

Engine Does Not Start/Starting Difficulty

Specific Symptom	Possible Cause
Starter motor not operating	■ Engine stop-switch off ■ Battery voltage low ■ Fuse blown ■ Ignition-switch trouble ■ Neutral-switch faulty ■ Relays not functioning ■ Wiring open or short ■ Starter-motor faulty
Starter motor operates but engine doesn't turn over	■ Starter-motor clutch faulty
Crankshaft won't turn over	■ Valve seizure ■ Camshaft seizure ■ Rocker arm seizure ■ Cylinder, piston seizure ■ Crankshaft seizure ■ Connecting rod seizure
Compression low	■ No valve clearance ■ Bent valve ■ Cylinder/piston worn ■ Piston rings worn

Runs Poorly at Low Engine Speeds

Specific Symptom	Possible Cause
Spark weak	■ Spark plug faulty ■ Spark plug cap faulty ■ Points worn ■ Ignition coil faulty
Air–fuel mixture incorrect	■ Air/fuel screw improperly adjusted ■ Fuel jet or air passage clogged ■ Air-bleed pipe bleed holes clogged ■ Air filter dirty or missing ■ Choke left on or stuck ■ Fuel level in float bowl incorrect ■ Fuel tank air vent obstructed ■ Bad fuel
Compression low	■ Cylinder head gasket leak ■ Incorrect valve clearance ■ Cylinder/piston worn ■ Piston rings worn ■ Valve spring broken or weak ■ Valve not seating properly

Runs Poorly or No Power at High Engine Speeds

Specific Symptom	Possible Cause
Timing firing incorrect	■ Spark plug fouled ■ Spark plug cap shorted or has bad connection ■ Breaker points out of adjustment ■ Pickup coil faulty ■ Ignition coil faulty ■ ICM faulty

(continued)

Runs Poorly or No Power at High Engine Speeds *(continued)*	
Specific Symptom	**Possible Cause**
Air–fuel mixture incorrect	■ Choke stuck ■ Fuel jet clogged ■ Air jet clogged ■ Air leak ■ Fuel level incorrect ■ Air filter dirty or missing ■ Water or foreign matter in fuel ■ Fuel tank air vent obstructed ■ Fuel valve blocked ■ Fuel line blocked ■ Bad fuel
Compression low	■ Valve clearance incorrect ■ Cylinder/piston worn ■ Piston rings worn ■ Cylinder-head gasket damaged ■ Valve spring broken or weak ■ Valve not seating properly
Knocking	■ Carbon buildup in combustion chamber ■ Fuel poor quality or incorrect fuel ■ Spark plug incorrect ■ Ignition timing incorrect
Poor performance	■ Throttle valve won't fully open ■ Engine overheating ■ Engine oil level too high ■ Engine oil viscosity too high

Engine Overheating	
Specific Symptom	**Possible Cause**
Air–fuel mixture incorrect	■ Fuel jet clogged ■ Fuel level in carburetor incorrect ■ Air cleaner poorly sealed or missing ■ Air-cleaner duct poorly sealed ■ Air cleaner clogged
Compression high	■ Carbon buildup in combustion chamber
Engine load faulty	■ Engine oil level too high ■ Engine oil viscosity too high
Lubrication inadequate	■ Engine oil level too low ■ Engine oil poor quality or incorrect
Gauge incorrect	■ Temperature gauge faulty ■ Temperature sensor faulty
Coolant incorrect	■ Coolant level too low ■ Coolant deteriorated
Cooling-system component incorrect	■ Radiator clogged ■ Thermostat defective ■ Radiator cap defective ■ Thermostatic-fan switch faulty ■ Fan relay faulty ■ Fan motor inoperative ■ Fan blades damaged ■ Water pump faulty

Does Not Reach Operating Temperature (Liquid-Cooled Engines)	
Specific Symptom	**Possible Cause**
Gauge reads incorrect	■ Water-temperature gauge faulty ■ Water-temperature sensor faulty
Cooling-system component incorrect	■ Thermostatic-fan switch trouble ■ Thermostat trouble

Excessive Exhaust Smoke	
Specific Symptom	**Possible Cause**
White smoke	■ Engine-oil level too high ■ Piston oil ring worn ■ Cylinder worn ■ Valve oil seal damaged ■ Valve guide worn
Black smoke	■ Air filter dirty ■ Choke left on or stuck ■ Fuel jet too large or fallen off ■ Fuel level in float bowl too high

Drivetrain Troubleshooting

Although not discussed in detail in this textbook, a transmission is employed by many power equipment engines to operate the machines they power. This section guides you in determining a problem with the transmission of an engine.

The two most common symptoms found when diagnosing power equipment engine transmission problems are as follows:

- The transmission is hard to shift.
- The transmission jumps out of gear.

There are other drivetrain-related problems as well. The following table provides the most common causes of drivetrain-related problems.

Transmission and Clutch Problems	
Symptom	**Possible Cause**
Transmission problems	
Hard to shift	■ Improper clutch adjustment ■ Incorrect transmission oil ■ Bent shift forks ■ Bent shift shaft
Jumps out of gear	■ Shift fork worn ■ Gear dogs and/or dog holes worn ■ Gear positioning-lever spring broken ■ Shift fork pin worn
Doesn't go into gear	■ Clutch not disengaging ■ Shift fork bent or seized ■ Gear stuck on the shaft ■ Shift-mechanism arm broken
Clutch problems	
Clutch slipping	■ Clutch plate(s) worn ■ Clutch springs broken or weak ■ Clutch cable improperly adjusted ■ Clutch cable sticking ■ Clutch-release mechanism sticking
Clutch dragging	■ Clutch cable improperly adjusted ■ Clutch plates warped ■ Transmission oil viscosity too high ■ Transmission oil level too high ■ Clutch-release mechanism sticking

FUEL SYSTEM TROUBLESHOOTING

Fuel system troubleshooting is one of the most common power equipment engine repair jobs. It can be a simple, straightforward, rewarding procedure or a tedious, complicated, unrewarding chore. The difference between these two extremes lies with your approach to problem solving. You can randomly disassemble and replace components, or you can take a systematic, step-by-step approach.

When troubleshooting fuel–system-related problems, start with simple tasks, such as verifying if there is fresh fuel in the gas tank and fuel flow to the carburetors and injectors.

A plugged gas-tank vent, a fuel shut-off valve, or a pinched fuel line can be responsible for restricting the fuel supply to the fuel system. Trace through the system in search for blockage. Begin with the vent, then the shut-off valve, and finally the gas line. If any of the components is plugged or restricted, it must be repaired.

Does It Run Rich or Lean?

Usually, fuel-system problems arise because of improper air–fuel mixtures: either too rich or too lean. Observe the engine exhaust and check the condition of the spark plug to determine if the mixture is too rich or too lean. Always keep in mind that a rich or lean mixture can have more than one cause. Too much fuel or not enough air can cause a rich mixture. Too much air or not enough fuel can cause a lean mixture. Either condition can become bad enough that the engine will not start. The following table shows some common carburetor-related symptoms and some likely causes.

When Is the Problem Apparent?

After determining whether the mixture is too rich or too lean, you must determine in which throttle position the problem occurs to know which circuit needs repair. This means the physical position of the throttle such as at idle or at full throttle.

Carburetor-Related Problems

Symptom	Problem
Lean mixture	■ Fuel jet clogged ■ Float level too low ■ Fuel line partially restricted ■ Intake-manifold air leak ■ Fuel pump not working properly
Rich mixture	■ Choke valve stuck ■ Float level too high ■ Carburetor air jets blocked ■ Air filter element excessively dirty
Engine stalls, hard to start, rough idling	■ Idle speed not properly adjusted ■ Fuel line restricted ■ Fuel mixture incorrect ■ Fuel contaminated/deteriorated ■ Intake-manifold air leak ■ Fuel pump not operating correctly ■ Fuel circuit blocked ■ Float level incorrect ■ Fuel tank breather clogged
Backfiring or misfiring during deceleration	■ Lean mixture in low speed circuit ■ Vacuum line loose or off
Backfiring or misfiring during acceleration	■ Fuel mixture too lean

(continued)

Carburetor-Related Problems *(continued)*	
Symptom	**Problem**
No fuel flow	■ Fuel petcock blocked ■ Fuel tank air vent obstructed ■ Fuel line blocked ■ Float valve stuck closed
Engine flooded	■ Fuel level in float bowl too high ■ Float valve worn or stuck open ■ Starting technique incorrect

Before starting to work on the fuel system, you should always check out some of the external components that can affect carburetion. If the mixture appears rich, check the air filter and the cable to the carburetor choke. If the air cleaner is excessively dirty, air will have difficulty getting to the engine. If the choke cable is too tight, the choke will be cutting off the air supply to the carburetor. If the mixture is too lean, ensure that the fuel is flowing properly from the fuel tank. Also, inspect the intake manifold for air leaks.

If everything on the external side of the engine is in proper working order, the carburetor will most likely need repair. The following tables are divided into throttle ranges and provide common causes of rich and lean mixtures. Also included are common repairs for each situation, as well as suggestions to follow if none of the common problems is present.

Surging at Idle			
Too Rich		**Too Lean**	
Problem	**Remedy**	**Problem**	**Remedy**
Choke activated	■ Verify that the choke is in the Off position	Carburetor mounted loosely	■ Tighten carburetor
Pilot air passage blocked	■ Blow out passage area with compressed air	Fuel jet plugged	■ Clean jet with compressed air
Low-speed jet not adjusted correctly	■ Adjust jet	Pilot outlet or bypass ports clogged	■ Clean with compressed air
Pilot-jet air bleed blocked	■ Clean jet with compressed air	Fuel level too low	■ Adjust level per service manual
Fuel level too high	■ Adjust level per service manual		
Lean the mixture by turning the adjustment screw ¼ to ½ turn. (Check service manual to determine if adjustment calls for turning clockwise (CW) or counterclockwise (CCW).)		Richen the mixture by turning the adjustment screw ¼ to ½ turn. (Check service manual to determine if adjustment calls for turning CCW or CW.)	

Full Throttle Operation			
Too Rich		Too Lean	
Problem	**Remedy**	**Problem**	**Remedy**
Fuel jet out of place	■ Reinstall	Fuel jet clogged	■ Clean with compressed air
Air passage blocked	■ Clean with compressed air	Needle jet blocked	■ Clean with compressed air
Fuel level too high	■ Adjust	Fuel level too low	■ Adjust
Air filter excessively dirty	■ Clean or replace	Air filter missing	■ Install correct air filter

Other Fuel–System-Related Problems

Aside from the carburetor problems previously discussed, other common problems also appear from time to time. The most common of these is water in the fuel system. Water is heavier than gasoline and penetrates the circuits of the carburetor. When this occurs, the engine runs rough or not at all. Draining the float bowl of the carburetor may correct the problem temporarily, but ultimately, the underlying cause needs to be determined and the problem fixed.

Water in the Fuel System

Often, cleaning a power equipment engine with a high-pressure washer causes water to penetrate the sealing area between the air filter and carburetor or the seal of the fuel cap. If water penetrates either area, it will eventually enter the fuel system and cause the problems just mentioned.

Clogged Fuel-Tank Vent

Another widespread and potentially baffling problem is a clogged fuel-tank vent. Normally, air enters the tank through the vent and replaces the space left by the fuel when it's burned. If the vent is clogged, a vacuum is formed in the fuel tank, which can restrict the flow of fuel. This restriction can sometimes be enough to cause the engine to stall and baffle a user. With the vacuum inside the fuel tank, assume that the user opens the fuel cap to just check if there's gas in the tank. Opening the fuel tank removes the vacuum (the user has unwittingly removed the problem, although only temporarily); the user sees fuel and starts the engine. The machine functions properly for a few minutes until the vacuum is formed again, and the fuel flow is slowed or stopped.

When confronted with a baffling fuel-system problem, exercising common sense is the only way to rectify the problem. Follow these basic tips when you've reached an impasse:

- Remove yourself from the situation and consider the total process of carburetion.
- Thoroughly think out all options before doing anything drastic.

Most important, implement one change at a time; multiple adjustments made simultaneously many times complicate the problem.

Electronic Fuel-Injection System Troubleshooting

As mentioned previously, fuel-injection power equipment engines are becoming more prevalent nowadays in larger engines. Fortunately, there are relatively few problems with fuel-injection power equipment engines, and when a problem does arise, in most cases, the fuel-injection light (FI light), also known in the automotive industry as the malfunction indicator lamp (MIL), lights up to let the user know that there is a problem.

When properly activated, the FI light displays a code as to what is causing the problem. Along with the FI light, most power equipment engine manufacturers now provide electronic diagnostic tools to assist with the troubleshooting of fuel-injection power equipment engines. This is due to the high level of technology involved. However, these tools are not regulated or customized as to what information is required to be provided to the technician, as they're in the automotive industry. Therefore, it's necessary to understand each specific manufacturer's special tool. Consequently, the information provided here has been made as generic as possible.

Symptoms on fuel-injection engines are different from those found on carbureted engines. The following example illustrates this point. A carbureted engine with low compression tends to run lean. This means that it takes longer to warm up and may not perform as well as a similar machine that has proper compression. Why is this? An engine with lower compression will have less intake port vacuum for the carburetor(s), and less fuel will be drawn into the engine. This makes for a lean running condition. But, fuel-injection engines don't act the same when the compression is low because fuel is injected into the port regardless of intake vacuum. Fuel-injection engines will generally run rich when they have low compression, just the opposite of a carbureted engine. Remember that recommended compression pressures vary between engines; so always check the appropriate service manual specification for the engine you're testing.

The real issue here is that even though the power equipment engine will seem to have a fuel-related problem, the fact of the matter is that the problem may be mechanical, and no FI light indicator will tell you that!

The real test for the technician with fuel-injection engines is determining the problem when the engine runs poorly and appears to have a fuel-related problem but there is no indication from the FI light. The following table shows some fuel-injection engine problem symptoms and some known problems that have been found with these symptoms that will not trigger an FI light.

Symptoms in Fuel-Injection Engines

Symptom	Suggestion	Explanation
Engine will not start: no spark or fuel injection	■ Check for normal Power On operation. The FI light on the dash and the fuel pump should operate (you can hear the pump working) for about 2 seconds when the ignition switch is first turned on.	If the FI light stays on or the fuel pump does not operate, inspect the fuses and confirm power and ground circuits to the ECM, including the bank angle sensor, if the machine has one.
	■ Check for a failed crankshaft or camshaft position sensor. If these sensors fail, a code may trigger but *only* after the engine has cranked for at least 15 seconds.	Test for these components to ensure that no failure has occurred by cranking the engine for 15–20 seconds. If the FI light does not turn on, these components are electrically OK.
	■ Inspect the crank and camshaft position sensor rotors for damage.	A bent finger on one of these rotors can cause a no-run condition.

(continued)

Symptoms in Fuel-Injection Engines *(continued)*		
Symptom	**Suggestion**	**Explanation**
Engine starts but runs poorly	■ Check that the battery terminals are tight. ■ Check crankshaft and camshaft position sensors for poor contact at their connectors. ■ Check that ground wires are tight at the ground bolt. ■ Check engine compression and cam timing.	
Engine starts, runs rich on all cylinders	■ Disconnect the throttle position sensor and see if there are any changes in the way the engine runs. ■ Measure throttle sensor output voltage with the throttle closed and compare with the manufacturer's specification. ■ Inspect fuel pressure ■ Inspect the fuel return hose connecting the fuel pressure regulator and fuel tank for signs of being pinched. ■ Inspect for insufficient or excessive battery voltage ■ Check the fuel-pressure regulator for a leaking diaphragm; that allows fuel into the vacuum hose.	If the throttle position switch is faulty, it can make the engine run rich. The FI system only looks for a voltage from this component not a specific voltage. Verify that the machine has correct pressure by testing it using the specific information in the appropriate service manual. The regulator should hold vacuum when tested.
Engine starts, runs rich on some but not all cylinders	■ Check engine compression. ■ Compare spark plug color between cylinders ■ Visually inspect the fuel injectors for leakage. ■ Measure the peak voltage from crankshaft and camshaft position sensors.	Verify the voltage with the appropriate service manual. Generally speaking, it should be above 0.7 V at cranking speeds.
Engine is hard to start, or has a misfire at mid to high rpm	■ Inspect the crankshaft and camshaft position rotors for damaged or bent fingers.	

ELECTRICAL PROBLEM TROUBLESHOOTING

Of all problems that come into a power equipment engine service department, electrical-system problems are usually considered the most difficult to troubleshoot and repair. One of the reasons for this is that many technicians don't fully understand electrical systems, and they can't actually see the electrical system working. They only know the symptoms. For instance, if a charging system stops functioning, you can't see that electricity isn't being produced. All you know is that the battery is dead. But, if a tire goes flat, you can see the result of the problem as well as the nail that caused it!

After you've mastered the ability to properly and quickly analyze electrical problems, you'll become a valuable asset to any service department. With a complete understanding of how the electrical systems in power equipment engines work, you'll rarely take more than an hour or so to diagnose any electrical problem. To help you categorize electrical-system problems, this section has been divided into four basic areas:

- Charging-system troubleshooting
- Ignition system troubleshooting
- DC circuit troubleshooting
- Electric starter-motor troubleshooting

Charging-System Troubleshooting

The symptoms found in a charging system that's not operating properly are simple and straightforward: The engine's charging system is either undercharging or overcharging!

In the case of a system that's undercharging, the battery will eventually go dead, and the electrical components will no longer function. Charging systems in most of today's power equipment engines are designed to provide more than adequate electrical output whenever the engine is running. If a battery constantly discharges even though it's been properly maintained and the vehicle has been used frequently, check the charging system before replacing the battery. Batteries can be quite expensive.

In the case of an electrical charging system that's overcharging the battery, there will undoubtedly be a faulty component in the charging system—most likely the voltage regulator, which in most cases is integrated with the rectifier as a single unit, as explained in Chapter 14.

In a way, troubleshooting electrical problems isn't difficult. As a matter of fact, it's one of the cleanest jobs you'll be required to do! In most cases, the causes of the problems are as simple as a dirty or loose connection. One manufacturer has let it be known that out of every 150 charging-system components that are returned for warranty purposes, only one is actually defective! This tells us that as the technician is diagnosing the problem in the charging system, he or she is fixing the problem without even knowing it! Over 95% of all charging–system-related problems are connection related, and not actual component problems.

Be sure you know the color codes used for wires before beginning to work on an electrical problem. Manufacturers use different color wires for their electrical circuitries. As you perform each step in the troubleshooting process, check to see if you've corrected the problem.

Use the following tables to supplement the basic charging-system troubleshooting procedures we've discussed. The troubleshooting procedures in the tables can be used for any charging system.

Symptom in Discharging or Weak-Charging System		
Step	**If Measurement Is Correct**	**If Measurement Is Incorrect**
1. Measure the charging voltage at the battery with the engine running at the specified rpm.	a. Check the battery for amperage loss with the key in the Off position. If excessive amperage is being drawn, locate and repair. b. Check the battery with a tester. Replace battery if necessary.	Go to Step 2.
2. Check the voltage between the battery's positive terminal and the ground side of the regulator/rectifier while the engine is running.	The problem is fixed.	a. Check for an open circuit or short in the wire harness. b. Check for poor connections. c. Go to Step 3.
3. Check the stator resistance at the point where it connects to the regulator/rectifier with the coupler disconnected.	Go to Step 4 (if applicable) or Step 5.	a. There's a poor connection at the coupler. b. The charging coil is defective.
4. Check for field coil resistance (if applicable).	Go to Step 5.	a. Check for an open circuit. b. The AC generator field coil is defective.
5. Measure the charging voltage at the battery at the specified engine rpm.	The battery is defective.	Go to Step 6.
6. Replace the battery with a fully charged battery that's known to be good.	The battery is defective.	The regulator/rectifier is defective.

Symptom in an Overcharging Charging System		
Step	**If Measurement Is Correct**	**If Measurement Is Incorrect**
1. Check for continuity between the regulator/rectifier ground wire and chassis ground.	Go to Step 2 (when applicable) or Step 3.	a. Check for proper connections at the regulator/rectifier. b. Check for an open circuit in the wire harness.
2. Check for proper resistance of the field coil wire at the regulator/rectifier coupler (when applicable).	Go to Step 3.	a. Check for a short circuit in the field coil. b. Check for a short in the wire harness.
3. Replace the battery with a fully charged battery that's known to be good.	The battery is defective.	Replace the regulator/rectifier.

Ignition-System Troubleshooting

The most common issue found with ignition systems is a no-spark condition. To check for spark, the spark plug can be removed or a known good spark plug can be placed on the pug wire and ground to the engine. Once you've determined that an engine's ignition system isn't producing a spark, the next step in the troubleshooting procedure depends on the type of ignition system. If the ignition system uses a breaker-points assembly, the points and condenser are the most likely cause of the problem. To check the points, remove all necessary covers and components. Check the contacts for pitting; check for dirt or moisture between the contacts.

In an electronic ignition system, the problem of no spark may be caused by several components. Fortunately, all these components are easy to check. First, check the spark plug to see if it's fouled. Then check to make sure that the engine stop-switch wire is properly connected and functioning correctly. This switch may be a switch that goes to ground or one that completes the ignition circuit. Check the service manual wiring schematic to be sure. If that is OK, then check for proper connections at all ignition-related components. If these connections appear to be OK, check for proper resistance and AC voltage at the pulse generator and exciter coil (in the case of capacitor discharge ignitions). If all these components are in proper working order, the problem is probably a failure in the ignition control module (ICM). Replace the ICM with a known good component and test the engine. If the engine operates properly, you can assume that the ICM was the problem.

In most power equipment engines, it's easy to remove and replace ICMs. But this component is usually quite expensive; so it's important to check all other components before replacing an ICM. Typically, ICMs are reliable, and the problem is likely to be found in another area of the ignition system.

In a battery-type ignition system, a weak battery can cause ignition failure. Check the battery using a voltmeter to see if the proper voltage (should be at least about 12 V) is present. Remember that the ignition switch or safety interlock switches can also be the cause of spark failure.

The following tables offer steps to follow with an AC-powered electronic ignition system and a battery-powered electronic ignition system.

CDI Ignition Troubleshooting: No-Spark Condition

Step	Action
1. Disconnect the coupler at the CDI unit.	a. Check for a proper ground connection. b. Measure the resistance of the exciter coil. c. Measure the resistance of the pulser coil. d. Measure the resistance of the ignition-coil primary windings. *Note:* If any of the above circuits have an open or short circuit, measure the resistance of the component at the coupler closest to the component.
2. Check for continuity between chassis ground and the ignition's stop-switch wire at the ICM.	a. In the Run position, there should be no continuity. b. In the Off position, there should be continuity. *Note:* If there's continuity when the switch is in the Run position, disconnect the stop switch and check for a spark. *(continued)*

CDI Ignition Troubleshooting: No-Spark Condition *(continued)*	
Step	**Action**
3. Measure the resistance of the ignition-coil secondary winding.	a. If the winding is open, remove the spark-plug cap and retest. b. If the winding is still open after the above test, replace the coil.
4. The exciter coil, pulser coil, ignition coil, and the engine-stop switches have all tested good, and all connections have been verified.	Replace the ICM with a known good unit.

Battery-Powered Electronic-Ignition-System Troubleshooting: No-Spark Condition	
Step	**Action**
1. Disconnect the coupler at the ICM.	a. Check for a proper ground connection. b. Measure the resistance of the exciter coil. c. Measure the resistance of the ignition-coil primary windings. *Note*: If any of the above circuits have an open or short circuit, measure the resistance of the component at the coupler closest to the component. d. Measure the battery voltage at the ICM with the ignition switch in the On position.
2. Measure the resistance of the ignition-coil secondary winding.	a. If open, remove the spark-plug cap and retest. b. If still open after the above test, replace the coil.
3. The battery has voltage at the ICM, the pulser coil, ignition coil, and the engine-stop switches have all tested good; and all connections have been verified.	Replace the ICM with a known good unit.

DC Circuit Troubleshooting

The battery in a power equipment engine provides electrical energy to operate the ignition and many other electrical components. We'll focus on two components that you'll frequently encounter: lights and switches.

Lightbulbs

Burned-out lightbulbs are replaced and not repaired. To check a bulb that has been removed from a circuit, you can use a battery and two wires. Connect one wire to the negative side of the battery and to the ground on the lightbulb. Connect the other wire to the positive side of the battery and to the insulated side of the lightbulb. If the bulb lights up, it's good. An ohmmeter can also be used to check lightbulbs that have been removed from the circuit. Connecting one lead wire to the ground of the lightbulb and the other to the insulated side of the bulb causes the ohmmeter to show continuity, that is, a complete circuit.

Lightbulbs can go bad due to excessive vibration. Excessive vibration can cause the filament inside the lightbulb to break. When this occurs, the bulb must be replaced.

Another problem that you may encounter results from a loose connection in the lightbulb socket or circuit. This condition can cause the bulb to get brighter and dimmer, flicker, or not light at all. This problem is corrected by locating the problem and repairing the faulty connection.

Lightbulbs of different wattages and voltages are of the same size; so always be sure that the replacement bulb is of the same voltage and wattage as the one removed. Check the service manual if you aren't certain about what size bulb should be installed.

Switches

Switches are designed to open and close a circuit. You can check a switch using an ohmmeter. An ohmmeter indicates continuity when the switch is in the On position and does not indicate continuity when the switch is in the Off position. If a switch is defective, it must be replaced.

Electric Starter-Motor Troubleshooting

There are four main troubleshooting problems that occur with power equipment engine electric starter systems:

- The starter motor turns slowly.
- The starter solenoid makes a clicking sound, but the engine doesn't turn over.
- The starter motor turns without turning over the crankshaft.
- The starter motor doesn't turn at all.

Refer to the following table to troubleshoot these starter-motor problems.

Starter-Motor Problems

Symptom	Likely Cause	Checks
Starter motor turns slowly	Low charge in the battery	a. Check for a loose battery connection. b. Check for a loose starter-motor cable. c. Check for a faulty starter motor.
Starter motor turns, but the crankshaft doesn't turn over	Starter motor clutch at fault	a. Check for a worn starter clutch. b. Check for a worn starter pinion gear. c. Check for worn or damaged starter-motor idler or reduction gears.
Starter motor does not turn at all	Faulty fuse or safety device	a. Check all fuses. b. Check all safety devices such as lockout devices. c. Check starter solenoid d. Check for faulty starter motor *(continued)*

CDI Ignition Troubleshooting: No-Spark Condition *(continued)*		
Symptom	**Likely Cause**	**Checks**
The starter solenoid makes a "click" sound but crankshaft turns over only by hand or with kick starter	Low charge in the battery Faulty solenoid switch or starter motor	a. Verify that a known good battery is in place. b. Connect the starter motor to a battery source that is known to be good. A direct connection to a good battery. I. If the starter motor turns, the solenoid switch is faulty. II. If the starter motor doesn't turn, the starter motor is defective.

ABNORMAL NOISE TROUBLESHOOTING

Abnormal noise complaints can be for virtually any part of a power equipment engine. The following table indicates classic symptoms and possible problem areas for abnormal noise.

Abnormal Engine Noise	
Symptom	**Problem**
Knocking	■ Carbon buildup in combustion chamber ■ Fuel poor quality or incorrect fuel ■ Spark plug incorrect ■ Overheating ■ Connecting rod big-end clearance excessive ■ Crankshaft bearings worn ■ Connecting rod small-end clearance excessive ■ Balancer bearing worn

(continued)

Abnormal Engine Noise *(continued)*	
Symptom	**Problem**
Internal slapping noise	■ Cylinder-to-piston clearance excessive ■ Cylinder or piston worn ■ Piston pin or piston holes worn ■ Piston ring worn, broken, or stuck ■ Piston seizure, damage ■ Loose alternator rotor
Ticking noise	■ Valve clearance incorrect ■ Valve spring broken or weak ■ Camshaft bearing worn
External engine noise	■ Cylinder-head gasket leaking ■ Exhaust pipe leaking at cylinder-head connection

Summary

This chapter has covered a wide variety of troubleshooting symptoms as well as possible solutions. The information has been derived from various power equipment engine manufacturer service manual suggestions and compiled into one general area.

Use of the tables in this chapter will help you determine the problem quickly and ensure that you've repaired the machine correctly the first time itself. The following list summarizes the chapter.

- Proper diagnosis of a malfunction makes disassembly, repair, and reassembly much easier. An improperly diagnosed problem renders the repair process long and tedious.
- Developing a systematic approach to solving problems will help you perfect your skills as you gain more experience.
- There are three types of failures that you may encounter: constant failures, intermittent failure, and improper-service failures.
- Always verify the problem, isolate the problem, repair the problem, and most importantly, verify the repair.

Chapter 17 Review Questions

1. Name the tool that's used to test a lightbulb after it has been removed from its socket.
   a. Voltmeter
   b. Coil tester
   c. Ammeter
   d. Ohmmeter
2. If the air–fuel mixture to a power equipment engine is too rich, the problem could be caused by
   a. an empty gas tank.
   b. an over full gas tank.
   c. an air leak between the carburetor and the intake manifold.
   d. leaving the choke on after the engine has warmed up.
3. What are the two most common symptoms found when troubleshooting a transmission problem? _____ and _____
4. If you turn on the choke and the engine runs better, this generally indicates a _____ carburetor mixture problem.
5. A possible cause of a transmission that jumps out of gear is
   a. shifting at too low an engine speed.
   b. damaged shift fork.
   c. excessive play in the clutch pedal.
   d. incorrect oil level.
6. An excessive amount of _____ exhaust smoke indicates worn piston rings.
   a. black
   b. brown
   c. red
   d. white
7. A four-stroke power equipment engine with insufficient valve clearance will have
   a. crankshaft seizure.
   b. incorrect ignition timing.
   c. low compression.
   d. extra power at higher speeds.
8. What are the four procedures that must be followed in proper order when developing the proper method of diagnostic troubleshooting?
   1. _____
   2. _____
   3. _____
   4. _____
9. What are the two main problems associated with charging systems? _____ and _____
10. If a charging system is overcharging, the _____ is most likely the faulty component.

Appendix A:

FRACTION–DECIMAL–METRIC EQUIVALENTS

Fractions	Decimal In.	Metric MM.	Fractions	Decimal In.	Metric MM.
1/64	0.015625	11.39688	33/64	1.515625	13.0969
1/32	0.03125	11.79375	17/32	1.53125	13.4938
3/64	0.046875	11.19062	35/64	1.54688	13.8906
1/16	0.0625	11.58750	40072	1.5625	14.2875
5/64	0.078125	11.98437	37/64	1.57813	14.6844
3/32	0.09375	12.38125	19/32	1.59375	15.0813
7/64	0.109375	12.77812	39/64	1.60938	15.4781
1/8	0.125	13.1750	39941	1.625	15.875
9/64	0.140625	13.57187	41/64	1.64063	16.2719
5/32	0.15625	13.96875	21/32	1.65625	16.6688
11/64	0.171875	14.36562	43/64	1.67188	17.0656
3/16	0.1875	14.76250	40133	1.6875	17.4625
13/64	0.203125	15.15937	45/64	1.70313	17.8594
7/32	0.21875	15.55625	23/32	1.71875	18.2563
15/64	0.234375	15.95312	47/64	1.73438	18.6531
1/4	0.250	16.35000	39876	1.75	19.05
17/64	0.265625	16.74687	49/64	1.76563	19.4469
9/32	0.28125	17.14375	25/32	1.78125	19.8438
19/64	0.296875	17.54062	51/64	1.79688	20.2406
5/16	0.3125	17.93750	13/16	1.8125	20.6375
21/64	0.328125	18.33437	53/64	1.82813	21.0344
11/32	0.34375	18.73125	27/32	1.84375	21.4313
23/64	0.359375	19.12812	55/64	1.85938	21.8281
3/8	0.375	19.52500	40002	1.875	22.225
25/64	0.390625	19.92187	57/64	1.89063	22.6219
13/32	0.40625	10.31875	29/32	1.90625	23.0188
27/64	0.421875	10.7156	59/64	1.92188	23.4156
7/16	0.4375	11.1125	15/16	1.9375	23.8125
29/64	0.453125	11.5094	64/64	1.95313	24.2094
15/32	0.46875	11.9063	31/32	1.96875	24.6063
31/64	0.484375	12.3031	63/64	1.98438	25.0031
1/2	0.500	12.7	1	1	25.4

Appendix B:

US CUSTOMARY TO METRIC CONVERSION CHART

US Customary to Metric			Metric to US Customary		
If you know	**Multiply by**	**Converts to**	**If you know**	**Multiply by**	**Converts to**
Length					
Inches	25.4	Millimeters	Millimeters	0.03937	Inches
Inches	2.54	Centimeters	Centimeters	0.3937	Inches
Yards	0.91	Meters	Meters	3.3	Feet
Miles	1.6	Kilometers	Kilometers	0.62	Miles
Area					
Square inches	6.5	Square centimeters	Square centimeters	0.16	Square inches
Square feet	0.09	Square meters	Square meters	1.2	Square yards
Square yards	0.8	Square meters	Square kilometers	0.4	Square miles
Square miles	2.6	Square kilometers	Hectares	2.47	Acres
Acres	0.4	Hectares			
Mass (weight)					
Ounces	28	Grams	Grams	0.035	Ounces
Pounds	0.45	Kilograms	Kilograms	2.2	Pounds
Short tons	0.9	Metric tons	Metric tons	1.1	Short tons
Volume					
Fluid ounces	30	Milliliters	Milliliters	0.03	Fluid ounces
Pints	0.47	Liters	Liters	2.1	Pints
Quarts	0.95	Liters	Liters	1.06	Quarts
Gallons	3.8	Liters	Liters	0.26	Gallons
Temperature					
Fahrenheit	Subtract 32, then multiply by 5/9ths	Celsius	Celsius	Multiply by 9/5ths, then add 32	Fahrenheit

Appendix C:

GENERAL TORQUE CONVERSIONS AND SPECIFICATIONS

Conversion Chart for Units of Torque					
To convert			To convert		
From	To	Multiply by	From	To	Multiply by
lb-in	lb-ft	0.08333	lb-ft	lb-in	12
lb-in	kg-cm	1.1519	kg-cm	lb-in	0.8681
lb-in	kg-m	0.011519	kg-m	lb-in	86.81
lb-in	N•m	0.133	N•m	lb-in	8.85
lb-ft	kg-m	0.1382	kg-m	lb-ft	7.236
lb-ft	N•m	1.356	N•m	lb-ft	0.7376

General Metric Torque Specifications (use *only* if known Specification is not Available)			
Bolt size (mm)	N•m	m-kg	ft-lb
6	6.0	0.6	4.3
8	15	1.5	11
10	30	3.0	22
12	55	5.5	40
14	85	8.5	61
16	130	13.0	94

General US Customary Standard Torque Specifications (use *only* if known Specification is not Available)							
Bolt Size (in)	Threads/ inch	Standard dry torque in foot-pounds					
		SAE Grade, 0-1-2, Low Carbon Steel	SAE Grade 3, Medium Carbon Steel	SAE Grade 5, Medium Carbon Heat-treated Steel	SAE Grade 6, Carbon Tempered Steel	SAE Grade 7, Medium Carbon Alloy Steel	SAE Grade 8, Carbon Alloy Steel
1/4	20	6	9	10	12.5	13	14
5/16	18	12	17	19	24	25	29
3/8	16	20	30	33	43	44	47
7/16	14	32	47	54	69	71	78
1/2	13	47	69	78	106	110	119
9/16	12	69	103	114	150	154	169
5/8	11	96	145	154	209	215	230
3/4	10	155	234	257	350	360	380
7/8	9	206	372	382	550	570	600
1	8	310	551	587	825	840	700

Appendix D:

TAP DRILL SIZING CHART IN SAE AND METRIC EQUATIONS

American Standard Thread		ISO Metric Thread	
Thread Size	Tap Drill Size (in)	Thread Size	Tap Drill Size (mm)
5-44	37	M3.5 × 0.6	2.90
6-32	36	M4 × 0.7	3.30
6-40	33	M4.5 × 0.75	3.70
8-32	29	M5 × 0.8	4.20
8-36	29	M6 × 1	5.00
10-24	25	M7 × 1	6.00
10-32	21	M8 × 1.25	6.80
12-24	17	M9 × 1.25	7.80
12-28	15	M10 × 1.5	8.50
1/4-20	7	M11 × 1.5	9.50
1/4-28	3	M12 × 1.75	10.20
5/16-18	F	M14 × 2	12.00
5/16-24	I	M16 × 2	14.00
3/8-16	5/16	M18 × 2.5	15.50
3/8-24	Q	M20 × 2.5	17.50
7/16-14	U	M22 × 2.5	19.50
7/16-20	W	M24 × 3	21.00
1/2-13	27/64	M27 × 3	24.00
1/2-20	29/64	M30 × 3.5	26.50
9/16-12	31/64	M33 × 3.5	29.50
9/16-18	33/64	M36 × 4	32.00
5/8-11	17/32	M39 × 4	35.00
5/8-18	37/64	M42 × 4.5	37.50
3/4-10	21/32	M45 × 4.5	40.50
3/4-16	11/16	M48 × 5	43.00
7/8-9	49/64	M52 × 5	47.00
7/8-14	13/16	M56 × 5.5	50.50
1″-8	7/8	M60 × 5.5	54.50
1″-12	59/64	M64 × 6	58.00

Appendix E:

SPARK PLUG CONDITION CHART

Normal

Combustion deposits are slight and not heavy enough to have a detrimental effect on engine performance. Note the brown-to-grayish tan color and minimal amount of electrode erosion, which clearly indicate that the plug is in the correct heat range and has been operating in a "healthy" engine.

Mechanical Damage

May be caused by a foreign object that has accidentally entered the combustion chamber or by a broken piece of piston or valve. This condition may also be because of improper-reach spark plugs that permit the piston to touch or collide with the firing end.

Oil Fouled

Too much oil is entering the combustion chamber with this condition. This is often caused by piston rings or cylinder walls that are badly worn. Oil may also be pulled into the chamber because of excessive clearance in the valve stem guides.

Overheated

A clean, white insulator firing tip and/or excessive electrode erosion indicates this spark plug condition. This is often caused by over-advanced ignition, timing, poor engine cooling-system efficiency, a very lean air–fuel mixture, or a leaking intake manifold. When these conditions prevail, even a plug of the correct heat range will overheat.

Bridged Gap

Seen more in two-stroke engines but seen also in four-stroke engines, this rare condition occurs when combustion deposits thrown loose lodge between the electrodes, causing a dead short and misfire. Fluffy materials that accumulate on the side electrode may melt to bridge the gap when the engine is suddenly put under a heavy load.

Preignition

Usually one or a combination of several engine operating conditions are the prime causes of preignition. It may originate from glowing combustion chamber deposits, hot spots in the combustion chamber due to poor control of engine heat, cross-firing (electrical induction between spark plug wires), or the plug heat range being too high for the engine or its operating conditions.

Carbon Fouled	Detonation	Worn
		
This is the most common cause of spark plug failure. Soft, black, sooty deposits are characteristic of this plug condition. It is most often caused by an over-rich air–fuel mixture. Check for a sticking choke, a clogged air cleaner, or a carburetor problem such as a high float level or a leaking needle or seat. Carbon fouling may also be attributable to weak ignition voltage, an inoperative preheating system (carburetor intake air), or extremely low cylinder compression.	This form of abnormal combustion can fracture the insulator core nose of the plug, as shown. The explosion that occurs in this condition applies extreme pressures on internal engine components. Primary causes include ignition time advanced too far, a lean air–fuel mixture, and insufficient gasoline octane rating.	The plug shown has served its useful life and should be replaced. On a worn spark plug, the corners of the insulator tip and electrode show signs of rounding. The voltage required to fire the plug has approximately doubled and will continue to increase with additional miles of travel. Even higher voltage requirements, as much as 100% above normal, may occur when the engine is quickly accelerated. Poor engine performance and a loss in fuel economy are symptoms of a worn spark.

GLOSSARY

A

Active combustion a phase in the combustion process in which there is rapid buildup of temperature and pressure; a chain reaction of burning molecules causes heat to be released very quickly

Adjustable wrench also called a crescent wrench; has movable jaws that allow you to adjust the opening to fit almost any size nut or bolt

Air vane governor also called a pneumatic governor; a governor that uses air flow coming off the flywheel to regulate throttle opening to control engine load

Allen wrench also called hex wrench; a short, six-sided rod that is used to tighten screws and bolts that contain similar six-sided (hex) indentations

Alternating current (AC) one of the two types of electric power sources; flows in alternating cycles

Alternator a battery-charging device that generates AC by the principle of electromagnetic induction; the higher the engine rpm, the stronger the current generated by the alternator

Atomization the process of combining air and liquid to create a mixture of liquid droplets suspended in air

Atomized liquid liquid drops suspended in air

Axial tension the stretching force that is exerted on a bolt when it is tightened into a case or when a nut is tightened onto it

B

Basic hand tools common tools that are found in just about every workshop toolbox, e.g., screwdrivers, hammers, pliers, wrenches, and socket sets

Battery a power source and an electrical storage device that supplies uninterrupted energy for the electrical system

Bearings friction-reducing devices used in engines

Bench grinder a useful tool in the power equipment engine service department that generally has two rotating wheels, one with an abrasive grinding surface and the other with a wire wheel.

Bench testing the process of verifying the correctness of reassembly before completing the reassembly or rebuilding process

Bench vise a useful holding device that clamps onto a workbench or table edge

Bleeding a method used to remove air bubbles from oil lines

Block diagram a precise schematic of the various subsystems within the electrical system, which helps a technician to focus on the subsystem in question

Bolt a metal rod with external threads on one end and a head on the other

Bolt head markings markings found on the head of bolts, which specify the tensile strength of the bolt; also known as grade markings

Bore the inside diameter of the cylinder

Bottom-dead center (BDC) the position of the piston wherein it is at its lowest position in the cylinder

Boyle's law law governing interplay between temperature, volume, and pressure; states that when a gas is compressed, its temperature and pressure increase

Brake horsepower the unit widely used to specify the power of an engine; the brake horsepower rating is the maximum power output of the engine

Bushings friction-reducing devices used to support large radial loads and, occasionally, axial loads

C

Camshaft also called cam; a mechanism to change rotary motion to reciprocating motion

Capacitor discharge ignition a type of electronic ignition configuration; often used in small power equipment engines

Carbon dioxide (CO_2) the most widely used extinguishing agent

Carbon monoxide a harmful but odorless gas that comes from engine exhaust that can cause suffocation when inhaled

Carburetor a device used to mix proper amounts of air and fuel together to enable effective combustion
Catalyst a chemical that speeds up a chemical reaction without undergoing any change itself
Catalytic converter a device used to reduce the toxicity of emissions from an engine
Centrifugal governor also called a mechanical governor; is a governor that uses centrifugal force generated by rotating flyweights inside the engine crankcase to regulate throttle opening
Chain reaction a chemical reaction that produces energy that causes further reactions of the same kind
Chisel a basic hand tool used for cutting, shearing, and chipping
Clamp a basic hand tool used to hold workpieces securely
Class A fire involves burning of wood, paper, cardboard, fabric, and other similar fibrous materials
Class B fire involves burning of flammable liquids, gases, and other chemicals
Class C fire involves burning of live electrical equipment
Class D fire involves burning of combustible metals
Clearances small spaces, typically those between two parts, such as spark plug gaps
Combustion chemical reaction characterized by rapid combining of oxygen molecules with other elements
Combustion chamber the space, between the cylinder head and the top of the piston, where combustion takes place
Combustion chamber volume (CCV) the cylinder volume at its smallest volume, that is, when the piston is at its TDC
Combustion lag a phase in the combustion process characterized by slow burning
Compression check a test that measures the amount of pressure produced in the combustion chamber in the compression stroke
Compression event an event in the operation of a two-stroke engine in which the secondary area decreases, the air-and-fuel mixture is compressed, and the ignition mechanism fires
Compression gauge a special tool used to measure pressure in an engine cylinder
Compression ratio the ratio of the largest cylinder volume to the smallest cylinder volume; a measure of how effectively fuel is burned in the cylinder
Compression stroke the stage in the operation of a four-stroke engine when the piston begins to rise, compressing the air-and-fuel mixture tightly in the combustion chamber
Conductor generally a metal that readily passes, or conducts, electricity
Connecting rod rod that connects the piston and the crankshaft
Constant failure a problem whose symptom is always continuously present
Contact dermatitis also called eczema; a skin inflammation commonly caused by chemicals
Control arm assembly a plate with levers and screw stops for the engine controls
Conventional system a system of weights and measurement used widely on power equipment engines made in the United States; also known as the standard or United States Customary (USC) system
Coolant a component of liquid-cooled power equipment engines
Counter-balancer a device that balances the power pulses created by the power strokes
Crankcase see *Cylinder block*
Crankshaft a crankshaft that, along with the connecting rod, converts the up-and-down (reciprocating) motion of the piston into circular (rotary) motion
Crosshatches tiny scratches cut into surface of some cylinders
Cylinder a circular tube that is closed at one end; houses the piston and combustion chamber
Cylinder block also known as the crankcase; the casing that is used to hold all engine components together
Cylinder taper a measure of cylinder wear from top to bottom
Cylinder volume the volume that lies between the piston and the cylinder head; periodically varies as the piston moves up and down the cylinder

D

Detonation a condition that causes improper burning of the air–fuel mixture, in which the air–fuel mixture fails to burn smoothly because it ignites a second time in another area of the combustion chamber. Also known as engine knocking.

Diagnosis the process of determining what is wrong when something is not working properly, by checking the symptoms

Dial indicator a precision measuring instrument to measure the distance a part has moved

Die cuts "male" threads (like the threads on a screw or bolt)

Dip-stick a widely used tool to check the oil level

Direct current (DC) one of the two types of electric power sources; is continuous and steady

Distilled water water that has virtually all its impurities removed through distillation; used for refilling batteries

Drill bit a tool that bores through material

Drill press a large, floor-standing device that can drill precisely located and angled holes

Dynamometer an instrument designed to measure engine power

E

EETC technician certification program a certification awarded by the Equipment & Engine Training Council; recognized as the standard for power equipment servicing

Elastic range the range of torque values applied over which the fastener stretches but returns to its original diameter when the applied torque is removed

Electric start a starting mechanism used in power equipment engines; uses an electric motor with a reduction gear to turn the engine's crankshaft

Electrolyte a chemical compound which, when molten or dissolved in certain solvents (usually water), conducts an electric current

Electronic fuel injection (EFI) an indirect fuel injection system that uses electronic modules to precisely control fuel supply to the engine

Electronic ignition system an ignition system that uses electronic components to perform the switching function; more durable than the mechanical ignition system

Energy the ability to do work

Engine break-in the process of not subjecting a new or just-reconditioned engine immediately to a constant maximum stress

Engine cycle one complete run through all four events of operation: intake, compression, power, and exhaust

Engine displacement the volume of space through which the piston moves as it moves from BDC to TDC

Engine seizure engine failure that occurs when two or more parts inside an engine are excessively hot and melt together; a result of inadequate lubrication

Entry-level engine technician generally the first job that many students obtain in the power equipment engine industry

Equipment & Engine Training Council (EETC) a non-profit association that addresses the shortage of qualified service technicians in the outdoor power equipment industry

Excited-field electromagnet alternator a charging system that uses DC-energized field coils to generate AC (when the rotor spins past the stator); potentially the most powerful AC generating system available

Exhaust event an event in the operation of a two-stroke engine in which the exhaust gases are pushed into the exhaust system

Exhaust stroke the stage in the operation of a four-stroke engine when the piston moves up and pushes the burned gases out of the cylinder through the exhaust valve

F

Feeler gauge a precision measuring tool; used to measure clearances

Fibrillation a condition characterized by erratic, non-rhythmic heartbeat; caused when the path of AC runs from one hand to another, putting your heart in line

File a basic hand tool used to smooth surfaces and edges

Fire extinguisher a device used in putting out a fire

Fire triangle the three conditions that must be present for a fire to start—fuel, oxygen, and an ignition source

Firing order the sequential order in which power strokes of the different pistons of a multi-cylinder power equipment engine occur; necessary to reduce rocking and imbalance problems

Forced draft an engine-cooling mechanism; uses air from an engine-driven fan

Four-stroke engine a power equipment engine that has a power stroke every two turns (720° of rotation) of the crankshaft

Fractional distillation a process by which crude oil is separated into its component hydrocarbons, making use of the fact that each hydrocarbon boils or vaporizes within a certain temperature range; the process by which gasoline is obtained form crude oil

Franchised dealership a business that is authorized to sell a particular engine or component, company's products, and services in a particular area

Friction resistance to motion created when two surfaces move against each other, or when a moving surface moves against a stationary one

Fuel Circuits fuel metering systems, which supply fuel for the air–fuel mixture in regulated amounts

Fuel filters used to remove contaminants from the fuel before they reach the carburetor

Fuel injector an electronically operated solenoid that turns fuel on and off

Fuel lines hoses used to flow gasoline from the fuel valve to the carburetion system, usually made of metal or neoprene

Fuel valves also known as fuel petcocks; on/off valves that control the flow of gasoline from the fuel tank to the carburetion system

G

Gasoline the fuel used in most standard power equipment engine; gasoline is mixed with air to burn

General manager the person who holds the highest position in a power equipment dealership; with overall responsibility for the sales, parts, and service departments

Governor throttle control system an engine speed control system that senses engine load and automatically adjusts engine speed when required

Grease a lubricant that is suspended in gel

Grounded circuit a circuit that allows power to flow back to the source after the load, but before the means of control

H

Hacksaw a basic hand tool used to cut metal stock that is too heavy to be cut with snips or cutting pliers

Half-wave rectification one of the processes by which AC is converted to DC; one (positive) half of the AC is allowed to pass through while the other (negative) half is blocked

Halon another widely used extinguishing agent that is effective on all classes of fire

Headset a personal protective device that protects hearing when working in a noisy area

Horsepower a unit of engine power; equivalent to work performed at the rate of 550 ft-lb/s or 33,000 ft-lb/m

Hydrometer a device that measures the weight of liquid as compared with the weight of water

I

Ignition a method of initiating combustion in an internal combustion engine

Ignition coil a transformer that consists of two wire windings, the primary winding and the secondary winding; the latter is connected to the spark plug, the former to the power source

Ignition timing the precise time at which the spark occurs to ignite the air–fuel mixture

Ignition timing advance process by which ignition is made to occur sooner, as required at higher engine speeds

Impact screwdriver used often on power equipment engines to remove and install fasteners where hand torque is insufficient

Improper-service failure a problem that is a result of a mistake during the servicing of the machine

Incipient fire a fire in its beginning stages; the stage at which a fire can be put out using a fire extinguisher

Induction the method used to pass the air-and-fuel mixture through the intake port of the engine

Intake event an event in the operation of a two-stroke engine in which the primary area increases, which causes pressure to decrease

Intake stroke the stage in the operation of a four-stroke engine when the air-and-fuel mixture enters the cylinder

Interference fit the tight fit with which ball bearings are installed

Intermittent failure a problem whose symptom is not present; difficult to troubleshoot

Internal combustion engine an engine in which compressed fuel and air are burned inside the engine to produce power

L

Law of action and reaction a universal law; states that for every action there is an equal and opposite reaction

Law of inertia a universal law; states that anything at rest or in motion tends to remain at rest or in motion until acted upon by an outside force

Leak-down test a comprehensive engine diagnosis test used to measure the percentage of air that leaks past the piston rings and valves

Lean mixture a fuel mixture in which the mass of air is more than 14.7 times the mass of gasoline; a lean mixture encourages detonation

M

Magnetic induction the phenomenon by which when an electrical conductor is passed through a magnetic field or vice-versa, an electric current, or voltage, is induced in the conductor

Maintenance-free (MF) batteries batteries that use an absorbed glass mat to totally seal all acid leakage from the plates, thereby eliminating the need to constantly refill the battery with water

Manual throttle control system an engine speed control system in which the operator sets and manually controls the engine speed

Material handling movement of materials from one place to another

Material safety data sheets (MSDSs) printed matter, usually from manufacturers of the chemicals used in the power equipment engine industry, carrying information on each chemical; must be posted by the employer so that it is readily available for every employee

Mechanic's stethoscope similar to a stethoscope that a doctor uses; picks up very faint sounds and can pinpoint the location of noises in an engine

Mechanical work a force that is applied over a specific distance

Metatarsal guards special covers that go over the instep of boots; used for protection of feet and legs

Metric system a system of weights and measurement used in virtually all countries around the world; also known as the International System of Units (SI)

Micrometer a precision measuring tool designed to measure the outer dimensions of an object; more accurate than a vernier caliper

Momentum the driving force that is the result of motion or movement

Multi-meter a precision testing tool, also called a volt-ohmmeter; used to measure voltage, current, and resistance

Multi-viscosity oil lubricating oil that is suitable for use under different climatic and driving conditions

Mutual induction the phenomenon by which when two conductors are placed close together and current is applied to one of the conductors, a voltage is induced in the other conductor

N

National Electrical Code® (NEC®) the national standard for all residential and industrial electrical installations in the United States and Canada; published by the NFPA

National Fire Protection Association (NFPA) the largest and most influential national group dedicated to fire prevention and protection

Nut a fastener that has internal threads and usually is made with a six-sided outer shape

O

Occupational Safety and Health Administration (OSHA) the federal agency established to prevent work-related injuries, illnesses, and deaths; publishes safety standards for business and industry

Octane rating also known as knock rating; a measure of a fuel's ability to resist detonation

Oil additives chemicals used in the manufacture of today's engine oils that improve the oils' operating qualities

Oil injection system a mechanism that supplies oil to engine components as needed, thereby leading to decrease in oil consumption

Open circuit a circuit in which the path for current to flow is incomplete

Otto cycle a four-stroke, gas engine cycle of intake-compression-power-exhaust

Outdoor Power Equipment and Engine Service Association (OPEESA) an industry-level association with more than 140 distributors and manufacturers of outdoor power equipment and air-cooled gas and diesel engine

P

Parallel circuit a circuit that has more than one path for electrons back to the source of power

Parts department the department in an independent dealership that sells repair parts and accessories

Parts technician the person responsible for supplying the service department technicians with the parts they need to complete their service and repair work

PASS a mnemonic to help you remember how to operate a fire extinguisher: pull (the safety pin), aim, squeeze, and sweep

Permanent-magnet alternator a charging system that uses a permanent magnet to generate AC; the most commonly used type of AC generating system

Personal protective equipment safety equipment worn by technicians at work; includes items such as dust masks, safety glasses, gloves, and special footwear

Piston a circular plug that moves up and down inside the cylinder

Piston ring a metal ring that is split at one point and is designed to be springy

Piston ring side clearance the small space between each piston ring and the inner side of its groove

Piston stroke each movement of the piston either up or down the cylinder

Piston-to-cylinder clearance also known as piston clearance; the space between the piston and cylinder wall

Plain flat washer a fastener used under bolt heads and nuts; use of correct-sized washers is necessary to achieve correct loads on bolt

Plastic range the value of torque applied at which the fastener begins to stretch permanently; that is, the point at which the fastener will not return to its original diameter when the applied torque is removed

Plastigage a fine plastic string used in the measurement of the amount of oil clearance in multi-piece connecting rods

Plier a basic hand tool used for holding, gripping, shaping, or cutting

Ports holes in the cylinder or cylinder head that allow the air-and-fuel mixture to enter the cylinder and exhaust gases to leave the cylinder

Post combustion a phase in the combustion process in which, after completion of actual combustion, exhaust gases are released out of the cylinder

Power rate at which work is done

Power event an event in the operation of a two-stroke engine in which the expanding combustion gases caused by the ignition force the piston downward; event at which mechanical power is delivered to the implement

Power stroke the stage in the operation of a four-stroke engine when the connecting rod causes the downward motion of the piston to force the crankshaft to rotate; stage at which mechanical power is delivered to the implement

Power tools special tools such as drills, power impact wrenches, and grinders used by a power equipment engine technician; may prove to be hazardous because electrical charge, high-speed movement, and momentum are involved in their use

Precision measuring tools used to make exact measurements of parts or distances between parts

Preignition a condition that causes improper burning of the air–fuel mixture, in which the air–fuel mixture in the combustion chamber ignites before the spark plug actually fires

Preload the technical term for the tension caused by tightening the fastener that holds the parts together

Prussian blue a dye used in valve width verification and correction

Puller used to safely remove gears, flywheels, or various such components from a shaft

Punch a basic hand tool used for aligning and driving items

R

Radiator also known as a heat exchanger; a cooling device that allows for rapid heat removal from the engine through the use of water

Reamer a long, round cutting tool with cutting edges along its length; used to enlarge existing holes

Reciprocating engine an engine that has a piston that moves alternately up and down inside a cylinder; used by almost all power equipment engines

Recoil starter a starting mechanism used in power equipment engines

Rectifier an electronic component that changes AC to DC

Respirators a personal protective device that protects lungs from harmful dusts, gases, or vapors

Revolutions per minute (rpm) a measure of how many complete turns (360°) the crankshaft makes in 1 minute

Rich mixture a fuel mixture in which the mass of air is less than 14.7 times the mass of gasoline; a rich mixture discourages detonation

Rotor the moving part component of an alternator; comprises a series of magnets and rotates either inside or outside the stator

S

Safety glasses a personal protective device that shields eyes from impact and flying particles

Sales department the department in an independent dealership that displays and sells products

Scheduled maintenance routine periodic service inspections of an engine to ensure trouble-free operation of the engine and the machine; performed even when the engine is operating properly

Score marks an indication of piston damage; deep, vertical scratches on the piston skirt

Scuff marks an indication of piston damage; wide areas of wear on the piston, usually appearing as shiny patches

Seal device used to prevent oil loss from the engine and bearings

Semiconductor a substance whose electrical conductivity is between that of a conductor and an insulator; used to make electronic components

Sequential fuel injection an electronic fuel injection process wherein fuel is delivered to the cylinder only as needed

Series circuit a circuit that has only one path for electrons back to the source of power

Service department the department in an independent dealership that carries out maintenance and repairs of power equipment engines

Service manager the person who holds the highest position in a service department; responsible for customer transactions, warranty claims, equipment needs, and service policy changes

Service writer the person responsible for writing the repair orders for service work

Short circuit a circuit that has developed a path for electricity to flow to the source of power before it reaches the load

Silicon-controlled rectifier (SCR) also called a thyristor; widely used as a switching device in electronic circuits

Solenoid a type of electromagnet that has a movable core; widely used in electric starter systems as well as in some safety devices

Spark plug the component of the ignition system that provides the air gap across which the high secondary voltage arcs to produce the spark that ignites the air–fuel mixture

Spark plug reach the length of the spark plug arrangement that protrudes into the combustion chamber; crucial for correct ignition

Specification manuals also known as "spec" manuals; specification sheets made by manufacturers, where they provide technical details of their products

Starter clutch also known as sprag clutch; a mechanism that allows the starter motor to engage only while the starter motor is operating to start the engine

Stator the stationary component of an alternator; comprises windings that generally enclose the rotor

Stellite an alloy used in the coating on the valve face to increase its longevity

Stoichiometric ratio the chemically correct air-fuel ratio necessary to achieve complete combustion of fuel

Stretched bolt a defective bolt, rendered so by overtightening

Stroke the distance that the piston travels up or down in a cylinder

Stud a fastener with external threads on each end

Symptoms the outward, or visible, signs of a malfunction

T

Tap a basic hand tool that cuts "female" threads (equivalent to the threads in a nut)

Technician the person with the required technical in background in power equipment engines, with knowledge of handling tools and repair work; frequently considered the backbone of the service department

Tensile strength refers to the amount of pull a fastener can withstand before breaking; also known as grade

Test light a precision testing instrument; used to determine if electrical power is available to a particular circuit

Thermostat a temperature-sensitive flow valve; provides for a quicker engine warm-up

Threads per inch (TPI) a measure of thread pitch per the conventional system

Throttle control a valve mechanism by which the operator of an engine controls its speed

Timing light a tool used to verify proper ignition operation; not used much nowadays

Toolbox a storage box for the tools used by a power equipment engine technician

Top-dead center (TDC) the position of the piston wherein it is at its highest position in the cylinder

Torque force applied at an angle; rotational force

Torx wrench similar to the Allen wrench, except the end of the Torx wrench is star shaped

Transfer event an event in the operation of a two-stroke engine in which residual exhaust gases are scavenged by pushing the remaining exhaust gases out through the exhaust port; this event takes place during the exhaust event

Transistor a semiconductor device that's widely used in power equipment engine electrical systems; used to control the flow of current in a circuit

Tune-up a set of service procedures used in maintenance of power equipment engines; may vary from shop to shop

Two-stroke engine a power equipment engine that has a power stroke every full turn (360° of rotation) of the crankshaft

V

Valve a device used to control the air-and-fuel mixture that is drawn into the cylinder and the exhaust gases that are expelled

Valve-closing devices devices that keep the valve closed when required

Valve float a condition in which the valve does not stay in constant contact with the valve train

Valve refacing also called valve grinding; the process of reconditioning valve faces that have experienced wear and distortion from use; generally not recommended with modern valves using Stellite

Vaporized liquid a liquid that is converted to its gaseous state though a heating process

Vent hoses hoses used on most fuel tanks and carburetors to permit atmospheric air pressure to enter into certain important areas within the fuel system

Venturi principle a theory based on which the carburetor is designed; states that a gas or liquid that is flowing through a narrowed-down section (venturi) of a passage will increase in speed and decrease in pressure

Vernier caliper a versatile and popular precision measuring tool; used to measure inside, outside, or depth measurements

Viscosity a measure of a liquid's resistance to flow; a liquid with higher viscosity offers greater resistance to flow

Viscosity index a number used to indicate the consistency of lubricating oil with changes of temperature

Vise a basic hand tool used to hold workpieces securely

Voltage regulator a device that regulates voltage going into the battery in order to prevent undercharging or overcharging of the battery

W

Water jacket an engine-cooling mechanism; comprises a series of passageways surrounding the cylinder and combustion chamber

Wrench a basic hand tool used to tighten or loosen nut-and-bolt-type fasteners

Wrist pin a cylinder-shaped piston assembly component; used to link the connecting rod to the piston

Y

Yield point the value of torque applied at which the fastener moves from the elastic to the plastic range

Z

Zener diode a diode that allows current to flow in the reverse direction only if the applied voltage exceeds a predetermined value called the trigger or breakdown voltage

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