Encotech, Inc.
201 State Street
P.O. Box 714
Schenectady, NY 12301-0714

# STEAM PATH AUDIT INFORMATION PACKAGE

**Page:**

## Contents

# INFORMATION REQUIRED BY ENCOTECH

In order to complete the steam path audit, Encotech requires information necessary to create an eSTPE computer model of the turbine. It is essential that this information be provided at least three weeks prior to the Auditor arriving on site to conduct the audit.

**Design Definition:**

Encotech will model the "new and clean" condition of the turbine using the eSTPE program. Information required consists of:

- The valves-wide-open (VWO) heat balance
- The turbine cross-section diagrams for all casings
- The design sealing clearances for all interstage packing, root spill strips, end packings, and tip spill strips
- The steam seal diagram
- The first stage shell pressure curve, if available

## APPROXIMATE CHRONOLOGY OF AN eSTPE STEAM PATH AUDIT

1. The Steam Path Auditor arrives on site prepared to inspect the horizontal joint of any casing about to be lifted.

2. Immediately upon lifting any top-half casing, the Steam Path Auditor inspects the horizontal joint for leakage paths and damage, and then takes photographs and measurements of any evidence of leakage at the horizontal joint.

3. Before the top-half stationary blading is grit blasted and before the packing rings are removed, the Steam Path Auditor takes the following measurements on the top halves of the casings:

    - interstage packing tooth heights at three locations for each stage,
    - tip spill strip tooth heights at three locations for each stage,
    - end packing tooth heights at three locations for each packing ring,
    - surface roughness on the suction and pressure sides of the stationary blading for each stage, and
    - evaluation of any solid particle erosion, deposits or mechanical damage.

4. After the rotor is exposed and set to the axial running position, the Steam Path Auditor takes interstage packing, root spill strip, tip spill strip and the end packing radial clearance measurements.

5. After the rotor is removed, the bottom-half tooth heights are measured in five positions for each stage. The tooth heights are measured on the interstage packings, root spill strips, tip spill strips and end packings. The Steam Path Auditor inspects the bottom half stationary blading for any solid particle erosion, deposits, and mechanical damage.

6. Before the rotor is grit blasted, the Steam Path Auditor takes rotor geometry measurements, evaluates the surface roughness of the blading and any solid particle erosion, deposits or mechanical damage. .

7. Following removal of the inner from the outer shells, the Steam Path Auditor examines the shell fits that act as pressure barriers for signs of leakage paths. Also, measurements are made of any other leakage paths that indicate flow has bypassed a portion of the steam path.

8. On an ongoing basis, the Steam Path Auditor verifies the default values from eSTPE and the design clearance diagrams, which includes sealing diameters of packings, types of packings and number of packing teeth.

9. On an ongoing basis, the Steam Path Auditor takes relevant photographs of the steam path to describe its condition. The Steam Path Auditor also inputs data into eSTPE to generate results reports.

10. The Steam Path Auditor conducts an on-site preliminary presentation of the audit results to performance engineers and managers. The results of the audit allow utility personnel

the ability to explore cost-effective repairs and help determine the highest payback for items they choose to replace.

NOTE: eSTPE's flexibility allows the Steam Path Auditor to input data as it is obtained in the field. Therefore, the Steam Path Auditor may, for example, get all the information from the HP top half casing and send it on to be grit-blasted while the IP casing is still being disassembled. This feature allows the audit to be conducted without jeopardizing the planned outage schedule

## HELPFUL PROCEDURES

The following list itemizes procedures taken by the utility during an outage that would facilitate the efforts of the Steam Path Auditor to obtain data necessary for the steam path audit. It has been our experience that these procedures are often followed by utilities as standard operating procedure.

1. Upon removal of the top half of the casing containing the stationary blading, **place the casing on the floor such that the horizontal joint is facing up** (i.e. "upside down"). This allows easy access to the blading for inspection

   NOTE: If with wheel and diaphragm blading it is necessary to lay the stationary blading on its side, please do so with the **trailing edges facing up**.

2. Upon removal of the top half labyrinth-type packing (e.g. N1, N2, "HP Dummy", etc.), **do not immediately remove the packing rings.** These rings are eventually removed from their casings, bound with duct tape, labeled and set aside for further action. The Steam Path Auditor's ability to gain access to these rings while they are in their casings for tooth height measurements, photographs and inspection of any unusual damage greatly enhances the steam path audit procedure.

3. If the utility plans to grit-blast top-half stationary blading immediately after its removal from the turbine, please inform the Steam Path Auditor so they will have an opportunity to inspect the blading. Quite often there is a one-to-two day gap between blading removal and grit blasting which allows plenty of time for the Steam Path Auditor to obtain the necessary data.

4. Please place the bottom half horizontal joint immediately upon its removal, the top half horizontal joint may be inspected providing it is accessible, e.g., on blocks high enough to allow measurements and photographs to be taken.

## eSTPE STEAM PATH AUDIT BACKGROUND INFORMATION

### Purpose of the Audit

The purpose of the steam path audit is to assess the thermal performance of the steam turbine-generator. The results of this audit identify problem areas and quantify the impact of the problems in order to assist the utility in making decisions whether to repair or replace steam path components.

Encotech will use the heat balance to characterize the unit's performance in its valves-wide-open, "new and clean" condition. An Encotech Steam Path Auditor will perform the turbine steam path audit during the outage to determine the condition of the steam path, its geometry and the clearances of the steam seals. The results of the audit will be used to identify the degradation in heat rate resulting from solid particle erosion, changes in clearances, deposits, changes in surface roughness, leakages, and mechanical damage. The Steam Path Auditor will present preliminary results of the audit during the outage to help prioritize maintenance.

### Description of the Audit

The basic approach of the audit is to examine the turbine steam path in detail and then compare the "as-found" condition with the "new and clean" condition of the machine. The audit will make use of the proprietary Steam Turbine Performance Evaluation (eSTPE©) computer software that Encotech developed for utility use.

The eSTPE program accepts the measured data collected during the on-site investigation and calculates the resulting power loss and heat rate degradation for each of the following loss categories, independent of other losses, at each turbine stage or location:

- Interstage Packings
- Tip Spill Strips
- End Packings
- Miscellaneous Leakages
- Solid Particle Erosion
- Deposits
- Mechanical Damage
- Surface Roughness
- Cover Deposits
- Trailing Edge Thickness

The results of solid particle erosion, mechanical damage, and deposits are combined as flow path damage to best represent the current condition of the unit at the time of the audit.

eSTPE compares the "as-found" data collected during the audit with the "new and clean" condition characterized as the "Design". The Design portion of eSTPE calculates the turbine geometric properties, the thermodynamic and fluid dynamic conditions at each stage, efficiency margins, and other operation and design dependent properties using the turbine cross-section and heat balance. Although complete restoration to the "new and clean" condition is generally not possible, it provides a fixed standard against which to make comparisons.

eSTPE evaluates losses on a stage-by-stage basis but recognizes that some of the stage losses are recoverable. Two important considerations are: first, loss recovery by downstream stages and second, the reduced heat input required by the boiler resulting from losses that occur above a reheat point. The analysis used in eSTPE accounts for both of these effects.

**eSTPE Report Format**

The eSTPE Program generates loss reports for individual stages, casings and the entire turbine. Turbine and Casing Loss Summary Reports outline the losses calculated in individual loss categories, such as tip spill strips, and provide totals of the heat rate and power losses. Loss Category Turbine Loss Reports compile total casing losses for one type of loss, for example End Packing Leakages. The Loss Category Casing Loss reports provide the calculated change in power loss and change in heat rate for each stage in the casing.

**Areas Addressed in the Audit**

The specific areas of concern addressed by the Audit are:

1. Leakages:
    - past stationary stage blading
    - past rotating stage blading
    - past shaft packings where rotors emerge from casings (end packings)
    - across poorly fitting joints
    - other miscellaneous leakages
2. Surface finish degradation from:
    - deposits
    - corrosion
    - solid particle erosion
    - mechanical damage
3. Flow blockages from:
    - deposits
    - foreign objects
    - solid particle erosion
    - water droplet erosion
    - mechanical damage

## Leakages

Labyrinth-type packings control leakage between stationary and rotating parts the machine. These packings include:

- **interstage packings** located at the inside diameter of the stationary blading,
- **end packings** located at the ends of casings, and
- **tip spill strips** located at the tips and roots of the rotating blades.

To calculate packing losses, the Steam Path Auditor determines the difference between actual leakage area and design leakage area. This determination is made by measuring the clearance between the teeth of the packing and the adjacent wall (generally the rotor, wheel, or blade cover surface) at the horizontal joint prior to removing the rotor. To estimate clearances at the top and bottom of the rotor the Steam Path Auditor measures tooth heights at the joint and at the top and bottom packing positions after rotor removal. The Steam Path Auditor then makes four additional tooth height measurements at locations around the rotor circumference: the upper left, the upper right, the lower left and the lower right. eSTPE calculates an average clearance and leakage area from these measurements and compares it with the design value.

eSTPE also applies a tooth condition to all packings. This tooth condition is entered as a "percent rounded". A rounded set of teeth will exhibit a greater flow passing capability than a sharp set of teeth. The difference in flow is due to the difference in flow coefficient between the sharp and rounded teeth. A set of packings with rounded teeth has a greater calculated flow passing ability than packings with sharp teeth with the same clearance.

The gap should, theoretically, be equal on the left and right sides for each stage while the rotor is running, but may be offset during alignment. An offset rotor causes the gap measurements to be smaller on the side where the rotor is closest to the casing than on the opposite side. An offset rotor position will not affect the clearance measurements or the calculation of the loss. The horizontal gap variance plots provide a check for casing, blade ring, or diaphragm alignment.

After determining the change in leakage area, eSTPE uses Martin's formula to calculate the changed leakage flow. Important inputs to this calculation are the pressures on each side of the packing and the upstream specific volume. The Steam Path Auditor can determine these parameters readily from the heat balance for end packings, but these parameters are functions of the reaction at the root and tip of each stage for flows past stationary and rotating blading. For this purpose, eSTPE uses the Design section that contains root, pitch and tip reactions of each stage. Another important input to the calculation is the number of teeth currently in place, compared with the expected or design value, since losing teeth in service can significantly increase packing leakage.

eSTPE calculates joint and miscellaneous leakages on a case-by-case basis by measuring the leakage areas and applying the equations for calculating flow through orifices.

## Surface Finish Degradation

The method for quantifying the impact of surface finish degradation makes use of laboratory data on cascade efficiencies developed by V.T. Forster (Ref. 4). The Steam Path Auditor uses a surface roughness comparator to compare each surface of each stationary and rotating blade to the standard grades of emery paper Mr. Forster used in his tests. eSTPE then calculates cascade efficiencies for the assumed new condition (64 microinch) and modified cascade efficiency for the observed existing surface finish. The modified cascade efficiencies are then used to calculate a change in stage efficiency and a resulting power loss for each stage. The Steam Path Auditor measures roughness of the suction (convex) and pressure (concave) surface of both the stationary and rotating blades for each stage. Additionally, the Steam Path Auditor estimates the portion of the blade, as measured upstream from the trailing edge that had the roughened surface.

## Flow Path Damage

Damage to the turbine blading can cause the steam path flow area to increase or decrease from design conditions, which will result in an increase in heat rate. The Flow Path Damage Section of eSTPE evaluates the impact of area changes brought about by erosion, deposits, and mechanical damage. Changes in surface finish, spill strip erosion, and other types of damage that also result from solid particle erosion, deposits, and mechanical damage are evaluated separately in the appropriate sections of the audit program.

Significant solid particle erosion, such as is typically observed on the first stages of the HP and IP turbines, not only disturbs the flow at the portions of the arc where erosion occurs, but also affects overall stage efficiency by changing the intrastage pressure and the resulting reaction (distribution of energy between the nozzle and the rotating blade). Solid particle erosion data are grouped into four severity-level categories and assigned a representative erosion "type", an erosion depth, and an erosion height. These data are then used by the program to determine the change in nozzle or rotating blade flow area. The change in area is then used, along with deposit and mechanical damage data to determine the net impact on the machine.

Foreign objects, deposits, corrosion, and mechanical damage to the steam path can cause flow blockage. To determine the performance degradation caused by flow blockage, the Steam Path Auditor estimates the change in flow area for each stage. eSTPE then uses this information to calculate losses on the stage that has the blockage, and determines the impact on adjacent stages resulting from a change in pressure ratios and stage energies. eSTPE addresses the effects that alter the flow path and change the flow area in a complex section titled "Flow Path Damage". Data are entered into the "Solid Particle Erosion", "Deposits", and "Mechanical Damage" subsections for flow path damage analysis.

The impact of water droplet erosion on turbine efficiency is often negligible, but is an important factor to consider when it threatens the unit's mechanical integrity. The only change in flow path condition of the turbine is an increase in surface roughness of the outer portion of the leading edge of the blades in the low pressure areas where Reynolds numbers are small. Forster and others determined in laboratory tests that leading edge surface roughness has relatively little effect on cascade efficiency.

## BIBLIOGRAPHY OF eSTPE TECHNICAL REFERENCES


1. K.C. Cotton, D.H. Cioffi, F.H. Kindl, "Solid Particle Erosion A Rapid Meaningful Evaluation of its Significance," paper presented at the EPRI Solid Particle Erosion Of Utility Steam Turbines Workshop, March 7-9, 1989.

2. K.C. Cotton, P. Schofield, "Analysis of Changes in the Performance Characteristics of Steam Turbines", paper presented at the ASME Winter Annual Meeting, November 30-December 3, 1970.

3. K.C. Cotton, J.C. Westcott, "Methods for Measuring Steam Turbine-Generator Performance", ASME paper 60-WA-139.

4. V.T. Forster, "Performance Loss of Modern Steam Turbine Plant Due to Surface Roughness ", Institution of Mechanical Engineers Proceedings 1966-67, Volume 181, Part 1, Number 17.

5. F.H. Kindl, "A Method to Calculate the Impact of Changes in Flow Area on Steam Turbine Performance", paper presented at the 1989 Joint Power Conference, October 22-26, 1989.

6. D. Lantzy and P. Schofield, "Steam Turbine-Generator Heat Rate Penalty Resulting from Solid Particle Erosion", paper from the Solid Particle Erosion of Utility Steam Turbines Workshop, 1985, EPRI CS-4683, pp. 5-1.

7. J.K. Salisbury, "Steam Turbines and Their Cycles", John Wiley and Sons, Inc., New York.

8. P. Schofield, "Maintaining Optimum Steam Turbine-Generator Thermal Performance", paper presented at the Missouri Valley Electric Association 1981 Engineering Conference, April 23, 1981.

9. P. Schofield, "Efficiency Maintenance of Large Steam Turbines", paper presented at the Pacific Coast Electrical Association 1982 Engineering and Operating Conference, March 18-19, 1982.

10. P. Schofield, D.A. Lantzy, "Steam Turbine Generator Performance Improvement Resulting from Redesigning to Minimize Solid-Particle Erosion Damage", paper presented at the 1986 American Power Conference, April 14-16, 1986.

11. R.C. Spencer, K.C. Cotton, C.N. Cannon, "A Method for Predicting the Performance of Steam Turbine-Generators..16,500 kW and Larger", General Electric Company GER-2007C, July 1974, based on ASME Paper 62-WA-209.

12. K.C. Cotton, "Steam Turbine Performance", seminar lecture notes, 1992.