

TURBINE STEAM PATH AUDITS FOR IMPROVED PERFORMANCE AND PROFITABILITY

PAUL E. BABSON, DIRECTOR, BUSINESS DEVELOPMENT, ENCOTECH, INC., SCHENECTADY, NEW YORK

ABSTRACT

This paper describes the use and value of conducting steam path audits in turbines. Critical measurements and observations made during overhaul identify and quantify the effects of component degradations upon turbine performance as compared to design conditions. The information generated permits performance oriented repair actions to be economically justified and prioritized.

Formerly regarded as a lifetime career activity, the complex audit methodology has now been computerized. This enables plant engineers to conduct in-house audits after a brief training session that covers measurements to be taken and procedures for entering data into a Personal Computer.

The paper describes the various flow path components evaluated in an audit and the impact that deviations from manufacturer's design conditions can have upon turbine performance. Economically oriented maintenance actions can be selected and prioritized through use of critical flow path measurements taken during the opening of a turbine. Workmanship can then be checked by means of a closing audit.

BACKGROUND

In the electric utility industry 70-80% of the operating cost to produce a kilowatt-hour of electric energy in a fossil plant is for fuel. For this reason, efficiency considerations command a high priority. As a result, steam path audits conducted during overhauls to evaluate all forms of performance oriented component degradations are a highly developed and commonly utilized technique.

In the past, these audits were performed almost exclusively by highly trained specialists of the Original Equipment Manufacturers (OEM's). These same services are now offered by individual consultants as well, who are generally retired OEM specialists. Recently introduced computer programs now enable a plant engineer to not only duplicate these services, but can provide much more detailed, concise, and consistent information than hand calculation methods permit. As a result, many utilities have started conducting

their own comprehensive audits as an in-house activity.

These highly developed steam path performance audit techniques are applicable to cogeneration turbines as well, and have been successfully applied.

Normal deterioration of steam turbine performance is progressive, commencing shortly after start up following an overhaul. Depending upon the duty and cogeneration operating conditions, this degradation can result in 0.5 to 2% decrease in electric power output within a few years of operation. A large electric utility unit can lose over 4% in a five to seven year overhaul cycle. This loss of efficiency increases the cost of fuel to produce the same amount of power.

The steam path audit serves to identify and quantify the causes of the degradation. Appropriate portions of the total loss are assigned to the various deteriorated flow path components. Repairs can then be scheduled and prioritized where economic justification is the criterion. This information serves as a valuable guide to those responsible for making repair/replace decisions.

STEAM PATH COMPONENTS

The steam path of a low-pressure utility turbine with reaction blading is shown in Figure 1. The condition, from a

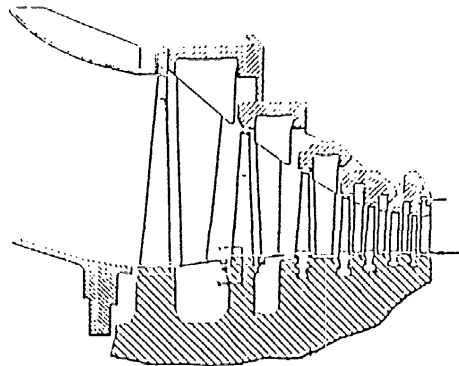


FIGURE 1 IMPULSE TURBINE STEAM PATH

performance point of view, of all components and their surfaces that serve to

contain, control, and direct the steam flow and to extract energy is subjected to scrutiny and evaluation by the performance audit engineer. It is in this area, and any structural support mating surfaces surrounding these areas, that the audit engineer concentrates the survey.

LEAKAGE CONTROL COMPONENTS

Leakage control components can be divided into three groups:

- o Interstage packings
- o Rotating blade cover seal strips
- o End packings

As shown in Figure 2, the blade ring carrier supporting the stationary blades between each set of rotating blades has a packing next to the rotating shaft to control interstage leakage of steam. Without this packing, the flow of steam around the stage blading would be excessive and would seriously degrade the performance of the turbine.

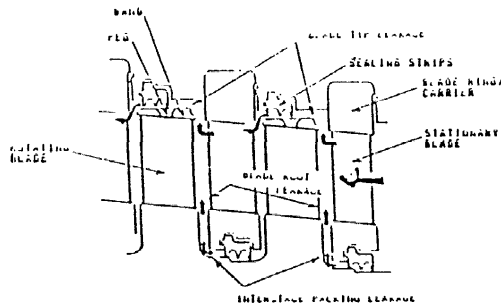


FIGURE 2 REACTION DRUM ROTOR CONSTRUCTION

Manufacturers design packings and set the clearances to minimize these leakage rates without incurring rubs during start and stops and in normal operation. It is therefore a good maintenance practice to observe these design clearances during overhauls. An excessive clearance will incur costly, unnecessary leakage. A setting too close can incur a rub, causing not only an increased clearance to be established by the turbine rotor, but the creation of a mushroomed tooth profile that can increase leakage flow rate by as much as 20% for the same clearance.

Figure 3 shows the annual fuel penalty incurred for progressively greater-than-design interstage packing clearances on a 300 MW unit. The three curves shown are additive for the entire three casing electric utility unit selected for this example. A typical cogeneration unit would be represented by the LP (low pressure turbine) curve. These are

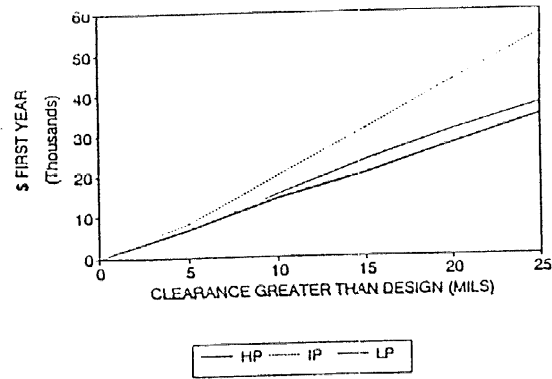


FIGURE 3 INTERSTAGE PACKING WEAR EXCESS RADIAL CLEARANCE

significant dollar amounts that have a direct impact on profitability.

Similarly, for rotating blade cover seal strips, the losses are also significant. Damaged or rounded strips in these areas should always be replaced or restored to the best possible condition. Missing strips can incur costs in the tens of thousands of dollars per year.

End (dummy) packings, as shown in Figure 4, control leakage between casings or to or from the atmosphere. Figure 5 is a plot of the increased fuel cost penalties that would result from clearances progressively greater than design.

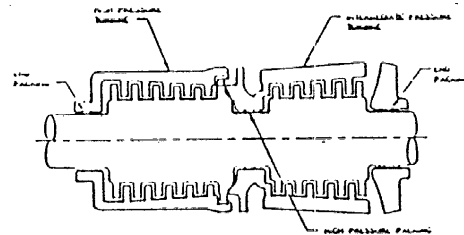


FIGURE 4 END PACKINGS SCHEMATIC DIAGRAM

Figure 6 illustrates the effectiveness of rounded versus sharp packings. A rounded tooth, whether the result of a rub or erosive wear, will incur up to 20% increase in leakage for the same clearance. Because of this, normal maintenance should prioritize the sharpening of packing teeth at every opportunity. Figure 7 shows the increased fuel cost penalties associated with both rounded and sharp teeth having progressively greater clearances for a

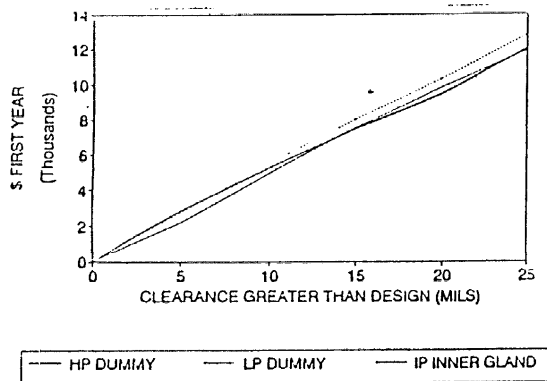


FIGURE 5 PACKING WEAR
EXCESS WEAR

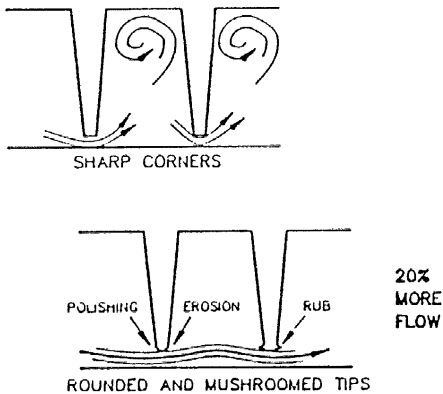


FIGURE 6 EFFECT OF TOOTH SHARPNESS ON FLOW

Round Vs Sharp for HP Casing

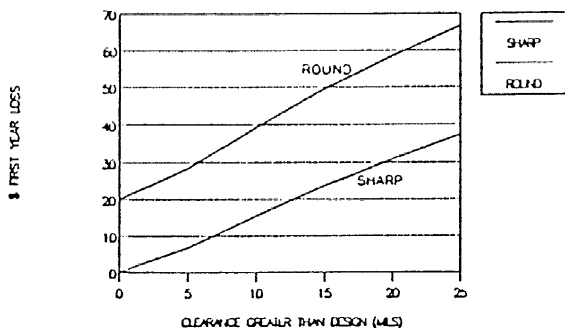


FIGURE 7 PENALTIES RESULTING FROM
INTERSTAGE PACKING WEAR

high pressure utility turbine interstage packing.

End packings have multiple teeth, and are therefore not as sensitive to individual tooth damage as are radial spill or other single tooth packings. Figure 8 shows the increased cost of fuel associated with progressively larger numbers of missing teeth for a typical end packing design.

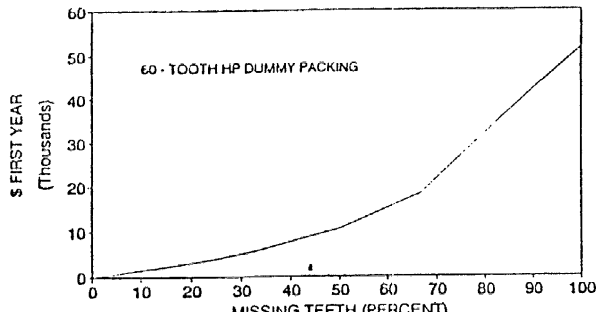


FIGURE 8 PACKING TEETH
EFFECT OF MISSING TEETH

BLADE RING MOUNTING JOINT LEAKAGE

Another leakage area that affects performance is at the locations where the blade ring carriers fit into the casings. These have dovetail joints that are prone to galling damage during assembly and disassembly and to warping in operation. When the fit does not seal, steam can bypass an entire blade ring.

The total bypass of a group of stages is very costly in terms of lost performance. Figure 9 shows the increased

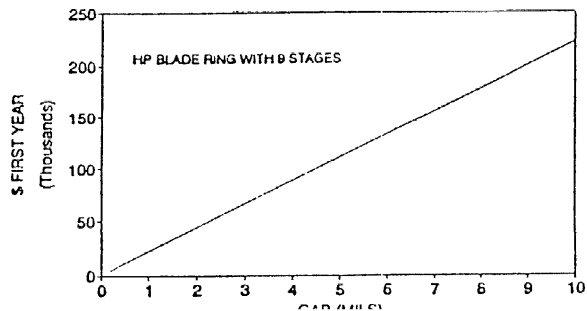


FIGURE 9 INNER CYLINDER RING FIT
GAP BETWEEN BLADE RING & INNER SHELL

fuel costs associated with steam losses from this type of leakage. Fortunately, the penalties shown are for a continuous gap around the entire ring. The normal

defect is for a gap to occur around only a portion of the entire circumference, resulting in reduced losses. The audit engineer calculates the leakage flow area involved and the computer program proportions the losses accordingly. Because even these losses can be substantial, good workmanship in these areas can result in considerable savings.

SOLID PARTICLE EROSION

Another cause of flow path deterioration is solid particle erosion. Erosion can result in:

- o Changes in the nozzle area,
- o Irregular blading trailing edges,
- o Eroded leading edges of rotating blades, making them less tolerant of changes in steam entry angle,
- o Increased clearances of radial spill strips,
- o Roughening of the steam path flow surfaces,
- o Accumulation of erosion products under rotating blade covers, and
- o Repairs to be required of blade trailing edges, often resulting in thickened airfoil cross sections.

Figure 10 depicts the particle trajectories that can cause erosion

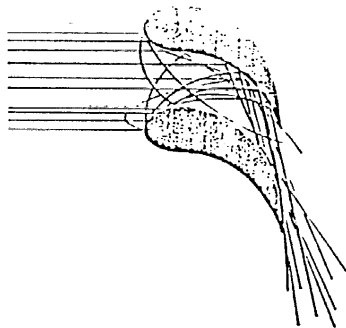


FIGURE 10 PARTICLE TRAJECTORY

damage. These trajectories are random, and the particles and their sizes vary according to their sources. They can come from the boiler and upstream piping and tend to be more prevalent during startups and cycling. They tend to centrifuge radially outwards and therefore erode spill strips as well as the blading. In the process, the spill strip particles and other debris adds to the downstream erosion.

Figure 11 illustrates the detrimental effect that excessive erosion can have

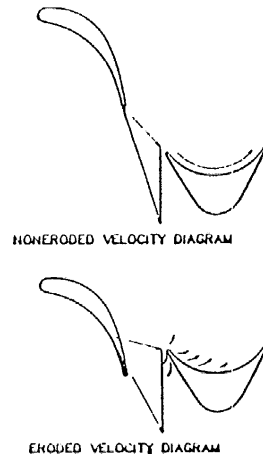


FIGURE 11 VELOCITY DIAGRAMS

upon the velocity diagram of the blading. Figure 12 shows an eroded trailing edge of

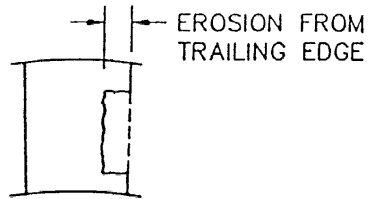


FIGURE 12 EROSION FROM TRAILING EDGE

a blade. This erosion increases the flow area and again is very detrimental to the stage velocity diagram. Figure 13 shows the excessive fuel cost penalties associated with control stage trailing

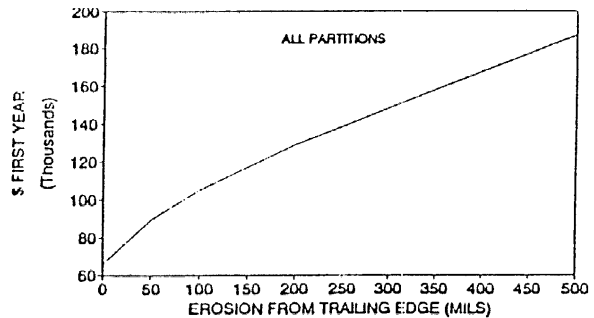


FIGURE 13 SOLID PARTICLE EROSION DAMAGE TO CONTROL STAGE

edge erosion. As partitions do not usually wear symmetrically, the audit engineer again proportions these costs accordingly by inputting the appropriate wear severity into the computer program.

Figure 14 shows the fuel cost penalties that can occur as a result of the trailing edge thickness increases that are difficult to avoid when repairs are required in this area. Note that the control (first) stage, which controls the flow rate of steam entering the turbine, is quite sensitive to trailing-end thickness increase.

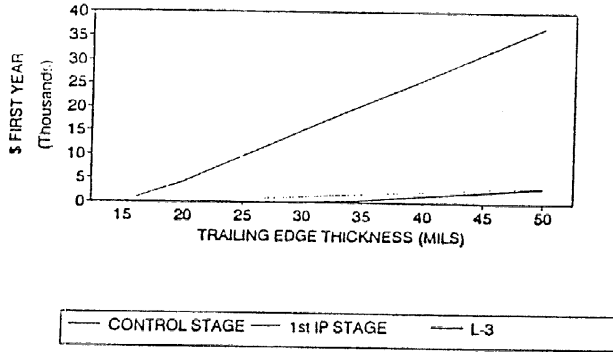


FIGURE 14 TRAILING EDGE THICKNESS STATIONARY BLADING

Figure 15 illustrates a buildup of erosion particles under a rotating blade

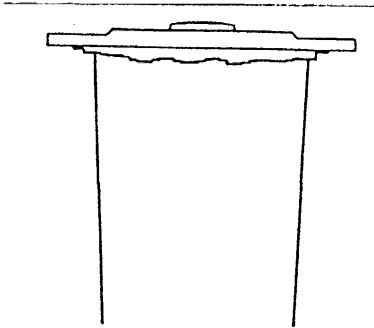


FIGURE 15 DEPOSITS UNDER SHROUD COVERS

cover. These built-up deposits cause a flow disturbance in the rotating blade flow for a small radial distance, which is costly in terms of performance loss. These buildups should be carefully removed without damaging the surface finish of the blade or cover.

Removal of the particles can be demanding, because the build-up is mostly due to the centrifuging action of the rotating blades upon the particles in a steam environment, causing a surprisingly

dense accumulation firmly bonded to the inside surface of the covers. Figure 16 is a plot of fuel cost penalties associated with progressively larger buildups of solid particles.

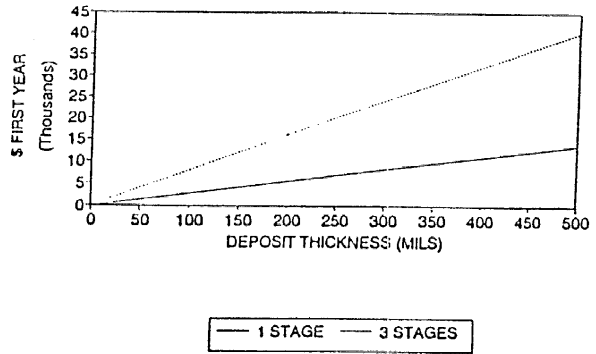


FIGURE 16 COST PENALTIES DEPOSITS UNDER SHROUD COVERS THICKNESS

SURFACE FINISH

The surface finish of the blading has one of the greatest effects upon performance. Based upon the detailed and well documented work of researcher V. T. Forster, as shown in Figure 17, profi

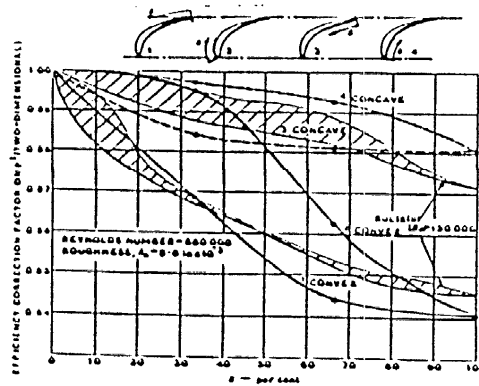


FIGURE 17 EFFECT OF LOCAL ROUGHENING

efficiency is affected more by roughness on the suction surface of the blading than the pressure surface. Additionally, the trailing edge on both the suction and pressure surfaces is more sensitive to surface roughness than the leading edge. Figure 18 translates this loss into excessive fuel cost for an L-3 stage with a roughness Equivalent Sand Grain Size

Stage L-3, ESGS = 1.0

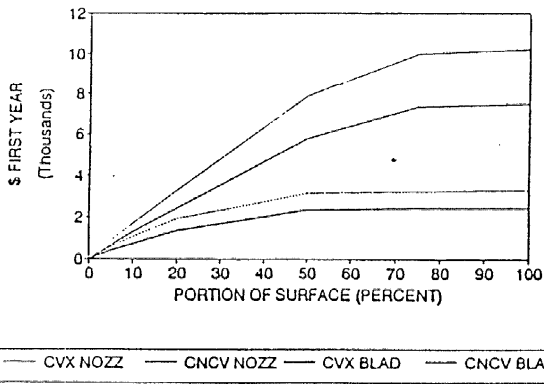


FIGURE 18 SURFACE ROUGHNESS ON NOZZLES AND BLADES

(ESGS) of 1.0, a normal roughness for a turbine that has been operated for a few years. As stated above, the suction (convex) sides of both the rotating and stationary blades are the most sensitive to roughness.

Figure 19 shows the fuel cost savings associated with the restoration of surface

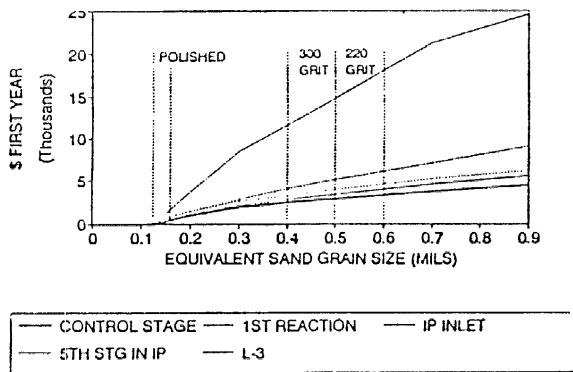


FIGURE 19 SAVINGS FOR IMPROVING SURFACE ROUGHNESS OF A SINGLE STAGE NOZZLE TRAILING EDGE, CONVEX SIDE

finish on the trailing edge of a nozzle. The control stage is by far the most sensitive. When new from the factory, all surfaces are polished and deliver design efficiency. The normal surface finish restored to blade surfaces during overhaul with grit blasting is in the range of 0.4 to 0.6 ESGS. Restoration of surface finish at every opportunity is recommended, as it will result in significant savings.

RESULTS

Figure 20 is a computer printout of an audit summary. These data can be

UNIT... 1	EXAMPLE ECONOMIC FORECAST	BENEFIT PERIOD	TURBINE NET SAVINGS (\$ THOUS)
CASE... 1	REPAIR COST	FULL YEAR	NET SAVINGS
			PERMS WORTH
LIABOR PACKINGS	170.000	62.938	213.457
END PACKINGS	75.000	149.803	830.180
SPILL STRIPS	210.000	251.308	1321.120
ENGINE	45.000	11.253	23.562
SURF ROUGHNESS	60.000	243.780	1449.630
MECH DAMAGE	0.000	0.000	0.000
DEPOSITS	50.000	53.810	277.844
MISC LEAKAGES	25.000	171.320	1018.785
REPL GENERATION	307.588		-307.588
TOTAL	942.588	948.292	4834.990
TIME UNTIL REPAIRS (YRS)...	0	HEAT RATE DEGRADATION (%/Y).....	1.00
BENEFIT PERIOD (YRS).....	5	REPAIR OUTAGE (MKS).....	8.00
CAPACITY FACTOR (%).....	65.00	REPLACEMENT GENERATION (\$/MWH)...	2.00
FUEL COST (\$/MWH).....	2.08	PRESENT WORTH FACTOR (1%).....	9.73

FIGURE 20 OUTAGE TIMING WORKSHEET

presented in virtually any combination and detail that a maintenance decision maker requires to optimize the use of available resources. For instance, individual spill strip losses can be presented to determine which should be replaced, sharpened, or left as is. This information will clearly indicate, from an economic viewpoint, the priority of repair actions to be taken. The availability of this computerized capability now provides users of large steam turbines with a viable means of improving profitability and competitiveness.

CONCLUSIONS

The acquisition and conversion of steam path audit data into meaningful information that can be used to determine the value, and to prioritize recommended repair scheduling, of steam turbines has in the past been a lifetime career for OEM specialists. These capabilities and the methodologies employed have now been computerized, permitting equivalent results to be achieved by utility engineers after several days of training in data measurement and entry into the computer.

Data for the performance penalty plots used in this paper were generated through use of such a program. The turbines used for these examples were the subject of an actual audit. Using the turbine model developed for the audit, the design clearances were selectively increased to generate the loss data shown. These were then plotted for presentation in graphic form.

In conclusion, the value of restoring flow path components to design conditions during overhaul can now be quantified as an in-house activity. Past experience with the electric utilities has shown that good maintenance practices can save many thousands of dollars per year in wasted fuel. With the ability to direct available resources towards addressing components representing the greatest savings, only economically justifiable repairs need be made.