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Gas Turbine Performance Improvement by Retrofit of Advanced Technology

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ABSTRACT

Development and operation of larger size gas turbines have demonstrated that higher turbine inlet temperature can be sustained due to advancement in material and cooling technology. After a feasibility study it was determined that modern available technology can be applied to existing previous generation of machines. These programs are identified as "The Performance Upgrade of Gas Turbine". Amongst the significant benefits that can be realized by retrofitting state of art parts in existing machines are higher power and more durable parts. This paper discusses various programs that are currently affered and implementation technique of upgrading the machines. A recent example is also presented. These unique programs are particularly attractive at the time of overall life consumption of the initial set of hot parts. At that point in an operating gas turbine it will be beneficial to retrofit the latest configuration parts to realize the performance improvements.

INTRODUCTION

Since the initial development of gas turbine technology and the use of smaller machines, User needs have continued to grow for larger and more dependable machines. Westinghouse Electric Corporation has been responding to these needs for the last three decades. With the evolution of larger size machines we were able to develop upgrades by applying evolutionary advances in technology to earlier production engines. The modifications necessary for the unit upgrade are dependent upon the type and frame of machine which is being considered for performance upgrade. In Table 1 we have briefly included a summary of major modifications.

In order to further appreciate "The Performance Upgrade of Gas Turbines" a series of evolution of the particular frame of gas turbines should be reviewed. The W501D gas turbine, for example, has been developed by a planned growth program of going through the various stages of W301, W501A, AA and B configurations. These step changes were ochieved due to advances realized in turbine cooling technology and application of better materials. Cooling was added to row 2 turbine blades in W501D along with increased cooling in upstream stages and material changes as required for higher turbine inlet temperature. With successful operation of W501D machines (have demonstrated annual availability over 90%) it became evident that higher power generation is possible with four stages of turbines. The conceptual engineering work to review the feasibility of a hybrid machine with W501B compressor and W501D turbine end was started with thought of retrofitting the existing W501B machines. This engineering study resulted in offerings of W501B5A and W501B6 programs.

Advantages of the Performance Improvement Program

In addition to the obvious advantage of achieving increased power output and reduced heat rate as shown in Table 1 for various Westinghouse gas turbine models, there are many other potential advantages achievable by the User depending on his specific model and situation. These are tabulated below;

1. Many of the parts used for performance improvements will enhance durability of the turbine due to the use of the latest state-of-art material for stationary and rotating stages.

2. During the performance improvement program implementation of other product improvements can be accomplished at a reduced cost since the unit is already open.

3. The performance improvement programs use the latest design components which for some models will improve unit maintainability. A prime example of this type of turbine component is the row 1 single vane segments. Its advantages are discussed later in this paper.

4. In evaluation of $/KW increment in performance investment User should consider the following:

   a. Additional training is not required for operators and the maintenance staff.

Table 1 Combustion Turbine Upgrade Program

ITEM	UPGRADE	IMPROVEMENT IN POWER	REDUCTION IN HEAT RATE	MAJOR MODIFICATION
1	PACE W501B COMBINED CYCLE*	4.5%	3.4%	R-1, R-2 TURBINE BLADES R-2 TURBINE DISC R-1, R-2 STATIONARY STAGES
2	W501B SIMPLE CYCLE	7.0%	0%	R-1, R-2 TURBINE BLADES R-2 TURBINE DISC R-1, R-2 STATIONARY STAGES
3	W501D	3.6%	0%	TURBINE 4TH STAGE TORQUE TUBE SEAL HOUSING
4	W251B	6.7%	2.2%	R-1 STATIONARY STAGE (TURB.) COMBUSTION SYSTEM
5	W171 TO W191	21%	1.8%	R-1 COMP. DIAPH. AND BLADES 3 ROWS OF CAST VANES
6	W81 TO W101	19%	5.4% -	TORQUE TUBE COVER TURBINE DIAPHRAGMS COOLING MODIFICATION
7	W52 TO W62	18%	2.4%	COMPRESSOR AND TURBINE BLADES COMPRESSOR AND TURBINE DIAPH.
8	W31 TO W41	24%	6.1%	TURBINE CYLINDER TORQUE TUBE COVER TURBINE BLADES, DIAPHRAGMS

*THE COMBINED CYCLE POWER AND HEAT RATE ARE EXPRESSED AS A PERCENTAGE OF PLANT POWER AND HEAT RATE. THE PLANT CONSISTS OF TWO GAS TURBINES AND A STEAM TURBINE.

b. There is no addition in existing supporting system for higher MW generation.

c. There is no addition in spare parts requirements, tools and manpower requirements.

d. The most advanced materials used for the turbine components provide a potential for extending the inspection intervals.

e. The land cost for additional power generation is eliminated because the unit is operational.

DEVELOPMENT OF UPGRADES

Higher performance of existing machines is obtained by increasing the turbine inlet temperature and changing the turbine parts, where necessary, to sustain the new temperature. Table No. 1 provides a summary of available performance improvement in ISO conditions for different sizes of Westinghouse combustion turbines. The major modifications range from turbine disc replacement to provide air for cooled blades to simple changes in the combustion system.

Higher turbine inlet temperature increases the exhaust temperature of the turbine, which is particularly beneficial for a combined cycle mode of operation as the afterburner firing (supplementary firing) can be reduced for the same boiler inlet temperature and mass flow. The reduced rate of afterburner firing economizes on fuel and results in a lower heat rate for the complete plant. This possible reduction in heat rate is indicated for the combined cycle stations in Table 1, Item 1. The specific values of power and heat rate can be quoted based upon the station elevation and average prevailing ambient temperature.

The program for performance improvement may have to be tailored to suit the operating conditions of users such as type of fuel, environment and the left-over service life of the parts. Although there may be variations in these programs, due to the operating condition of the machine, it is important to review the latest technology available for its application in upgrade programs.

Row 1 and Row 2 Turbine Blades

New sets of R-1 and R-2 cooled turbine blades of U-720 material are used for W501 upgrade programs to provide dependable operation at higher firing temperatures. These turbine blades can be coated to mitigate the corrosive effects of fuelborne and/or airborne contaminants. Udimet 720 combines stress rupture strength of Udimet 700, the hot corrosive resistance of Udimet 710 and the forgeability of Udimet 520. The impact resistance of U720 is approximately seven times of Udimet 710. Further, the excellent microstructure stability and limited high temperature impact degradation during prolonged high temperature exposure made U-720 a very desirable material for the latest frame of turbines.

Row 1 Single Vane Segments

For W501B6 upgrade program single vanes are incorporated in the first stationary stage of turbine. The single vane concept has been patterned after our latest W501D stationary row 1 stage design for retrofitting to replace three vane segments currently in service on W501B1-B5 units.

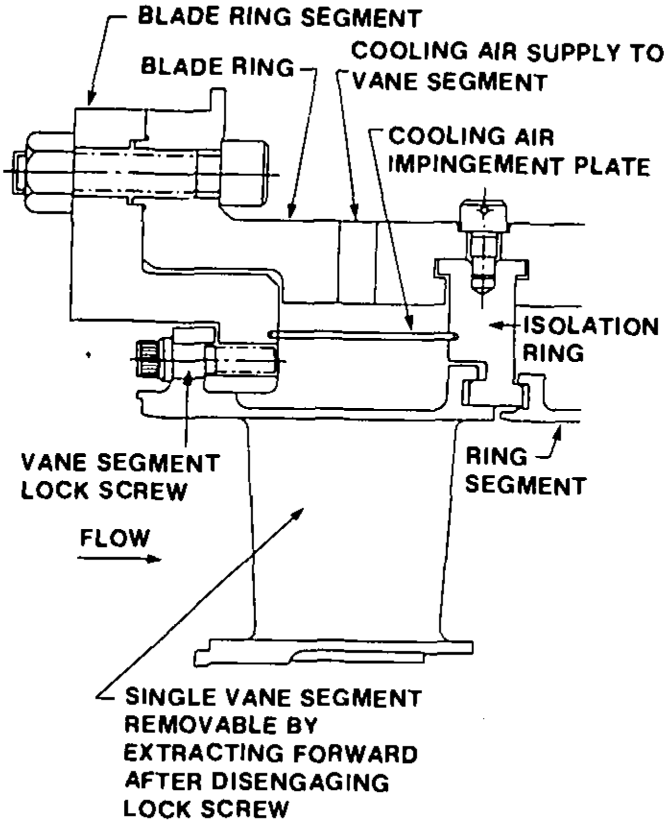

Fig. 1 Single Vane Segment

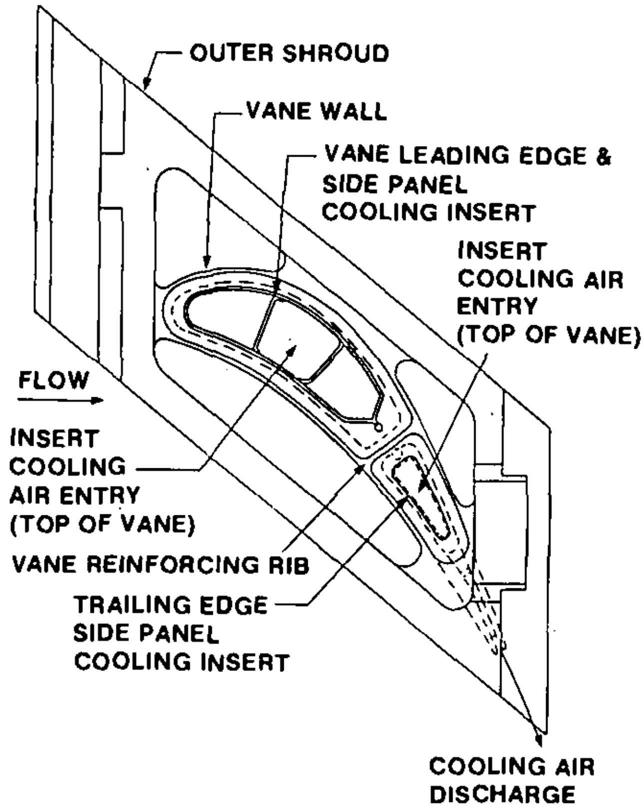

Fig. 2 Top View of Vane Showing Inserts

The first replacement with single vane requires a new blade ring, a new seal segment at the outer shroud of the vane and modifications to the static seal at the inner shroud of the vane. The installation of a single vane is shown in Figure 1. The design features of the single vane are shown in Figure 2. The vane contains two cavities separated by a vane reinforcing rib. Dual element cooling inserts are used. Cooling air enters at the top of vane into the insert and exits through the multiple holes of insert to maintain the vane surface within the necessary operating temperature. Multiple fins in the vicinity of the trailing edge facilitate the convective cooling in this area. In addition, there are two rows of gill holes on the suction and pressure sides of the vane airfoil to provide film cooling of the vane panels on the hot gas side of the vane as shown in cross section in Figure 3.

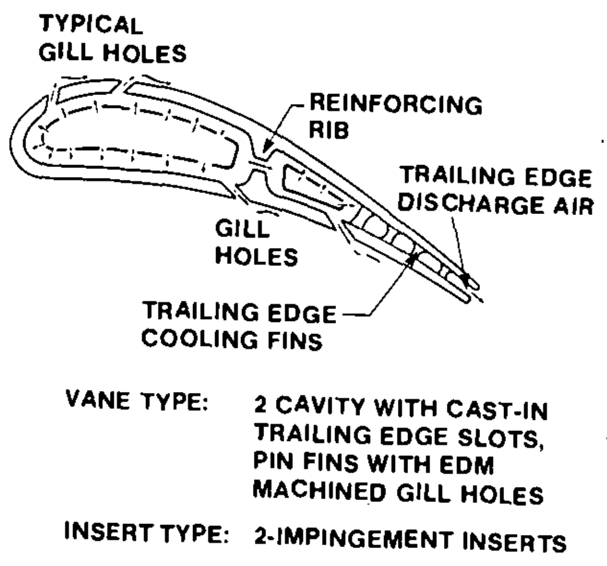

Fig. 3 Cross Section of Vane

Advantages of Single Vane Segments

1. Vanes can be changed out without lifting turbine covers after initial installation. The vane segments are removable from within the combustor shell after removal of combustor transition.

2. As all the elements of vanes are easily accessible the inspection, cleaning, repair and coating process can easily be completed.

3. Vanes are individually replaceable without disturbing the other vanes in the blade ring.

4. More sophisticated cooling features allow vane operating temperature to be significantly lower than the multiple vane segments.

5. The single vane segments will have higher creep life.

6. Lower thermal stresses between airfoil and shroud will lead to longer expected life.

Coating of Turbine Components

Starting in the mid 1960's Westinghouse pursued an active corrosion evaluation and coating development program. The increasingly high use of contaminated and low-grade fuels demanded that the turbine parts be suitably coated to retard corrosion on turbine blades and vanes. The precious metal aluminide diffusion coating was selected for application to the first two stages of turbine blades and vanes. This type of coating has been exposed to different contaminants in field experience and has proven to retard the corrosive effects.

Most of the alloys which have been used in the manufacture of Westinghouse turbine blading are amenable to coating after service, provided the physical condition of the blade permits. Alloys included in this group are Inconel X-750, U-520, U-720 and U-500. The only exception to these has been Inco 700 and U-710, where the inconsistent results obtained on stress rupture tests after coating do not permit coating of service run parts of these two materials.

During the performance upgrade, coating of the turbine parts should be considered by the users to take advantage of improved technology for protecting against reduced parts life due to corrosion.

The decision for application of anti-corrosion coating on turbine parts falls into the optional area and will require customer preference as well as detailed knowledge of operating conditions.

Compressor Coating

Our latest generation of combustion turbines are supplied with the coated compressor diaphragms and blades. We have successfully coated service run compressor parts with aluminum/chromate phosphate coating to produce a surface finish which is aerodynamically smoother than the finish produced in the normal fabrication of new blades. The increased surface finish leads to higher compressor efficiency. The coating also provides corrosion protection.

The decision to coat the service run compressor parts, however, would be weighed carefully in terms of the condition of the parts. The general experience with the coating of repaired parts has been excellent if the parts are repaired in accordance with established Westinghouse specifications.

Besides the aluminum/chromate phosphate coating, we have participated in the application of packed diffused aluminum coating for Users with mature frames. We have found that aluminum/chromate phosphate coating can easily be patch repaired if it is damaged during installation of the compressor components. Therefore, we feel that this type of coating offers a higher degree of versatility in comparison to diffused aluminum type coating.

We have experienced that a coated compressor provides the same volume of air flow for longer period due to a significantly slower degradation rate of coated parts. From this point of view, once the turbine inlet temperature is increased and suitable turbine parts are retrofitted improved performance can be maintained for increased operating periods.

IMPLEMENTATION

It is usually desirable to accomplish the upgrade program in the shortest possible time in order to minimize the impact on unit availability. In line with this desire, Westinghouse has developed sophisticated planning and project management techniques to assist the User in meeting his objective.

The material required for the upgrade program is released as soon as a customer commitment is established. This is an important step because of the long lead times of some of the turbine components. The detailed shop scope of work and the field scope of work are developed and issued. The coordinated inputs of shop and field are monitored on a CPM schedule of the upgrade. Based upon the complexity of an upgrade program and the number of units involved, an appropriate project management type of organization is established to support the implementation.

EXAMPLE

To provide an insight in general scope of work a most recently completed W501B2 to W501B5A upgrade program is discussed in this paper.

All roof sections of turbine enclosure were removed to gain accessibility to turbine cylinder covers. The turbine cylinder covers were removed in the following order; combustor, compressor/combustor, compressor and turbine section. Figure 4 shows the compressor/combustor cover upper half set aside for spindle removal. The blade ring upper halves and

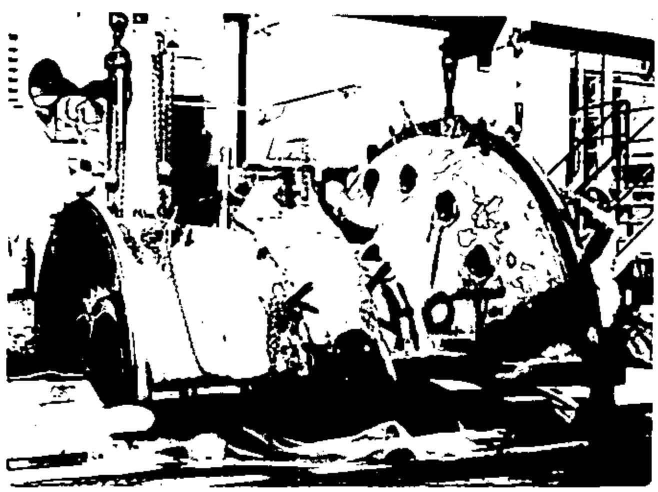

Fig. 4 Compressor/Combustor Cylinder Upper Half

torque tube covers were removed next in preparation for the spindle lift. Figure 5 below shows the open torque tube area of a W501B engine. The exhaust

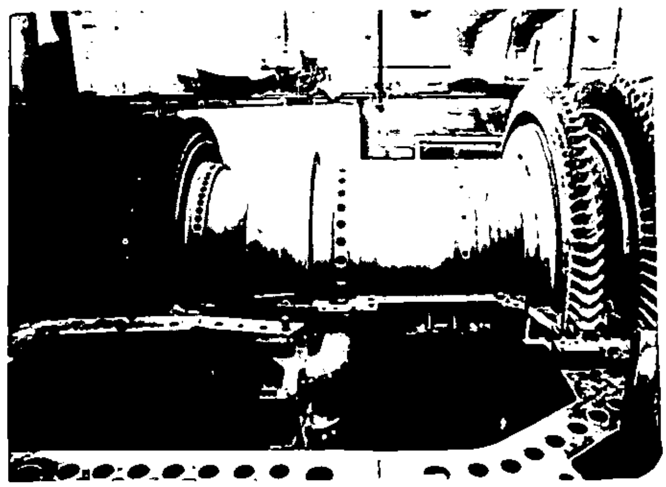

Fig. 5 Torque Tube Area

cylinder cover, inlet manifold and finally the bearing tops were removed to lift the spindle. Figure 6 shows the spindle being picked up by an overhead crane.

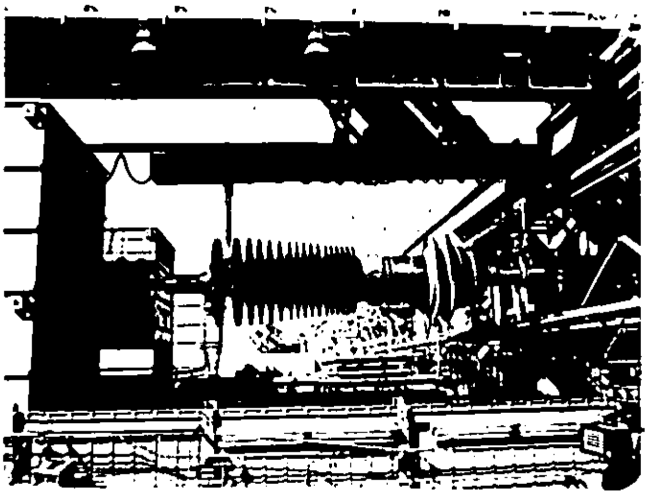

Fig. 6 W501B Rotor Lifted by Overhead Crane

A 50T overhead bridge crane, as shown in the photograph, greatly facilitated all disassembly and assembly operations during the program. The spindle was supported by wooden pedestals (Figure 7) for shipment to the

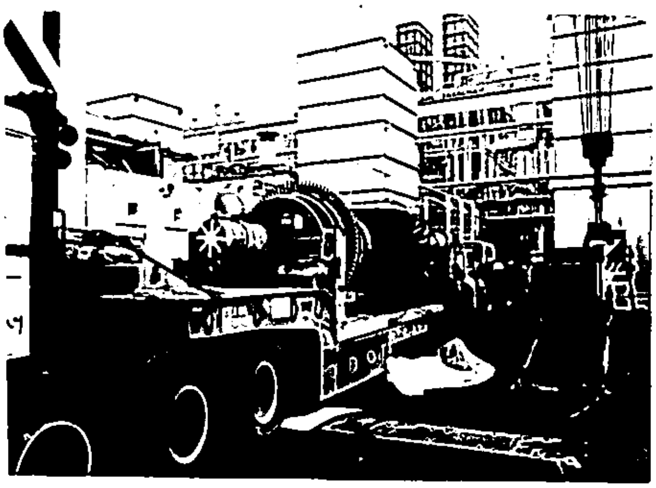

Fig. 7 W501B Rotor Ready for Transportation

Westinghouse shops for modifications. The spindle support system and trailer is specially designed by our Traffic Department engineers to insure that spindle will not be damaged during the transit.

The row 3 and 4 turbine blades and compressor diaphragms were also removed and returned to shops for inspection and necessary repairs. The coating of compressor was required as a part of upgrade program, therefore, all compressor parts were coated after repair.

After receiving the spindle at our shop, a complete incoming inspection was performed. The compressor to turbine coupling flanges were modified as a part of the product improvements to gain increased margin for transient thermal conditions during operation. The turbine was then completely unstacked for changing the row 2 turbine disc and installation of a new set of air baffles. A new row 2 turbine disc is used with the provision for cooling air holes as shown in Figure 8.

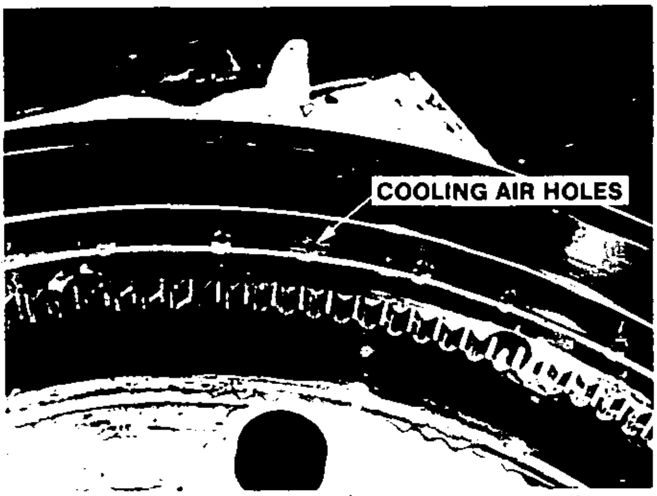

Fig. 8 New Row 2 Turbine Disc

The row 1 and row 3 turbine discs are reclutched to insure proper match up with the new row 2 disc. New chrome plated air baffles were installed in all stages of turbine as shown in Figure 9 below. The turbine

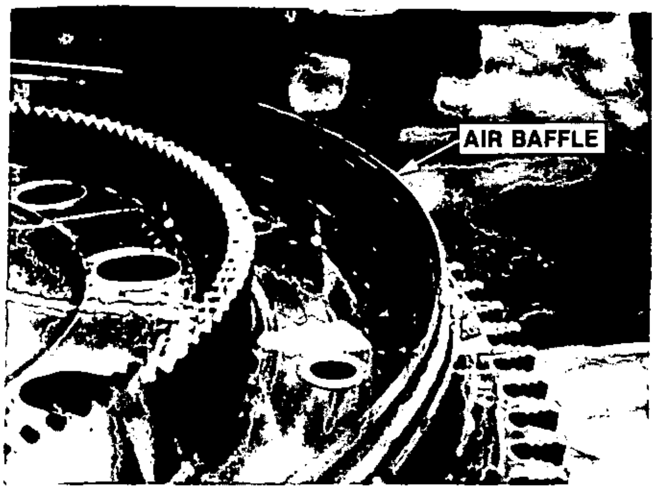

Fig. 9 New Air Baffle on Turbine Disc

was restacked using a new set of through bolts. A new set of row 1 U-720 coated and cooled and a new set of row 2 U-720 coated and cooled turbine blades were installed in turbine. Remainder of turbine was bladed and coupled to compressor.

While the turbine spindle work was progressing in the shops, site work on the stationary stages of the machine was performed to support an upgrade schedule. Cooling air piping modifications, installation of new row 1 and row 2 vane segments with special inserts and isolation rings were completed at the site. When the spindle was received at the site, assembly work could proceed with installation of the torque tube seals and completion of blade ring assembly upper halves. Upon the satisfactory completion of turbine, compressor, compressor/combustor and combustor cylinder installation and combustor system check out, the turbine was prepared for a test run. The satisfactory completion of the test run allowed the release of unit for load generation to the dispatcher.

Careful planning efforts during the upgrade program paid off handsomely. The course of action was adjusted to overcome the effects of unexpected problems that developed during the project. After the first spindle upgrade, shop time for subsequent spindles was reduced from 14 to 8 weeks. This reduction in shop turnaround time was reflected in the overall schedule with close communication and support by the customer. An overall compression of about nine months in the original schedule of twenty-four months was made possible by using the strategy explained herein.

ECONOMIC ANALYSIS

The basic economic analysis will yield actual cost savings to the operators. These economic benefits are suggested for consideration of an upgrade program.

Where:

Current generation capacity of plant	= A KW
Current heat rate	= B BTU/KWH
Improved heat rate (by upgrade)	= C BTU/KWH
Fuel cost in year of calculation	= D \$/BTU x 10^6
Plant capacity factor	= CF
Unit KWH sale price	= H \$/KWH
Improved generation capacity of plant (by upgrade)	= K KW

I. Annual fuel cost saving at constant fuel cost during a payback period can be expressed as;

\$ savings fuel cost/yr. =

$$A \times 8760 \frac{\text{hours}}{\text{year}} \times CF \times D \times (B-C) \times 10^{-6}$$

II. Gain in revenue by higher power generation at the plant,

\$ by higher power generation/yr. =

$$H \times (K - A) \times \frac{8760 \text{ hours}}{\text{year}} \times CF$$

III. Approximate payback period can be determined as shown below;

Payback period in years =

$$\frac{\text{Total capital expenditure for upgrade}}{\text{Summation of dollars/yr. in (I) and (II)}}$$

The fuel cost savings and revenue by higher power generation will be of significant value for the plants operating at a higher capacity factor. Also, the higher unit sale charges will provide substantial gain in revenue by upgrade to the operators. A shorter payback period is possible if a fuel cost escalation and progressively improving tariff (\$/KWH sales) are considered in the calculation.

CONCLUSION

By applying the evolutionary advances in combustion turbine technology to earlier production models, significant improvements in performance can be achieved with the additional benefits of improved parts durability and improved maintainability for many units. The basic economic analysis technique is included in this paper for the realization of upgrade payback period. We have not discussed an economic analysis using a particular example because of variations possible in calculation methods. A detailed economic analysis will involve use of fluctuating prime rates, fuel availability, and standards of amortization periods. We will, however, support the User's needs by participating in the economic analysis to reach a balanced decision.

Users of machines that have accumulated high hours of operation and may require turbine parts changeout due to exhaustion of life should consider a performance upgrade program as part of their next major inspection. It is also suggested that Users review their load growth forecast and consider upgrades as a possible option to meet new load values in the future.