GER-3696D

GE Power Generation

Upgradable Opportunities for Steam Turbines

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INTRODUCTION

In today's challenging marketplace, existing power plants can remain competitive by increasing the efficiency and reliability of their steam turbines. This paper explains how GE can improve both efficiency and reliability of steam turbines by retrofitting advanced technology features. Efficiencies approaching those of modern units with state-of-the-art technology can be achieved by retrofitting features that incorporate today's latest technology and material improvements. Reliability has improved as a result of continual design improvements which also help the cycling capability of the turbine. These technological improvements are the result of GE's ongoing development programs and experience gained from having the largest fleet of utility turbines.

This paper begins with an introductory statement about the current state of the industry. The rest of the paper explains the efficiency and reliability improvements. The efficiency section discusses the technology features in detail and how they improve the two components of efficiency: initial heat rate and sustained efficiency. The reliability section considers the technological improvements in the last-stage bucket, shell and rotor designs.

CURRENT STATE OF THE INDUSTRY

The efficiency and reliability improvements by GE are opportune since the electrical power industry is undergoing revolutionary changes. These changes demand that power producers strive for lower operating costs and increased reliability to maintain their position in the industry. The continuing dependency of the industry on older units for generating capacity is illustrated in Figure 1. This chart shows the percent of generating capability older than 30 years over time. As illustrated, the dependence on these older units rapidly increases as we approach the year 2000. Unfortunately, as the dependence on older units increases, the two key ingredients of competitiveness – efficiency and reliability – continue to decrease. The decreasing efficiency and reliability for aging steam turbines are illustrated in Figures 2 and 3.

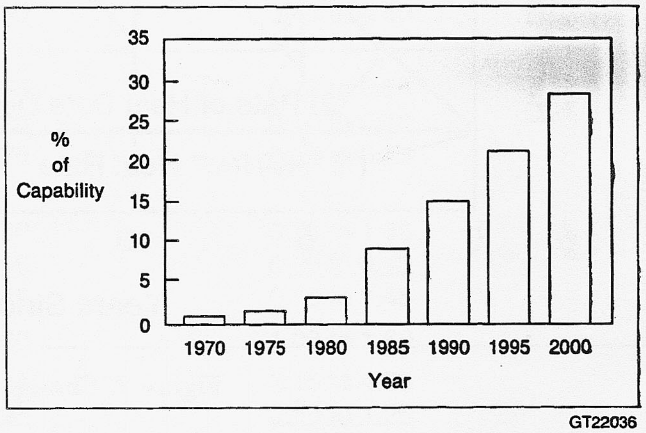

Figure 1. Utility dependence upon older units with ages greater than 30 years

A steam turbine can lose as much as 2% of the unit's efficiency per decade. Therefore, if a turbine is approaching 30 years of age, it's likely that 6% of the possible output is lost. The reliability also decreases with time, as shown in Figure 3. After 30 years, the forced outage rate increases significantly.

These trends for efficiency and reliability can be reversed through modifications to the existing turbine with modernized components. Figure 4 illustrates the efficiency gain possible with a variety of performance enhancement features. Thus, even though the industry data shows some troubling trends, relief is available from GE.

COMPONENTS OF EFFICIENCY IMPROVEMENT

Before discussing what GE can do to improve efficiency, it is necessary to understand the components of efficiency improvement. Figure 2 shows a typical unit's heat rate plotted over time.

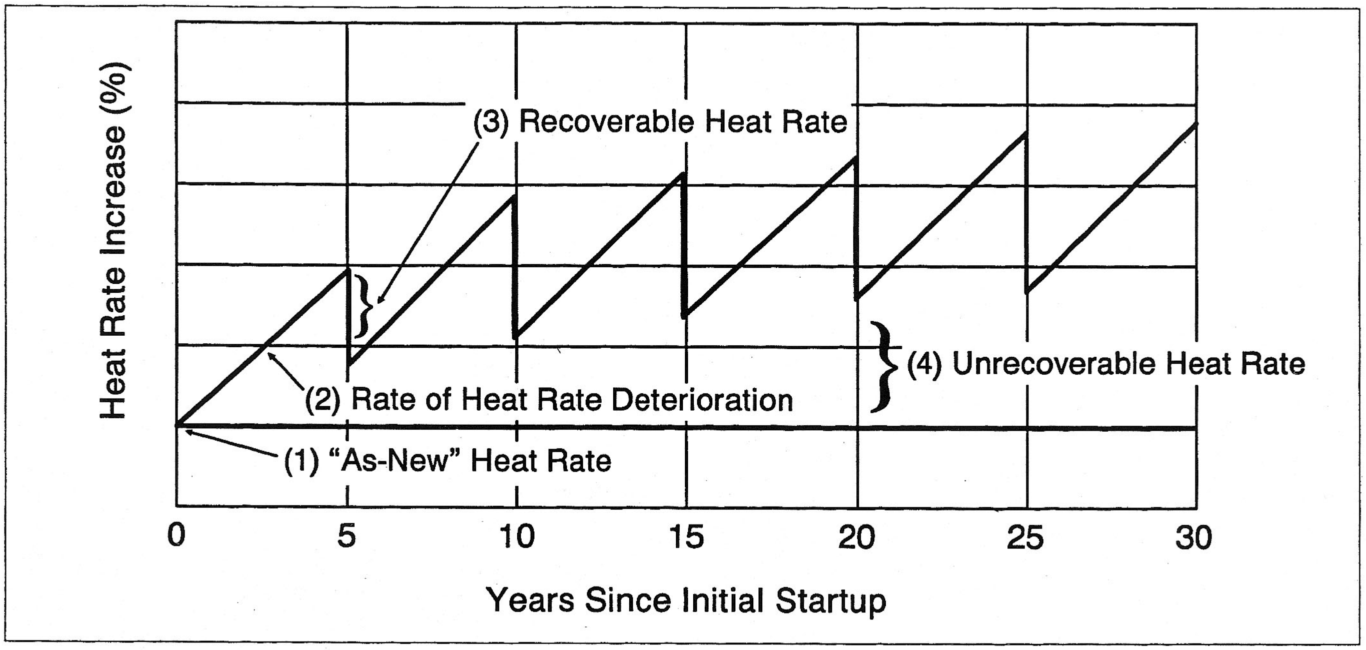

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Figure 2. Change in heat rate over time

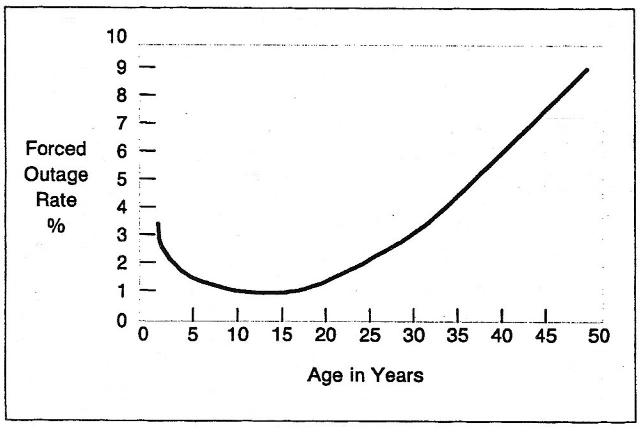

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Figure 3. Typical aging reliability trend

This particular graph assumes that the unit has a major outage every five years and the steam path components are not changed.

The "Recoverable Heat Rate" (3) is the portion of the turbine efficiency recovered during the outage. Such things as tightening clearances, replacing packing, realigning the unit and repairing damage will improve the unit's performance. Although performance improved after outage, it never returned to the "As-New" performance point (1). The "Unrecoverable Heat Rate" (4) is the difference between the "As-New" heat rate and the heat rate after the outage.

As shown in Figure 5, the advanced technology improves performance in two ways. The first is by lowering the "As-New" heat rate (6) to a point well below the unit's original heat rate by means of GE's technology developments. (The technology features that bring about this improvement will be discussed in detail in the next section.) Not only is recoverable and unrecoverable heat rate deterioration restored but, because the baseline heat rate is lower, performance will be even better than that of the original unit in new and clean condition.

The advanced technology also improves sustained efficiency by reducing the rate of efficiency deterioration. The technology features which bring about this improvement are discussed in an upcoming section – Technology Features to Improve Sustained Efficiency. This is shown in Figure 5 by the lower rate of heat rate deterioration for line 5 vs. line 2. Since the rate of deterioration is reduced, the performance delta between the original and new designs will increase with time.

ADVANCED TECHNOLOGY FEATURES TO IMPROVE HEAT RATE

The first component of the efficiency gain is the lowering of the initial heat rate due to steam turbine technology improvements. Figure 6 shows the attainable heat rate for new units over time which is a result of the continuous technol-

	Heat Rate Improvement - %	Output Increase - %
HP Section		
Advanced Design	0.40 to 0.60	0.70 to 1.00
Recovery of Aging	0.25 to 0.40	0.40 to 0.70
HP Section Total	0.65 to 1.00	1.10 to 1.70
IP Section		
Advanced Design	0.30 to 0.40	0.30 to 0.40
Recovery of Aging	0.10 to 0.20	0.10 to 0.20
IP Section Total	0.40 to 0.60	0.40 to 0.60
LP Section Without Last Stage		
Advanced Design	0.45 to 0.55	0.45 to 0.55
Recovery of Aging	0.10 to 0.20	0.10 to 0.20
LP Section Total	0.55 to 0.75	0.55 to 0.75
Last Stage		
Advanced Design	0.70 to 1.30	0.70 to 1.30
Recovery of Aging	0.05 to 0.15	0.05 to 0.15
Last Stage Total	0.75 to 1.45	0.75 to 1.45
Longer Last Stage Bucket	1.00 to 1.60	1.00 to 1.60
Total for Advanced Design	2.85 to 4.45	3.15 to 4.85
Total Recovery of Aging	0.50 to 0.95	0.65 to 1.25
Potential Improvement	3.35 to 5.40	3.80 to 6.10

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Figure 4. Efficiency gains

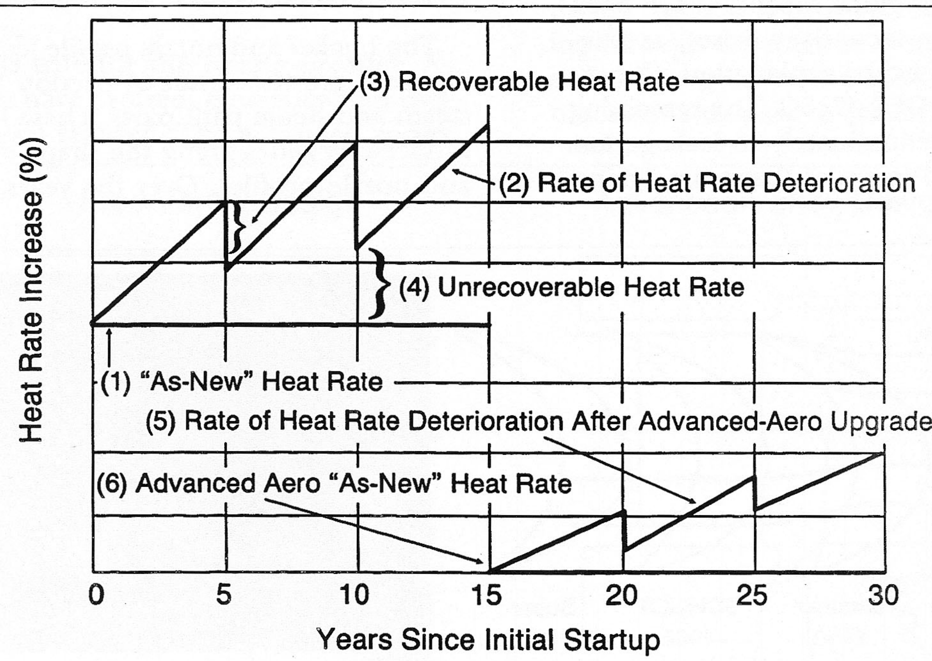

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Figure 5. Heat rate change after advanced aero upgrade

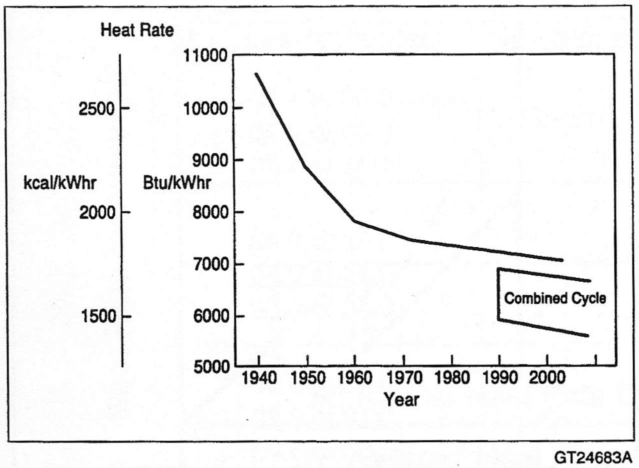

Figure 6. Heat rate improvement over time

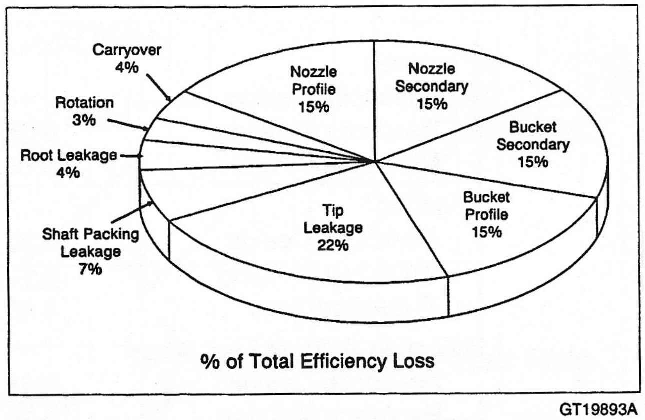

Figure 7. Typical turbine stage efficiency losses

ogy development in both balance of plant and turbine modifications. There are seven components which improve the initial heat rate of the turbine:

- Bucket and nozzle profiles
- HP/IP stage design
- Low-pressure stage design
- Last-stage bucket design
- Increasing the last-stage bucket length to reduce exhaust loss
- Contoured sidewalls
- Leakage loss

The components of loss addressed by the advanced technologies listed are shown in Figure 7. The largest gains recently have been the reduction of the secondary losses, as illustrated in Figure 8. Further explanation of these losses is provided in GER-3713C. The remaining losses are related predominately to leakage loss and profile (friction) losses of the steam against the steam path.

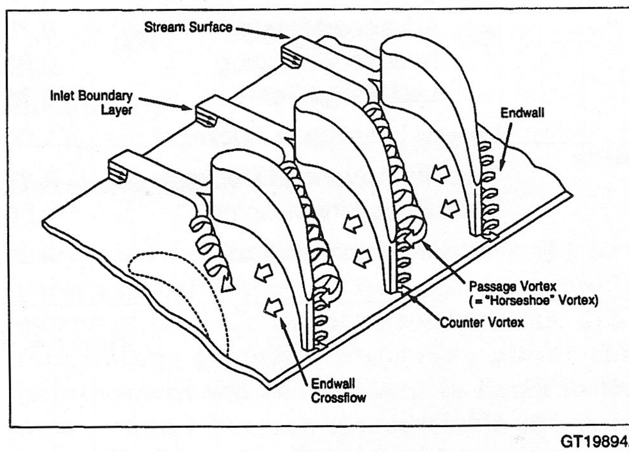

Figure 8. Secondary flows in turbine nozzle cascade

Bucket and Nozzle Profiles

The bucket and nozzle profile losses shown in Figure 7 are the result of friction between the steam and steam path parts. These losses can be reduced by redesigning the shape of the bucket and nozzle profiles. Over the years, bucket and

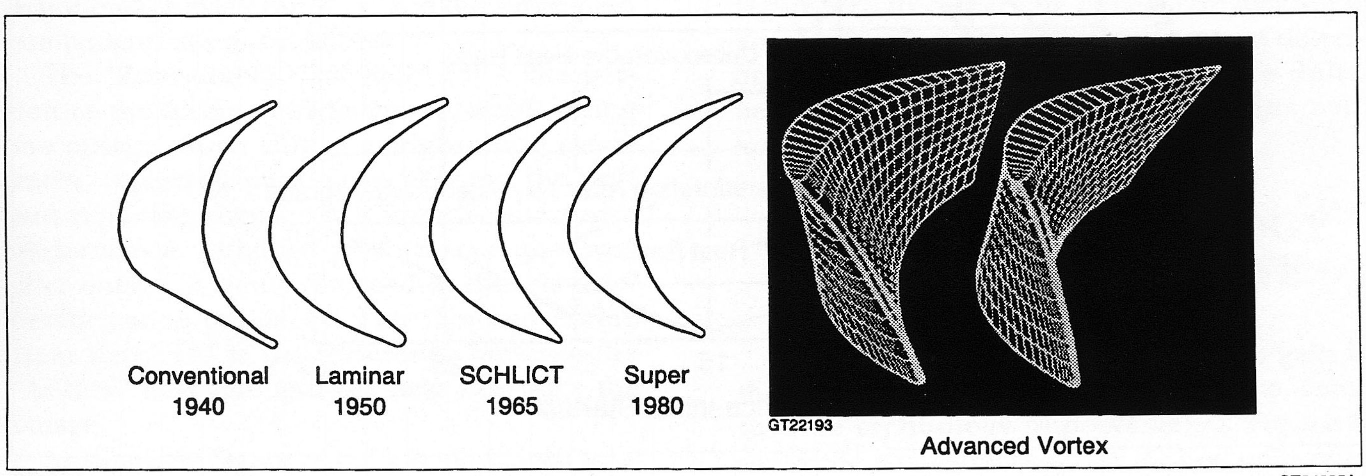

Figure 9. Bucket profiles enhancement

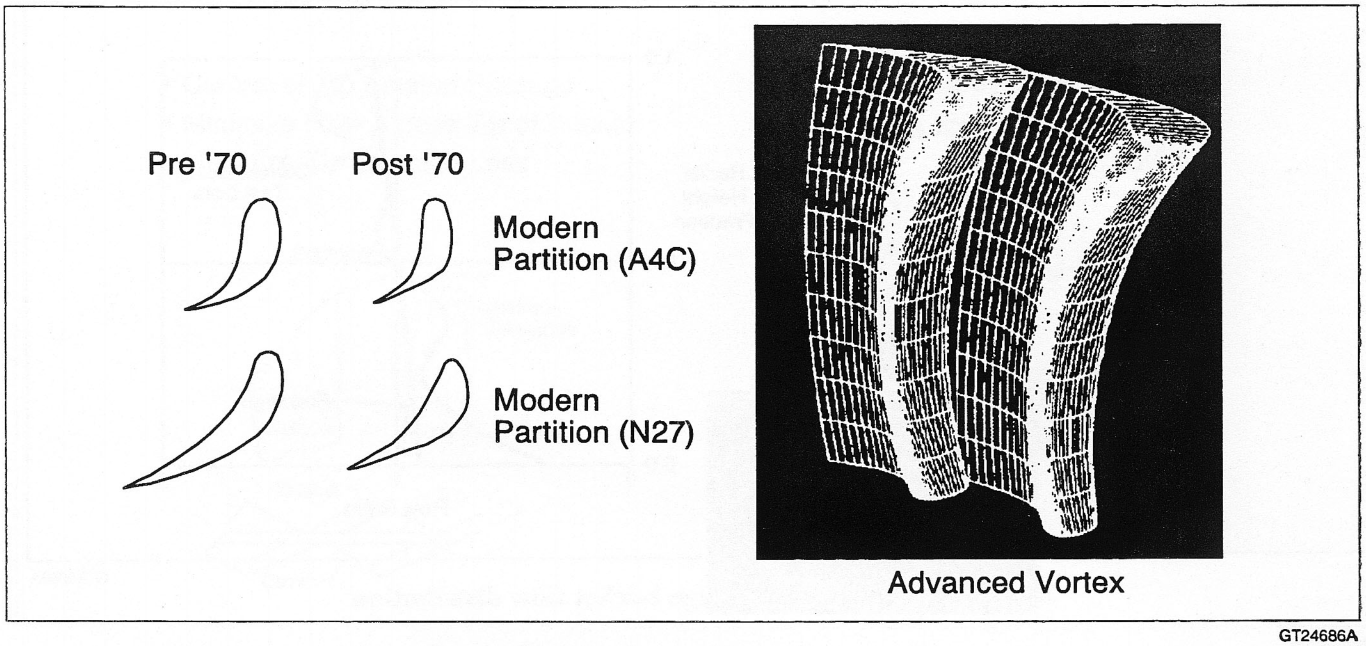

Figure 10. Nozzle profiles enhancement

nozzle profiles have been improved tremendously. Figure 9 illustrates how the profiles have evolved over time to the modern advanced vortex design. The improvement in bucket profiles has assisted in minimizing the magnitude of bucket profile loss. This may not seem very significant; however, the profile losses as shown in Figure 7 comprise roughly 15% of the total loss for a typical stage. Therefore, installation of the modern bucket profiles results in immediate efficiency gains.

The same is true for the nozzle profiles. As nozzle profiles have evolved, efficiency improvements have been realized. The advanced vortex nozzle design shown in Figure 10 is the current state-of-the-art design.

HP/IP Stage Design

Combining the advances in nozzle and bucket profiles into the stage design is a key component for improving efficiency. Figure 11 compares the modern and traditional stage design methods. The goal of the traditional free vortex stage design method is to keep the stream lines passing through the stage in as straight a line as possible. The goal of the modern vortex design method is to pass as much steam as possible

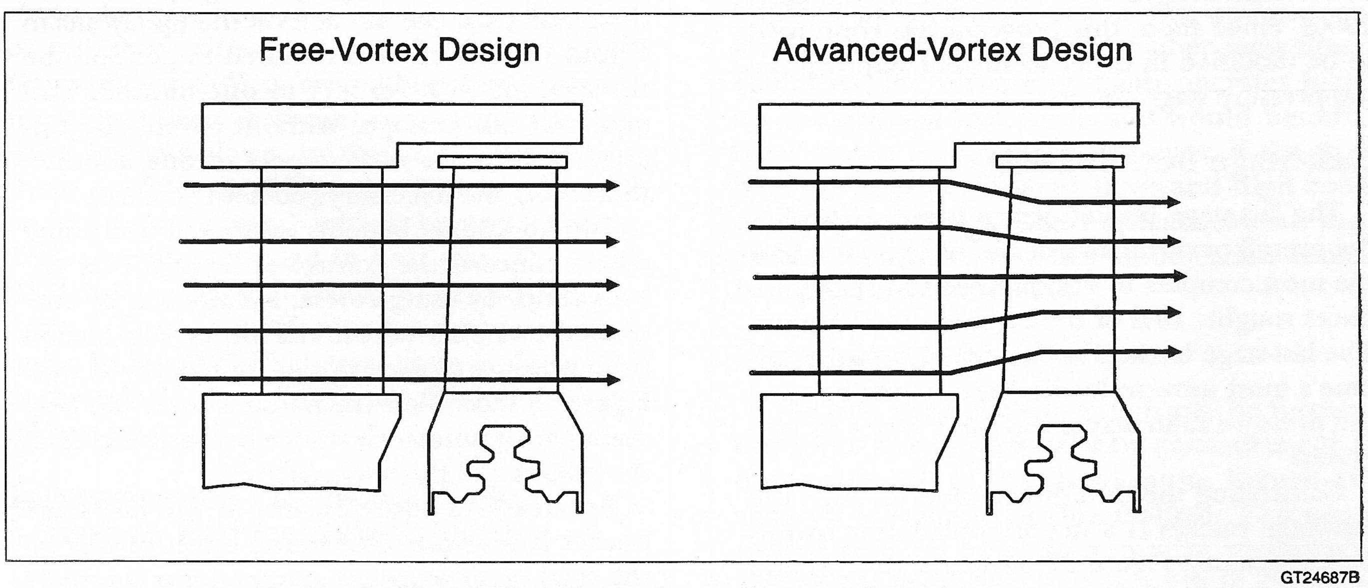

Figure 11. Advanced aero design philosophy

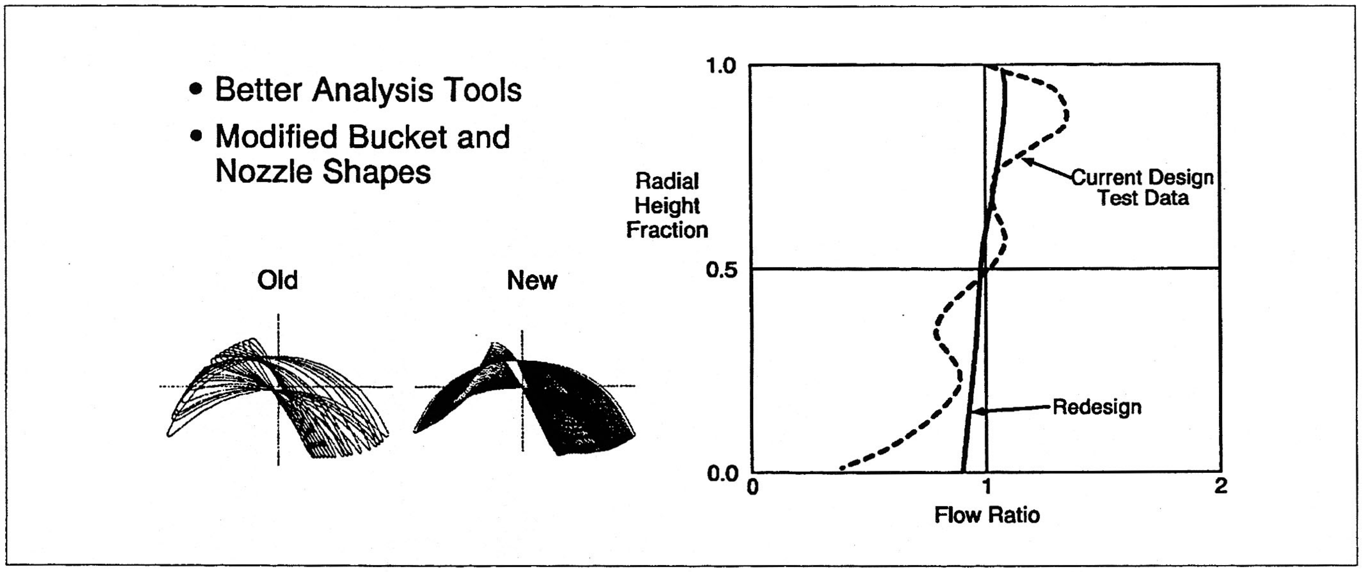

Figure 12. Improved last-stage bucket flow distribution

through the center portion of the bucket for more efficient transfer of energy. Through this modern design method, substantial improvement in the stage performance has been made for these shorter stages.

Low-Pressure Stage Design

Low-pressure stage design differs in two principal ways from the HP/IP stage design. First, in the low-pressure stage design, the radial flow component is very significant. This is evident by the rapid divergence of flow that occurs through these stages. The second major difference is the larger pressure ratio across the stage. The first analytical tools that could effectively deal with these stage designs were developed in the early 1960s. Since then, this program has continued to be modified in order to further improve the low-pressure stage designs.

Last-Stage Bucket Design

The last-stage bucket design is very critical to the overall performance of the turbine. It is also the most complex to design since this stage produces roughly 10% of the turbine's total output. The last-stage buckets are also subject to the turbine's most adverse loading conditions because the pressure ratio across this stage varies considerably.

Controlling the flow distribution through the last-stage bucket is a major contributor to turbine efficiency. Figure 12 compares the old and the redesigned flow distribution through the bucket. By redesigning the stage, the flow distribution has become much more uniform. This was accomplished using modern design tools that model the flow and optimize the nozzle and bucket stack-ups and orientations accordingly.

Covers are a second method of gaining performance from the last-stage bucket. There are three primary reasons why a cover helps to improve performance. The first is that the tip sections are not allowed to move with respect to one another. This is important because the steam velocities at the tips of the last-stage buckets are supersonic and, to efficiently convert the steam's energy, a converging diverging passage is needed. The converging diverging section of the steam path can be seen on the tip layouts in Figure 13. The cover is required to position the tip sections with respect to one another and maintain this passage. Without covers, the tips are free to move with respect to one another, thus losing the necessary geometric control.

Two additional benefits associated with using covers concern the control of leakage over the bucket tip. By using covers, leakage can be controlled not only across the tip of the bucket from pressure to suction side, but axially as well. Figure 13 shows how the fin on a cover can help maintain a minimal clearance between the tip of the bucket and the stationary wall.

Because the contribution of the last-stage bucket is so great, the overall effect of this on the total plant output is tremendous. Figure 14

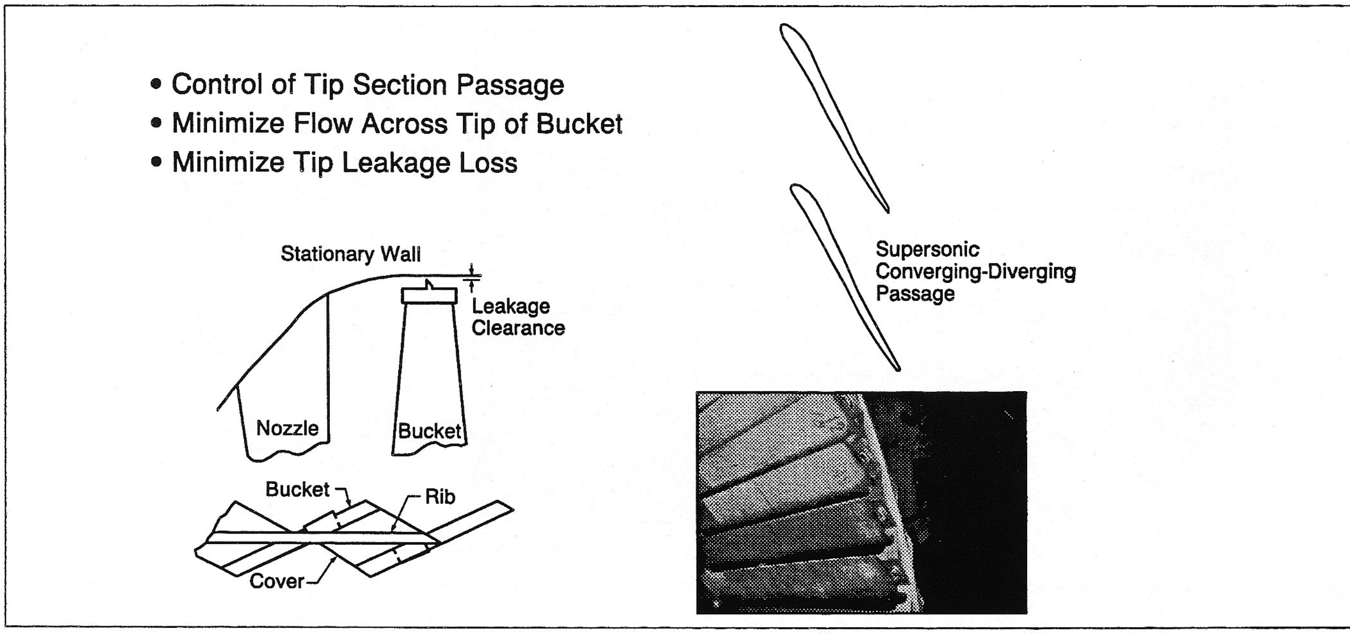

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Figure 13. Benefit of last-stage bucket covers

		Overall Performance Improvement	
RPM	Bucket	Bucket Only	Bucket & Diaphragm
3600	20" (508mm)	0.1 to 0.4%	0.25 to 1.0%
	23" (584mm)	0.25 to 0.75%	0.5 to 1.0%
	26" (660mm)	NA	1.0%
	30" (762mm)	0.6%	1.0%
3000	26" (660mm)	NA	1.0%
1800	43" (1092mm)	0.75%	1.0%

NA = Not Applicable

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Figure 14. Last-stage bucket design - performance gains

shows the total heat rate improvement associated with these different retrofit buckets by RPM. Gains of over 1.0% in overall heat rate improvement have been realized by replacing the last-stage buckets alone. In the 3600 RPM arena, there are 20-inch (508mm), 23-inch (584mm) and 26-inch (660mm) retrofit buckets offering 1.0% plus improvement in heat rate. The 3000 RPM has the 26-inch (660mm) retrofit bucket again offering a 1.0% plus heat rate improvement. In the 1800 RPM area, there is a new 43C bucket which offers 0.75% to 1.0% gain in overall heat rate.

Increasing the Last-Stage Bucket Length to Reduce Exhaust Loss

Exhaust loss reduction is another area where retrofits can offer rewards. Exhaust loss refers to the energy lost to the condenser as a result of the steam velocity going into the condenser. The faster the steam leaves the last-stage buckets, the greater the energy lost. Two key parameters in the equation are the condenser pressure and the mass flow of the steam. The only way to reduce the velocity of the steam is to increase the area it is flowing through.

This is achieved by increasing the last-stage bucket length. The typical last-stage bucket length changes are listed in Figure 15. Depending on where the turbine is operating on the exhaust loss curve, this may or may not improve performance. If the unit operates at low condenser pressures and higher mass flows (Point A), the turbine probably operates high on the exhaust loss curve and would benefit from such a modification. However, if the turbine operates at low mass flows and high condenser pressures, it might operate low on the exhaust loss curve and this modification could hurt performance (Point B).

Contoured Sidewalls

The first stage of each section can be further improved aerodynamically by contouring the outer sidewall of the diaphragm. Figure 16 shows a schematic of this feature. The contoured sidewall helps to minimize secondary and profile losses, resulting in a 1% to 2% gain in stage efficiency.

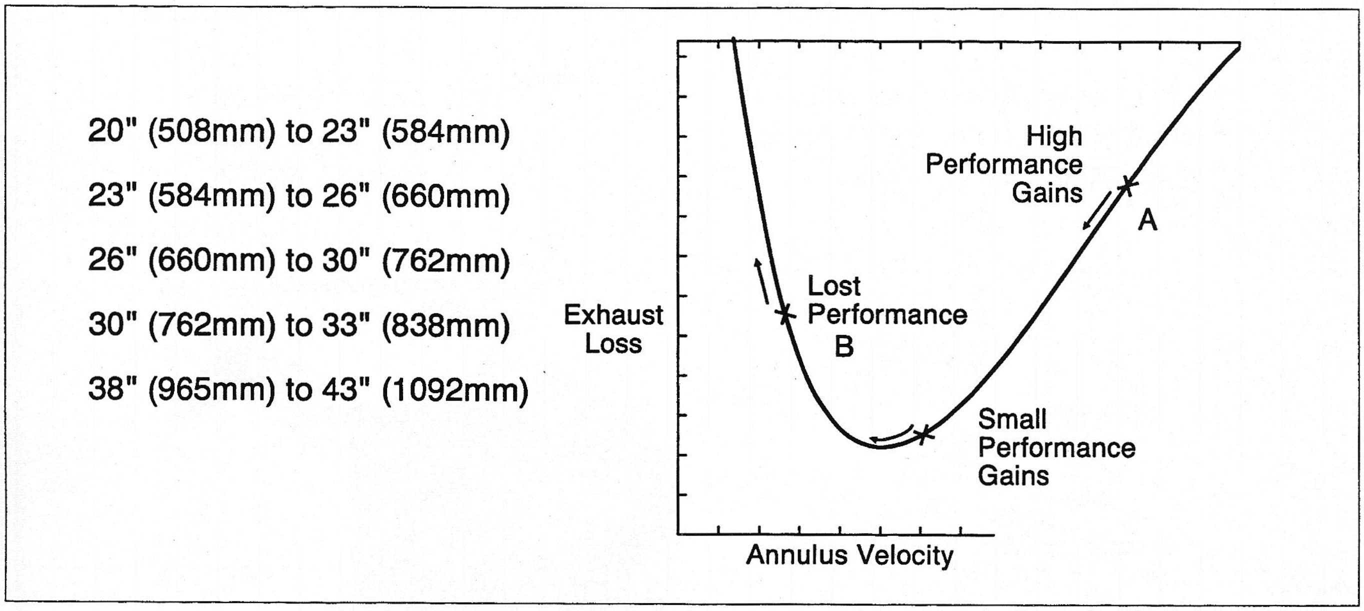

Figure 15. Reduction of exhaust loss from increased last-stage bucket length

A contoured sidewall can be used on the first HP, first IP and first LP stage of the turbine. On occasion, a contoured sidewall can also be used on the second HP stage. This concept has been routinely used on a variety of applications including mechanical drive turbines, fossil reheat turbines and nuclear low-pressure turbines.

Leakage Loss

As noted in Figure 7, leakage loss represents the greatest portion of the total stage loss. The designer's objective is to pass all of the steam through the buckets. However, there are both rotating and stationary components in the steam path; therefore, a perfect seal is not attainable. The leakage paths the steam typically follows are illustrated in Figure 17. Here, the steam can either leak between the rotor and the diaphragm packing, to bypass the nozzles, or around the bucket tip or root.

To reduce leakage, there are two further enhancements that are used in a rebuild. The first is to optimize the steam balance holes by sizing them to accommodate the flow leaking between the diaphragm packing and the rotor. With this modification, the flow intrusion into the steam path is eliminated. If the steam balance holes are oversized, steam will be drawn in from the bucket root. By optimizing the design, efficiency gains are realized.

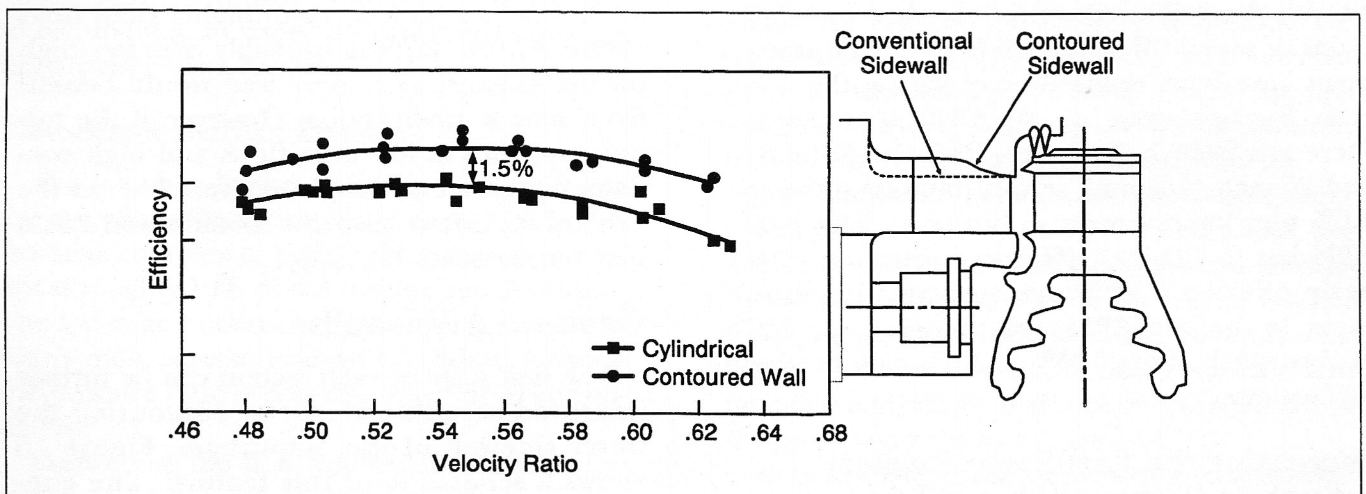

Figure 16. Contoured sidewall test

- Advanced Tip Sealing (Illustrated in Figure 18)
- Wheel Hole Optimization
- Multiple Tooth Spill Strips

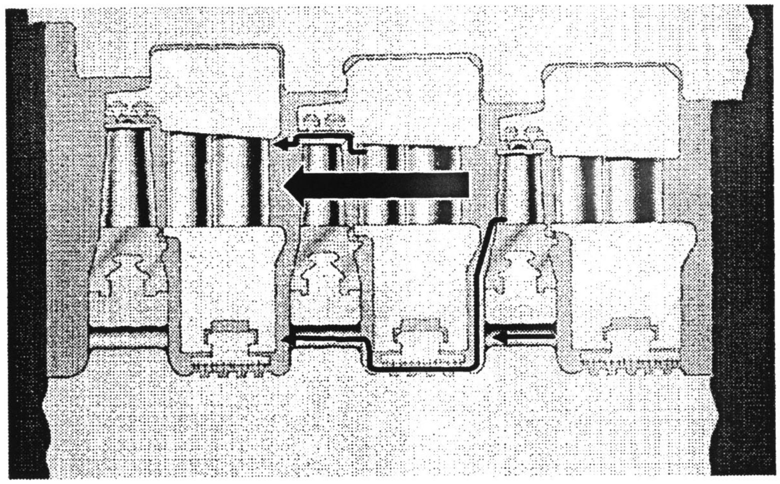

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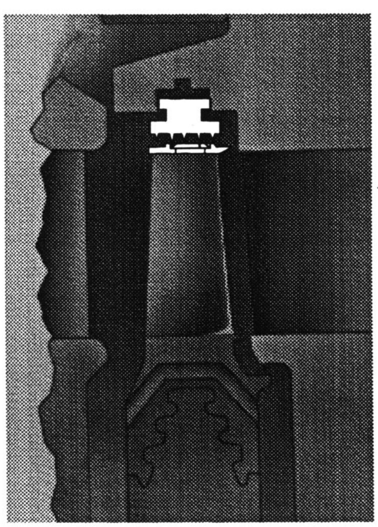
Figure 17. Leakage control mechanisms to improve performance

The second feature GE uses to reduce leakage loss is advance tip sealing over the buckets. Advanced tip sealing arrangements shown in Figure 18 minimize this loss. The two designs offered with the advanced section replacement are the fox-holed cover design and the integral cover bucket design. The design illustrated on the left side of the figure is the fox-holed cover design with a multiple tooth spill strip. The design on the right side is the integral cover bucket with a high low tooth configuration. Both of these designs can be obtained as retrofit options.

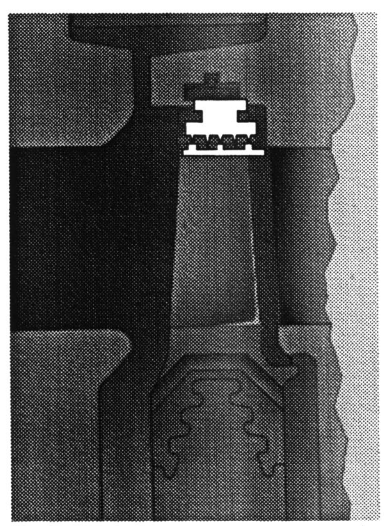
TECHNOLOGY FEATURES TO IMPROVE SUSTAINED EFFICIENCY

The second component of efficiency improvement is sustained efficiency. It was estimated earlier there is an approximate 2% decrease in efficiency every 10 years for a typical unit. This being the case, there is a clear need to pursue methods which sustain plant efficiency.

Figure 19 shows the typical breakdown of aging loss for a turbine stage. The sources of aging occur in the nozzle and bucket surface roughness, erosion and repair, steam path



Foxholed Cover



Integral Cover

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Figure 18. Advanced tip sealing

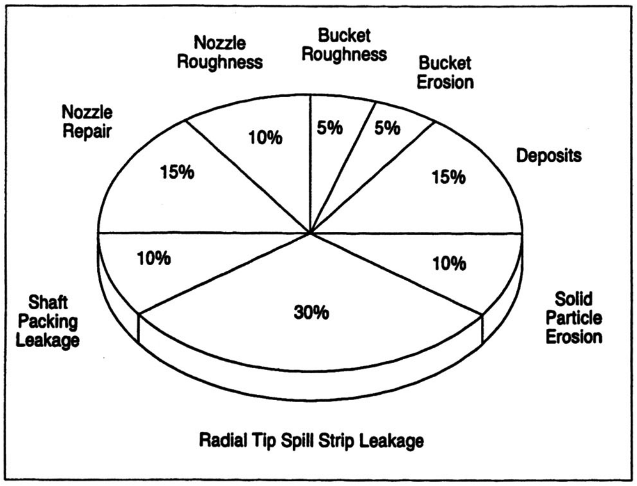

Figure 19. Typical causes of efficiency deterioration

deposits, and increased leakage flow. Technological advancements similar to those improving initial steam path efficiency have also been developed for improving sustained efficiency. These include:

- Solid particle erosion package
- Low solidity nozzles
- Improved tip leakage controls

Solid Particle Erosion Package for the Steam Path

Since solid particle erosion is a major contributor to aging loss, GE developed a solid particle erosion package to minimize adverse effects for those affected stages, typically the first HP stage and the first IP stage. Solid particle erosion

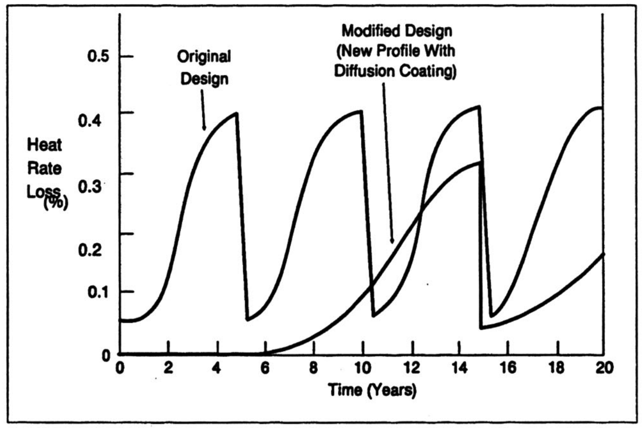

Figure 20. Control stage heat rate loss due to severe SPE damage

occurs when iron oxide particles exfoliating from the boiler tubes are transported to the turbine and erode the steam path. The damage is usually most severe on the first high-pressure stage and the first reheat stage.

Figure 20 shows a three-fold life increase for the first stage when the solid particle erosion package is applied. The design modification for the first-stage nozzles (nozzle boxes and nozzle plates) involves a new nozzle profile in which the partitions are slanted to minimize particle impacts that cause exit edge erosion (Figure 21). A diffusion coating is also applied to the nozzles, and the first-stage buckets are coated with Diamond Tuff™.

The erosion package for the first reheat stage effectively eliminates any further erosion of the reheat nozzle partitions, as shown in Figure 22.

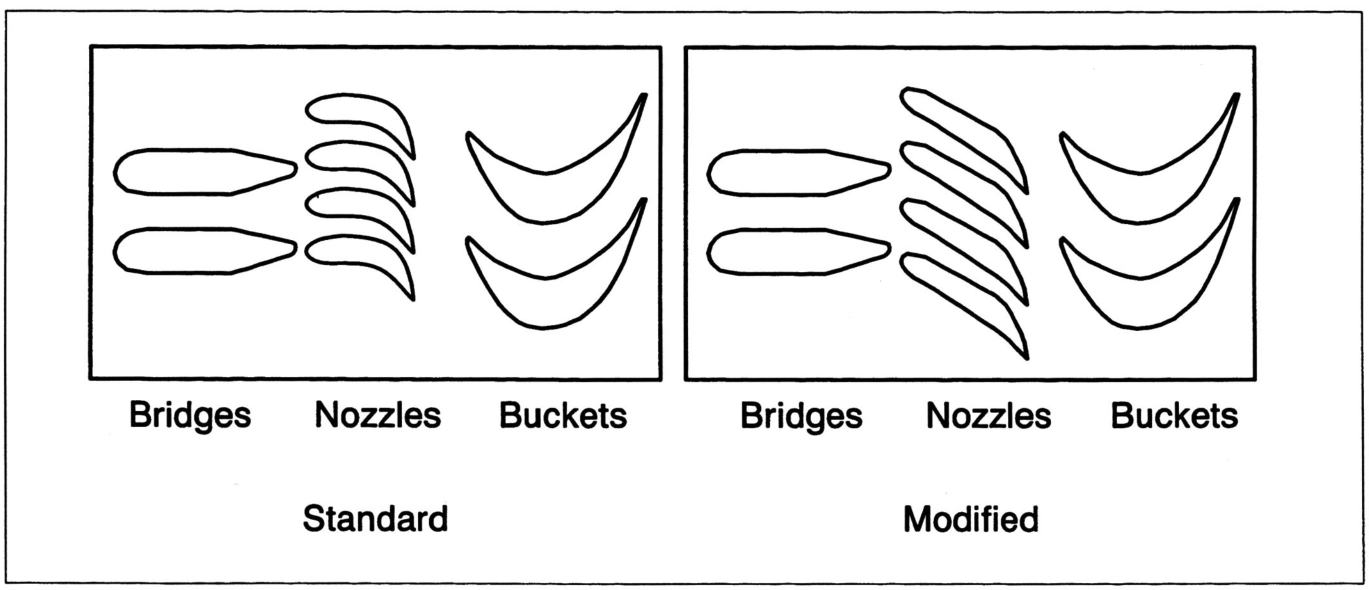

Figure 21. SPE for High-pressure turbine

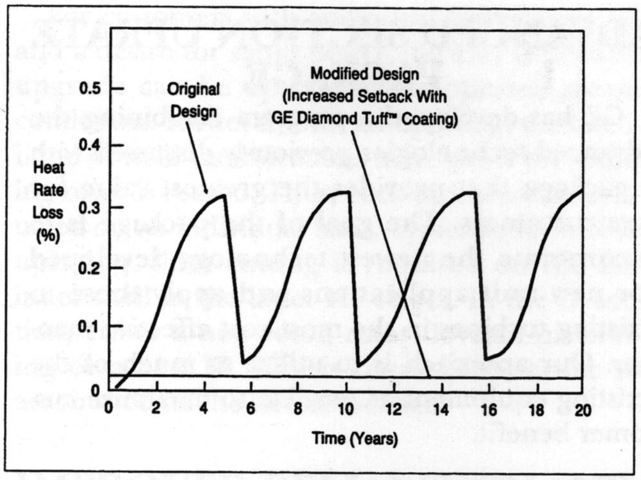

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Figure 22. First reheat stage heat rate loss due to severe SPE damage

A detailed particle trajectory analysis shows that the nozzles are eroded when particles rebound off the buckets and strike the exit end of the nozzles, as Figure 23 illustrates. The design modification increases the clearance between the nozzles and buckets which dramatically reduces the rebounding effect.

The time it takes to upgrade nozzle boxes has also been improved in order to be more responsive to industry needs. Now, a nozzle box can be upgraded with an erosion resistant steam path within a typical planned maintenance outage, thus minimizing shutdown losses for the plant.

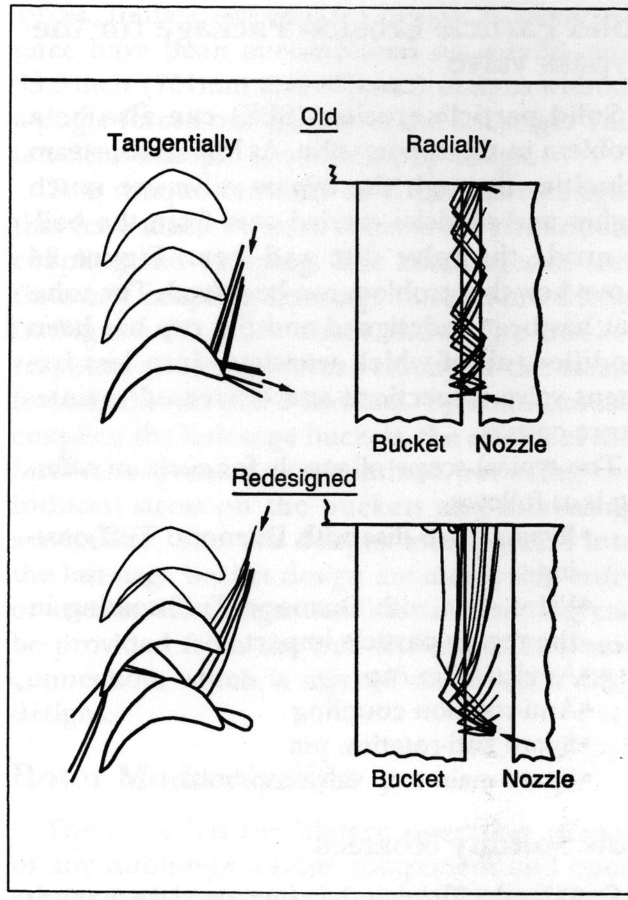

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Figure 23. Solid particle erosion reduction on first reheat stage
a) Original design
b) SPE-resistant design

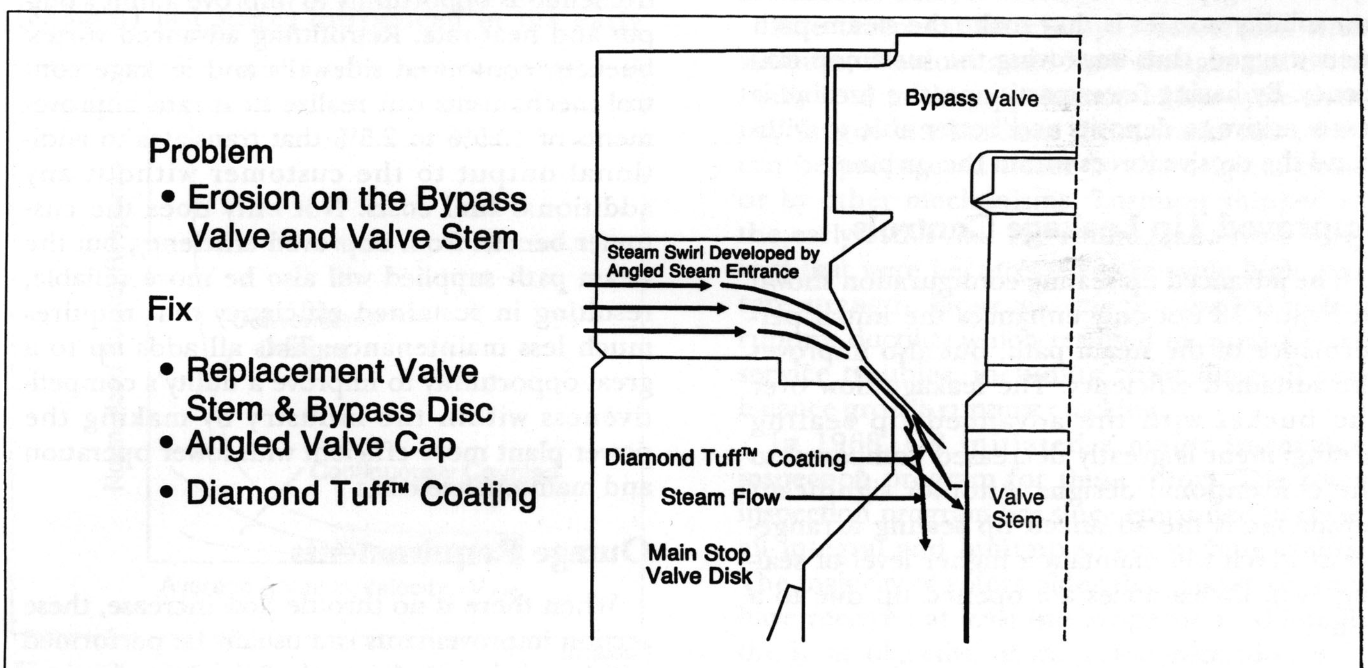

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Figure 24. SPE - Bypass valves

Solid Particle Erosion Package for the Bypass Valve

Solid particle erosion (SPE) can also be a problem in the bypass valve. At low loads, steam velocities through the bypass valve are much higher and particles carried over from the boiler erode the valve disc and stem. Figure 24 shows how this problem can be solved. The valve seat has been redesigned and the cap has been modified, all of which translates into less frequent valve inspections and decreased maintenance costs.

The typical scope of supply for such an offering is as follows:

- Bypass valve disc with Diamond Tuff coating
- Valve stem with Diamond Tuff coating in the region particle impact
- Angled valve cap
- Anti-rotation coupling
- Spare anti-rotation pin
- Spare main stop valve cap bolts

Low Solidity Nozzles

Sustained efficiency has improved as a result of using low solidity nozzles resulting in fewer nozzles per diaphragm. This feature is standard with the Advanced Section Uprate package and is included primarily to improve performance by reducing profile losses. A second benefit of low solidity nozzles is they make the steam path more rugged, thus improving the sustained efficiency. By having fewer partitions, the turbine is less sensitive to deposits and better able to withstand the erosive forces within the turbine.

Improved Tip Leakage Controls

The advanced tip sealing configuration shown in Figure 18 not only enhances the initial performance of the steam path, but also improves the sustained efficiency. The leakage flow over the bucket with the advanced tip sealing arrangement is greatly decreased compared to the conventional designs. Another significant advantage is the advanced tip sealing arrangement which will maintain a higher level of sealing even if clearances are opened up due to a rub.

ADVANCED SECTION UPRATE PACKAGE

GE has developed a program combining the advanced technologies previously discussed with a package that provides the greatest value for our customers. The goal of the package is to incorporate the newest technology developed for new unit applications and apply these to existing turbines in the most cost effective manner. Our approach is to utilize as much of the existing equipment as possible to maximize customer benefit.

Hardware Requirements

A complete steam path replacement is usually required to obtain maximum benefits for an HP/IP section upgrade. A typical two-casing unit with an opposed flow HP/IP section and a double flow LP section would require replacement of 12 stages of buckets and 11 stages of diaphragms, as well as a nozzle box refurbishment. The features included in the steam path replacement are contoured sidewalls on the first HP and first IP stage as well as advanced tip sealing over the buckets. The SPE package is incorporated in the first HP and IP stage.

Heat Rate Improvement

The new Advanced Section Uprates offer tremendous opportunity to improve a unit's output and heat rate. Retrofitting advanced vortex buckets, contoured sidewalls and leakage control mechanisms can realize heat rate improvements of 1.25% to 2.5% that translates to additional output to the customer without any additional fuel costs. Not only does the customer benefit from improved efficiency, but the steam path supplied will also be more reliable, resulting in sustained efficiency that requires much less maintenance. This all adds up to a great opportunity to improve a utility's competitiveness within the industry by making the power plant more efficient with lower operation and maintenance costs.

Outage Requirements

When there is no throttle flow increase, these section improvements can usually be performed with a minimum amount of field machining. The HP/IP rotor is reused and field assembly of the buckets is required.

For customers with additional boiler capacity and a desire for more power, the HP/IP section upgrade can be optimized for uprated steam conditions. However, with an uprating, the likelihood of field modifications increases if the existing rotor is reused. Thus, each unit must be evaluated on an individual basis. Typically, for a 10% uprating, skim cutting is required on the HP inner shell in the latter HP stages. In the IP section, either a new rotor, rotor dovetail machining or a new IP shell is required in order to accommodate the new IP buckets.

IMPROVED RELIABILITY AND CYCLING

Reliability and cycling are the second part of the equation in making power plants more competitive. Three key aspects to this improvement are:

- Last-stage bucket reliability
- Design improvements in the rotors and shells
- Other improvements.

Last-Stage Bucket Reliability

Beginning with last-stage bucket reliability, GE's last-stage buckets have a long history and proven track record for reliability. This first started with the very successful experience of the modern 30-inch (761mm) and 33.5-inch (853mm) last stages introduced in the early 1970s. To date, over 4,000 wheel-years of experience have been accumulated on the 30- and 33.5-inch (761mm and 853mm) designs without a single forced outage due to the last stage. This is a clear example of reliability by design.

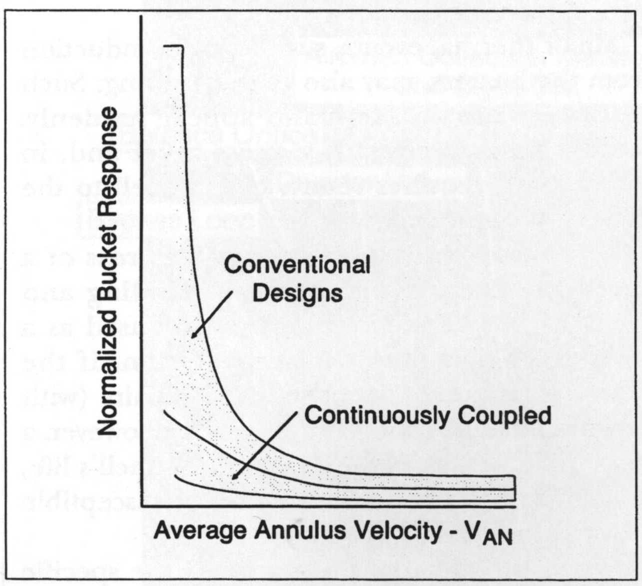

Figure 25. Continuously coupled vs. conventional last-stage bucket design

Two unique features of GE bucket designs that have made them so reliable are continuous coupling and damping. The advantages of continuously coupling last-stage buckets are shown in Figure 25. This chart shows the bucket response vs. the annulus velocity of the steam leaving the last-stage buckets. By continuously coupling the last-stage buckets, the effects of this bucket response are minimized, reducing the induced stress on the buckets and increasing service life. The two designs incorporated into the last-stage bucket design are either side entry or over-under design. Additional damping can be provided from the nub-and-sleeve mid-vane connection, which is offered on many of GE's designs.

Rotor Modernization

The rotor has the highest operating stresses of any turbine-generator component and operates in the harshest environment. HP and IP turbine rotors are required to operate at sustained high temperature, which can eventually lead to creep rupture cracks in localized stress areas, such as the dovetails or wheel packing fillets, or at the rotor bore.

The temperature changes associated with start-ups, shutdowns and load changes can eventually lead to the appearance of low-cycle thermal fatigue cracks. Once these cracks start, they can be propagated either by the original cause or by other mechanisms. Turbines shipped in the early 1950s had HP rotors made from forgings that were heat-treated to provide high rupture strength. However, this process led to low rupture ductility which resulted in a number of service troubles, including rotor dovetail and balance groove rupture cracking.

In 1968, GE initiated a major in-service inspection program for these rotors. The rotor inspection program has since expanded to cover all integral and built-up steam turbine rotors. The majority of rotors older than about 10 years have received at least one inspection. Although the basic objective of the rotor inspection is to reduce the likelihood of rotor bursts, it is also an opportunity for an economical rotor.

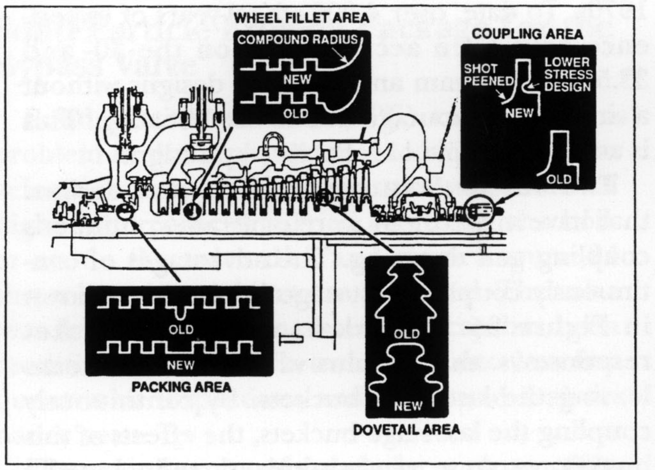

Figure 26. Rotor design improvements

Over the past two decades, improvements in metallurgy and design have produced rotors that have improved resistance to the effects of a harsh operating environment. These improvements are used for replacement rotors as well as on new applications. Some of the features included on a new replacement rotor have been designed and manufactured with today's newest technology. The following are examples of these features:

- Current alloys using modern, proven forging and heat treating practice
- Modern material acceptance procedures and criteria, including ultrasonic examinations
- High-speed balance and factory 20% overspeed test
- Modern dovetail geometries to reduce wheel and bucket dovetail stress concentrations (Figure 26)
- Stress tolerant shaft geometry, e.g., wheel fillets and steps, based on current design practices within the constraints of the existing stationary parts; no heat grooves (Figure 26)
- Integral thrust runner, if a water-sealed rotor with a shrunk on runner is replaced with a new rotor along with a steam seal conversion

Shell Modernization

High pressure and reheat shells operate in environments similar to high-temperature rotors and, therefore, are subject to similar types of long-term wear. After many years of successful operation, the material life of the shell may be consumed and cracks may begin to appear.

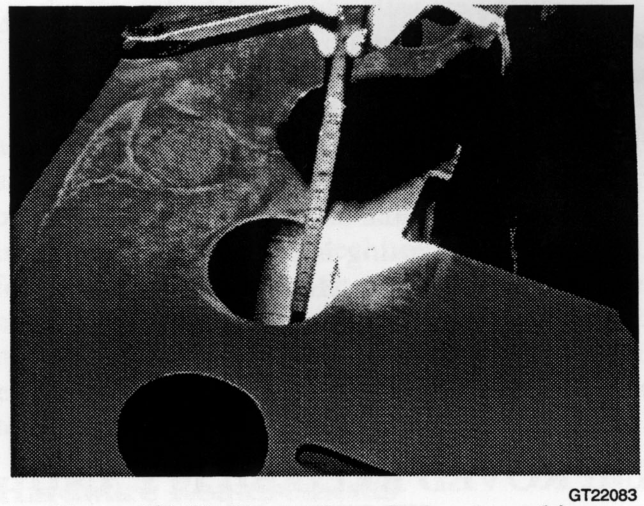

Figure 27. Shell transient thermal cracking

The most common cause of shell cracking is low-cycle thermal fatigue. This is caused by the temperature changes associated with start-ups, shutdowns and load changes, and most frequently appears in shell geometry transition areas. For example, cracks may appear in the relatively thin "bridge" between the bolt holes and nozzle ports of a shell (Figure 27). This occurs because the bridge heats and cools faster than the more massive parts of the shell to which it is attached, causing thermal strain. Fatigue cracks can also initiate in the more massive parts of shells, such as the flanges, also because of large temperature gradients. For instance, cycling duty, with its inherent temperature changes, can accelerate the initiation of thermal stress cracking.

Major thermal events, such as water induction from the heaters, may also cause cracking. Such cracks are usually large and appear suddenly. Repair generally entails a stress relief and, in many cases, requires return of the shell to the factory or service shop.

Very minor cracking in accessible areas of a shell can often be removed by grinding and blending, or "stopper" holes can be used as a temporary means to stop progression. If the cracking becomes extensive, weld repairs (with or without stress relief) can be made. However, a stress-relief repair will not restore the shell's life, and other areas will continue to be susceptible to aging and possibly cracking.

When the material properties of the specific shell are suspected to have changed to the point where continued reliable service cannot be anticipated without frequent outages, shell

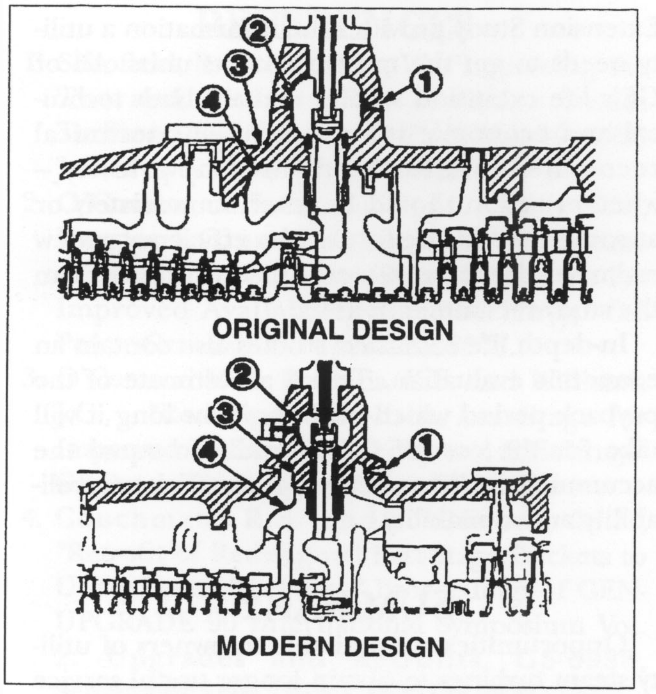

Figure 28. Modern replacement shell design improvements

replacement is indicated. Generally relatively old shells exhibiting substantial thermal fatigue damage and a tendency to crack are candidates for replacement. The basis for the decision to replace shells include: economic considerations taking into account the remaining expected service life; the cost of repairs; and the impact of potential unavailability of replacement shells.

Much has occurred in shell design since older units were put into service. When a shell requires replacement, the following modern features are incorporated (Figure 28):

- A design to optimize shell sections, transitions, etc., thus significantly reducing the impact of thermalcycling
- Castings with increased tapers in all sections and larger radii leading to higher quality material
- Modern materials with increased ductility, toughness and lower fracture appearance transition temperature, offering high resistance to brittle fractures
- Large-as-practical radii reducing stress concentrations, and larger ligaments between bolt holes and the inner and outer shell surfaces
- Separate packing heads to decrease the metal mass at the packing bore, reducing thermal gradients and providing better joint sealing and less steam leakage
- Relocating welds to more tolerant locations on shells with integral valve chests and using thermal stress tolerant geometries
- Where applicable, free expanding nozzle-chest designs

Other Improvements

Other features that can save the utility money through reduced maintenance costs, fewer on-line problems causing unplanned outages and

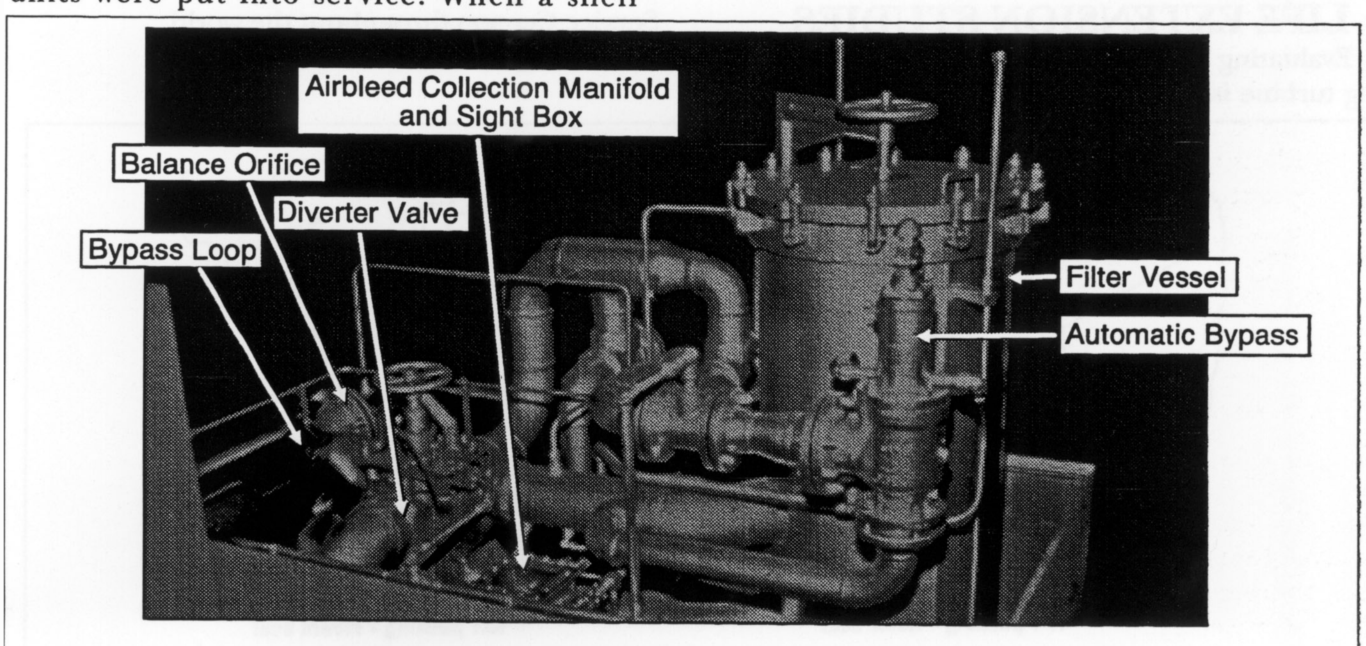

Figure 29. Full-flow filter available for retrofit

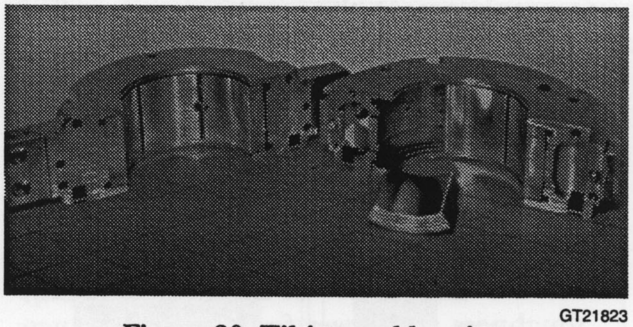

Figure 30. Tilting-pad bearing

greater availability include:

- Full-flow lube oil filtration systems to reduce start-up flushing time and in-service bearing damage (Figure 29)
- Mark V SPEEDTRONIC™ control
  - — Simplex-single channel
  - — TMR-Triple Module Redundant
- Tilting pad bearings to provide tolerance to misalignment during start-up or rapid load changes (Figure 30)
- Temperature-controlled water sprays in the exhaust hood
- Sequential tripping
- Conversion to steam seal systems on older units allowing sealing on turning gear, reduced maintenance and simpler operation (Figure 31)
- Reroundable packings to correct clearances on distorted diaphragms

LIFE EXTENSION STUDIES

Evaluating the best way to revitalize an existing turbine is a very complex process. A GE Life Extension Study provides the information a utility needs to get the most out of its units. All of GE's life extension studies contain both technical and economic information. The technical recommendations are divided by priority -- whether action should be taken immediately or at some time in the future. An efficiency review estimates the improvements that will result from the study recommendations.

In-depth life extension studies also contain an economic evaluation. This is an estimate of the payback period which evaluates how long it will take for the cost of the upgrade to equal the accumulated savings from higher efficiency, reliability and availability.

SUMMARY

Opportunities are available to owners of utility steam turbines to obtain longer useful service lives and lower operating costs. These can be accomplished by upgrading their machines with retrofit features that are based on the technology and material improvements that have occurred over the past two to three decades. The features are the result of the ongoing engineering programs at GE which not only have improved the new unit offerings, but also have been designed to support the fleet of over 1,400 GE utility steam turbines in active service. These improvements are implemented via the GE factory and its many Power Generation Service Centers throughout the world.

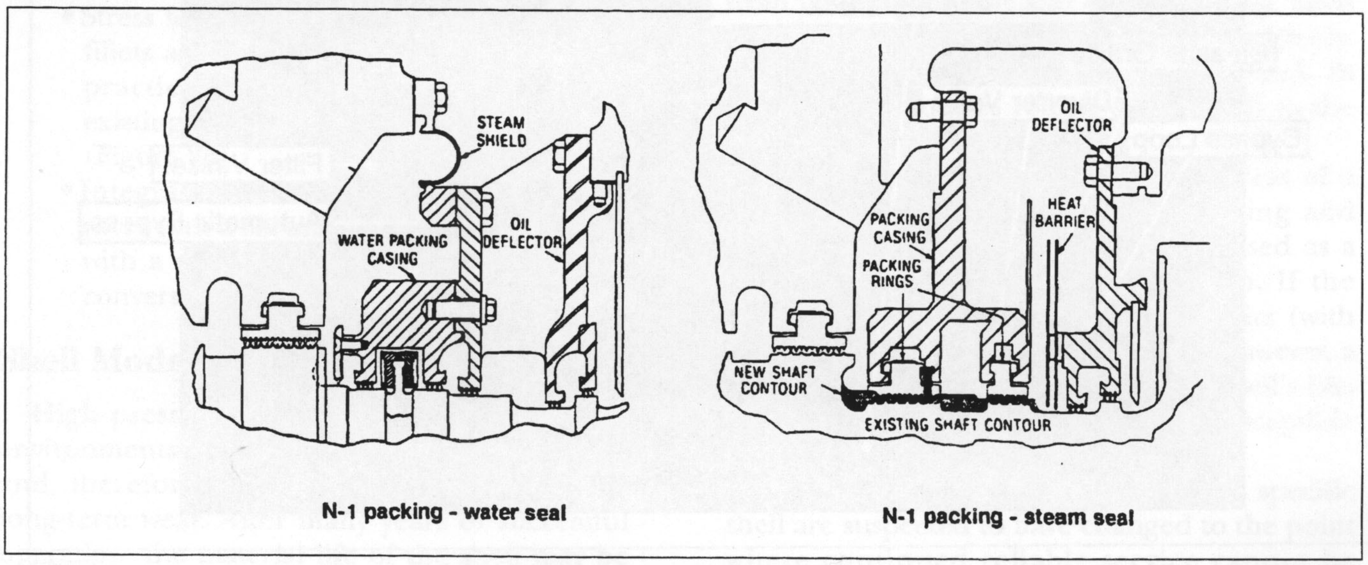

Figure 31. Water seal to steam seal conversion

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LIST OF FIGURES

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