STEAM TURBINE MODERNIZATION SOLUTIONS PROVIDE A WIDE SPECTRUM OF OPTIONS TO IMPROVE PERFORMANCE

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INTRODUCTION

Steam turbine modernization solutions are typically defined by their ability to increase electrical output performance and/or heat rate reduction by application of the latest technologies. Siemens Power Generation is continually involved in research and development to provide the most advanced technologies for electricity producers in order to maximize the output of their turbine generators.

Modernization solutions are normally considered for older turbines which utilize technology that is approximately 30-years old or more, however recently, much newer steam turbine operators, on units that are in operation for as little as 5-years, are inquiring into options to maximize their performance output.

The turbine technologies that are available for existing units, as well as replacement steam paths, are:

- **Advanced Shaft Sealing** - retrofitting with retractable, brush, and abradable sealing
- **Blade Replacement** - re-blading existing turbine stages with advanced blading, such as 3-dimensional blading
- **Major Component Modernization Options** - entire replacement steam paths utilizing state-of-the-art materials and technology to maximize performance and reduce reliability and availability issues
- **Condenser Optimizations –** analysis, reconfiguring, and tube replacement to optimize the condenser performance

The key aspects of these technologies will be discussed to provide an executive summary of their features and benefits.

ADVANCED SHAFT SEALING TECHNOLGY

Improvements to the shaft steam sealing can be applied to existing operating units as well as new steam paths. These technologies allow operation at smaller seal clearances and include features that improve reliability in the event of rotor to seal contact.

These seal technologies are the abradable coating, retractable, and brush seals, which are discussed below.

Abradable Coating Seals

In this solution, an abradable coating, normally of a metal alloy composition for steam turbines, is applied by spray coating to the standard design seal segments. This reduces leakage flow by reducing the tip clearances. As shown in figure 1, the abradable coating reduces the clearance between the hard metal parts of the rotor and seal segment base material. The abradable coating can be applied to various types of seal segments, especially for applications in the balance piston and dummy piston section of high pressure turbines.

Figure 1 below shows the typical configuration for a Abradable Seal.

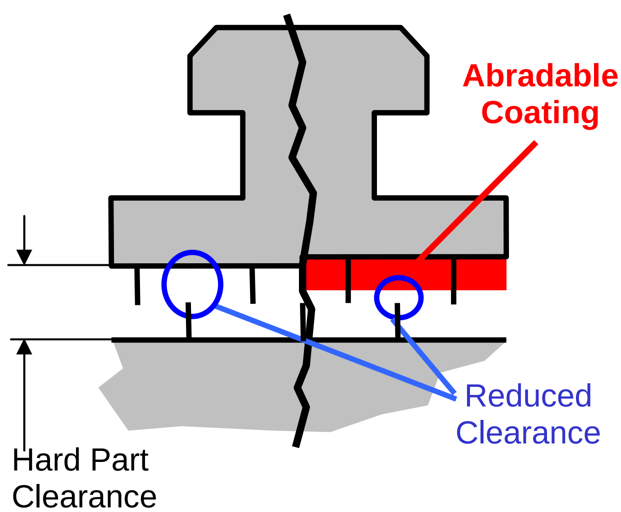
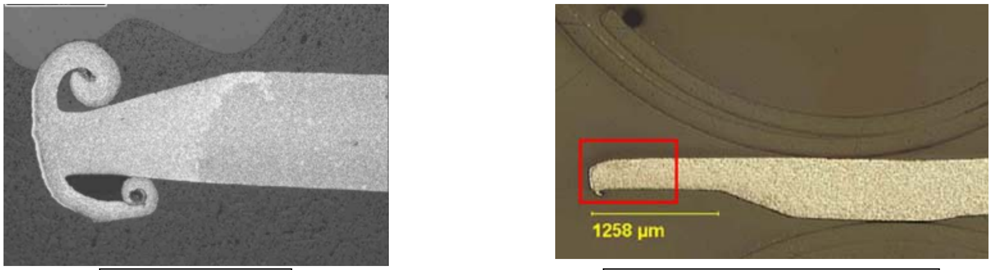


FIGURE 1- TYPICAL ABRADABLE SEAL ARRANGEMENT

Operational benefits in the event of a rub, are that the sharp edge of the rotor seals, which are harder that the abradable coating material, will have minimal damage or wear during contact with the coating. ***Figure 2*** below demonstrates this benefit between a hard rub (metal to metal compared to a rub with coating.



Hard Rub **Rub with Coating**

FIGURE 2- NORMAL SEAL (HARD RUB) AND ABRADABLE SEAL RUBBING COMPARISON

Based on scope of implementation, these generally provide 0.1 to 0.2% performance improvement depending on application.

Retractable Seals

Conventional labyrinth seals are segmented and positioned by radial flat springs. Retractable packing replaces the flat springs with coil springs between the segments to enlarge shaft clearances during start-up in order to avoid damage caused by thermal distortion and vibration as the unit passes through its critical speed zone. As shown in the ***figure 3*** below, the coil spring at the end of each seal segment holds the segment away from the shaft during start-up. At steady state condition, high pressure steam enters the ring segments to restore design clearance for normal operation at the design clearances.[1]

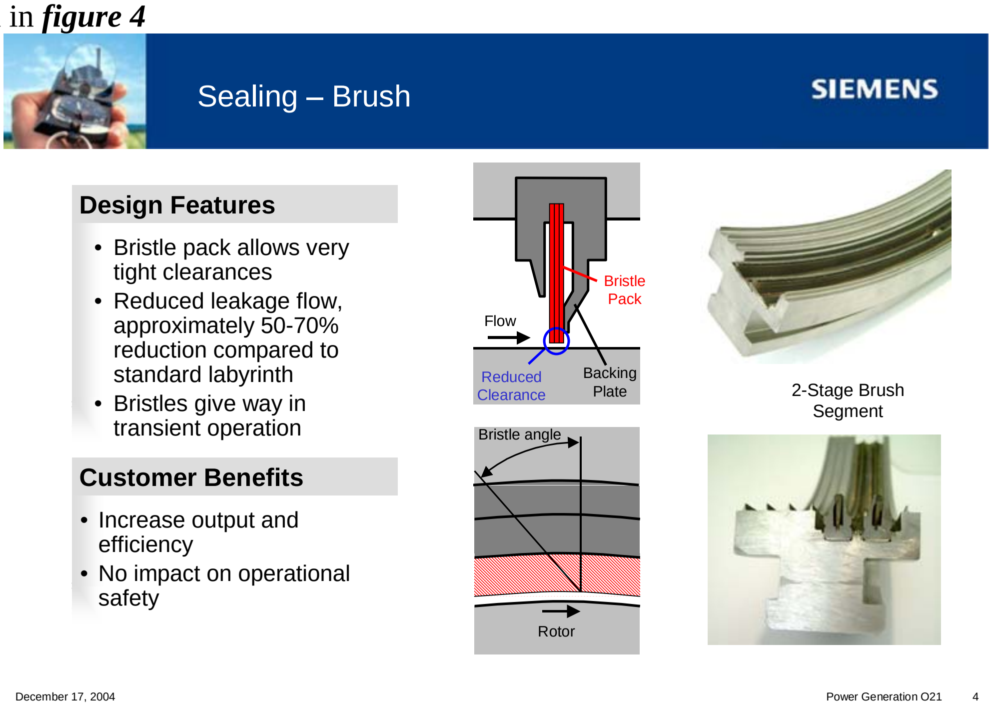
The retractable seal provides reliability improvements by making starts smoother and eliminating contact during start-up. Fewer rubs translates into less maintenance on the seals. The smaller clearances improves performance, sustains heat-rate, and reduces degradation.

[1] Inventions and Innovations Impact Sheet – www.oit.doe.gov/inventions/folio/htmls/power/turbicare.shtml, p.1.

FIGURE 3 – RETRACTABLE SEAL SEGMENT AND COIL SPRING

Brush Seals

An additional sealing technology is the use of brush tip seals that provide "zero clearance" during operation and gives way during transients. The brush seals can be incorporated into the retractable sealing design to give a very effective seal compared to previous designs and is shown in ***figure 4***



below.

FIGURE 4 – BRUSH SEAL ARRANGEMENT AND DETAIL

BLADE REPLACEMENT WITH ADVANCED 3-DIMENSIONAL BLADING

With the continued advances in blading development, options exist where existing operating turbine components, such as high pressure and intermediate pressure turbine sections can be upgraded by replacing select blade rows with advanced blading. Siemens latest design blade family are the 3DV and 3DS types. For example, as ***figure 5*** shows below, Siemens Advanced 3DS airfoil design is approximately 2% better on stage to stage efficiency than the former T4 blade profile design that it replaced in the late 1990s.

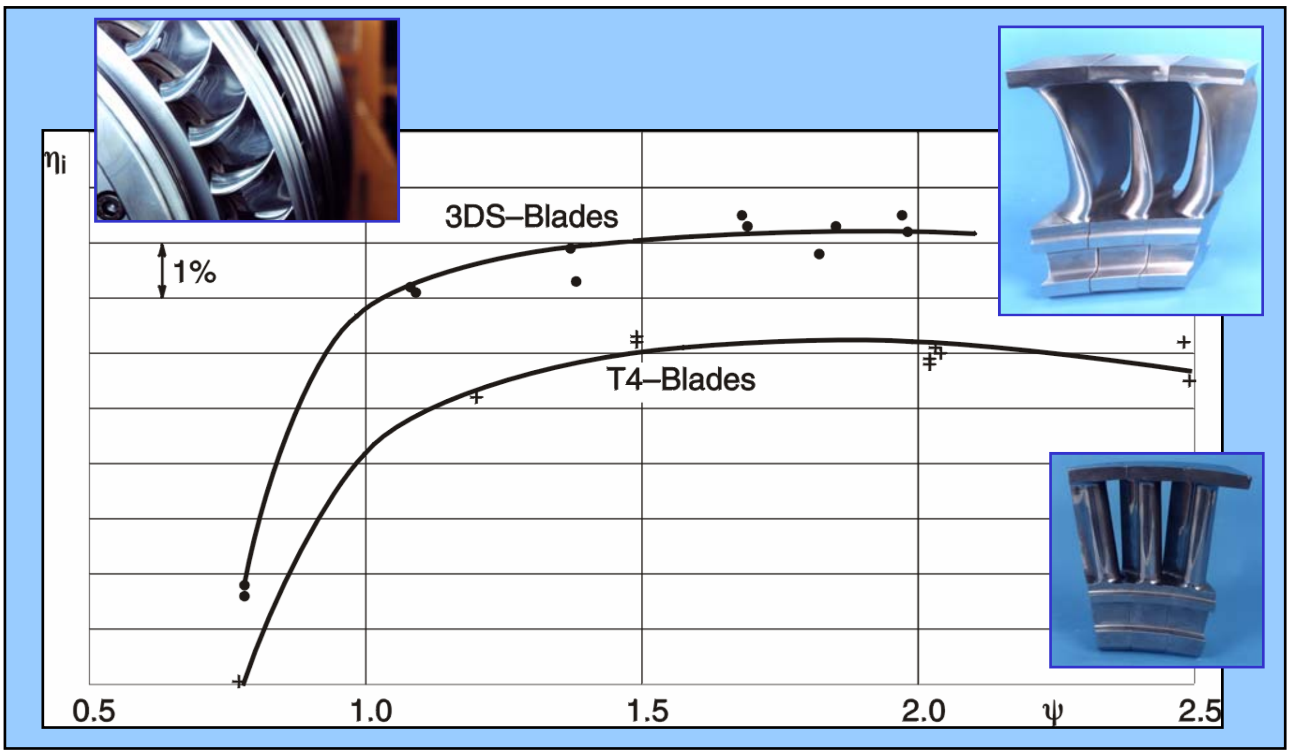


FIGURE 5 – GRAPH COMPARING 3DS BLADING EFFICIENCY WITH FORMER T4 SERIES

The main technological improvements of these blades are:

- Fully 3D airfoil design
- Twisted blades – to reduce incidence losses
- 3DS™ blades – 3D design to reduce secondary losses

Often times, utilities find that it is not feasible, due to time constraints, to remove a turbine component, such as a High Pressure section, from service and replace blading and sealing. In this situation, a "seed component" would be manufactured ahead of a planned maintenance outage requiring 18 to 24 months lead-time. This new component would be available for a future installation, which would minimize the outage duration. Such major component replacements are discussed further below.

MAJOR TURBINE COMPONENT MODERNIZATION OPTIONS

This option involves replacement of the entire component, with reuse of the outer casings with new components that use the latest technology. This approach corrects reliability issues and improves performance, maintenance requirements, and emissions to levels comparable with new turbines. This approach aims to reuse as much existing equipment as possible, such as bearings, bearing pedestals, outer casings, piping, and supports. The modernized turbine steam path incorporates much of the technology previously discussed such as new sealing, blading, and larger cross sections to maximize performance.

EXAMPLE – HP/IP TURBINE MODERNIZATION (FOSSIL APPLICATION)

One example of a fossil steam path modernization is the BB44/044 replacement module which is designed as a "drop in" replacement for the HP/IP (combined high and intermediate pressure) turbine used in fossil power plants in 330 to 585 MW nominal application range that were originally installed up to the mid-1980s. As ***figure 6*** shows below, the original configuration is shown on the lower-half of the split view. The modernized design appears in the upper-half view. The main design and latest technology features in this new design are:

- integral inner casing – reducing number of components
- partial-arc admission or full arc design are both available
- optimized blading
- improved blade path seals
- retractable HP and LP dummy seals
- monoblock, no-bore rotor

These features provide the following operational and maintenance benefits:

- improved start-up times
- simple installation
- capable of daily start and stop operation
- reduced alignment needs

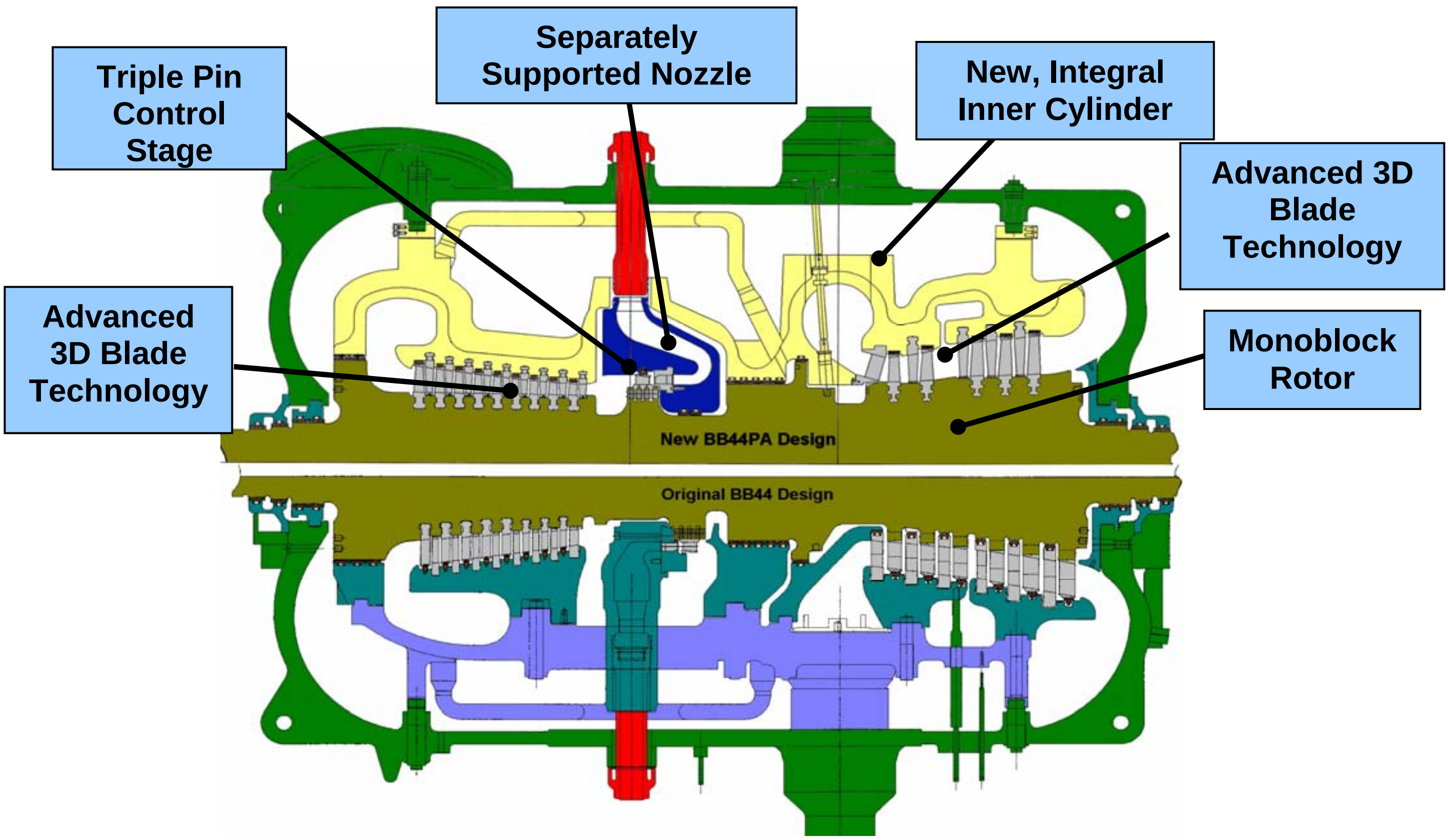


FIGURE 6 – BB44/044 PARTIAL ARC CROSS SECTION AND COMPARISON WITH ORIGINAL DESIGN (LOWER)

EXAMPLE – LP TURBINE REPLACEMENT (FOSSIL APPLICATION)

The low pressure turbine modernization option is another long-term solution that addresses reliability and maintenance problems of old components while providing the added benefit of significant electrical performance increase. On certain low pressure turbine elements, stress corrosion cracking (SCC) problems have been discovered in areas of the blade attachments or blade roots in the wet regions of the steam path. Additional reliability problems in the blades and tenons have been found that required repair or replacement.

Based on the remaining life time and other technical and economical factors, repairs like weld repair and blade replacement may be a sufficient solution for units that have an imminent retirement date. Once problems escalate and repair costs increase, then a modernization solution may be the most technically and economical option. The photograph below in ***figure 7*** shows a typical LP turbine installation where the new LP turbine blade ring components are assembled awaiting upper-half casing installation.

FIGURE 7 –LOW PRESSURE TURBINE REPLACEMENT FOR FOSSIL PLANTS

EXAMPLE- STEAM PATH REPLACEMENTS (HP and LP) AT A NUCLEAR POWER PLANT

A further example of a common modernization approach is the full steam path HP and LP turbine replacement that a number of nuclear plants have implement within the last 10 years. On the HP element, the standard approach is to replace the entire steam path – rotor and steam path and reuse the outer casing. An example of this concept is shown in ***figure 8*** below.

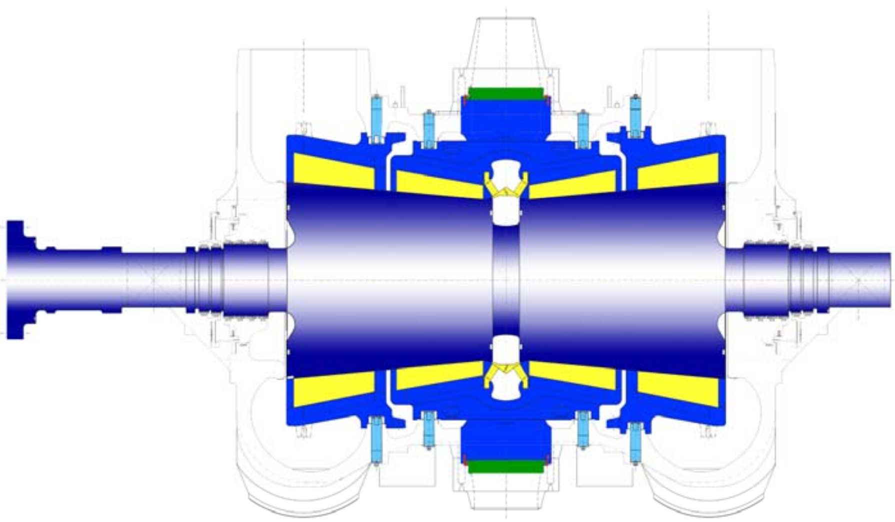


FIGURE 8 – NUCLEAR HIGH PRESSURE TURBINE REPLACEMENT

The nuclear HP turbine modernization is typically not reliability driven, but has been either due to a thermal uprating program requiring more flow passing capability in the HP turbine or part of a full steam path replacement project including LP turbines, or is due to the additional MW gained by replacing the HP module.

Many LP turbines at nuclear plants have been replaced due to stress corrosion cracking concerns, which has been found on all types of LP designs such as built-up disc, welded, and monoblock rotors. Siemens has provided its Advanced Disc Design LP rotors as a modernization replacement for all mentioned designs for OEM and non-OEM applications and this is the standard product offering for large nuclear LP rotor modernizations due to its trouble-free history regarding SCC.

The application uses a three disc per flow design and addresses the reliability issues of the old turbines, while providing between 3-5 % performance improvement from technology alone.

MAIN LP TURBINE DESIGN FEATURES FOR NUCLEAR APPLICATIONS

The major design features that were incorporated into this LP turbine design are summarized as follows:

- Disc-type-rotors (shrunk on disc rotors) with optimized number of discs (three per flow).
- Integrally shrouded stationary and rotating drum stages with advanced 3D blading. In addition, interstage sealing is accomplished through the "see-thru" or parallel seal strip arrangement.
- Free standing LP rotating section blades (3 stages per flow) with longer last stage blades providing an increased exhaust annulus area.
- Flame hardened leading edges of the LP freestanding rotating blades to mitigate moisture erosion.
- Forward leaning last stage stationary blades for improved last stage rotating stage flow distribution.
- Hollow vanes with moisture removal slots in the last stage stationary blade ring to reduce moisture erosion.
- High Chrome steel in erosion susceptible areas, e.g. high chrome steel blade carriers and blade ring components.

Features that contributed to the increased performance improvement are:

- Able to use longer back-end blading
- Improved design of the last stage blades
- Improvement of cylindrical drum blades and twisted 3-dimensionally shaped drum blades
- Flexibility to optimize number of blade stages
- Improved blade sealing
- Optimized turbine design for the current steam conditions or optimized for a future uprate

The main points of a HP and LP nuclear turbine modernization that contribute to the reliability and extended maintenance intervals are:

1. Entire steam path is replaced which minimizes/eliminates the need for repairs of aging equipment in the future and reduce the probability of a forced outage.
2. Major turbine components are ready for 40+ years service life that fits into license extension plans.
3. Design is for 100,000 equivalent operating hour (EOH) inspection intervals.

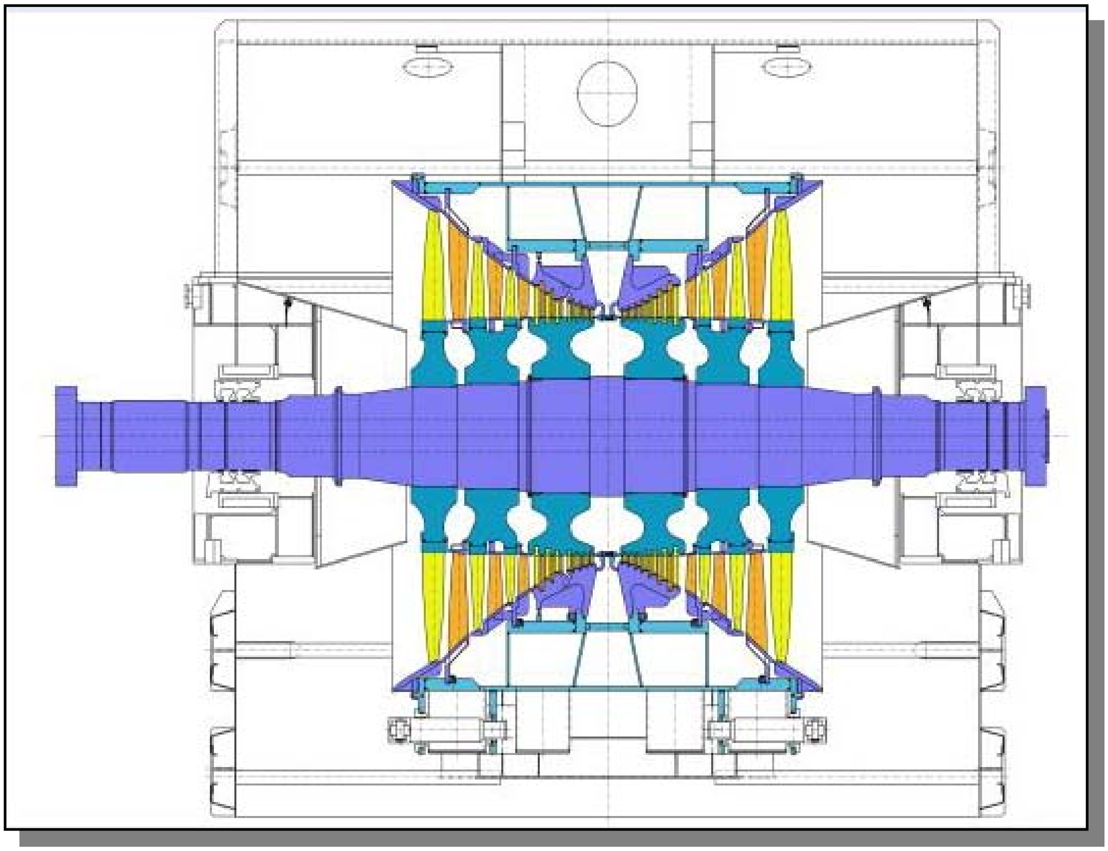


FIGURE 9 – TYPICAL ADVANCED DISC DESIGN LOW PRESSURE TURBINE MODERNIZATION CROSS SECTION

CONDENSER REPLACEMENT AND OPTIMIZATIONS

Another option that can be implemented to improve performance of steam turbines is a condenser optimization. This can be a stand-alone project or can be performed in conjunction with other turbine modernization options. This option entails first performing a conditional survey on the existing condenser to determine potential improvements. Modifications can range from reconfiguring the existing condenser tubes for better flow and reduced backpressure up to a new condenser replacement.

The benefits of the condenser optimization can include:

- Lower Back Pressure - Higher Power Output
- Increased Condensate Deaeration
- Lower Condensate Subcooling
- Possibility of higher output LP modernization

Additionally, new materials, such as titanium and stainless steel, are used on replacement tube bundles, which provides maintenance, reliability, and availability benefits such as:

- Reduced Condenser Tube Corrosion and Erosion
- Improved Cleanliness Factor
- Reduced Cooling Water in-leakages or “Tight Condenser“
- Minimized Stress Corrosion in Steam/Water Cycle

CONCLUSION

Modernization solutions are the application of the latest steam turbine technology to existing machines to maximize their efficiency, improve reliability, and reduce life cycle costs. The discussion of these solutions focused on the technology and application of these options, which can range from replacing seals with upgraded designs at a scheduled maintenance outage, up through major component replacement and the alternatives in between. All options provide a definite payback period that in most cases “pays for itself” in under 5-years. In many cases, these can be considered investments rather than expenses associated with traditional maintenance work.

The main characteristics and benefits of modernization projects are that they provide:

- Reduced Maintenance Costs
- Increased Capacity and Associated Revenues
- Improved Efficiency and Lower Fuel Consumption
- Improved Availability and Reliability
- Reduced Emissions

With the demand for electricity on the increase, plant operators are continually looking for ways to improve the efficiency and operation of their existing steam turbines. The modernization solutions discussed provide cost effective solutions while being environmentally friendly and reliable.