STEAM TURBINE LOSS PREVENTION INSPECTION

INTRODUCTION

Steam turbine loss prevention requires paying attention to how turbines, their driven objects, and associated safety devices and systems are designed, applied, installed, operated, maintained and repaired. Losses may result from a centrifugal rotor burst, an overpressure rupture, overspeed, mechanical breakdown or other equipment failure.

This section suggests ways to minimize turbine losses by making periodic inspections. It focuses on steam turbines driving generators rated at 750 kW and above and mechanical drive turbines rated at 1000 hp (750 kW) and above. The approach recommended also applies to smaller machines, however, some features may not be necessary. Turbine fire protection is covered in PRC.17.12.1.

POSITION

Turbine Loss Prevention Management

Management commitment is the key to successful loss prevention. Loss prevention and control programs must convey and enforce this commitment. Loss prevention inspection, one of the fourteen interlocking management programs described in *OVERVIEW*, helps management evaluate the effectiveness of all the other loss prevention programs. Every facility should formally adopt programs similar to those in *OVERVIEW*.

Personnel at facilities having large turbines can perform most activities *OVERVIEW* recommends. If a facility contracts out tasks, management must set up written procedures in advance to make sure the contractors comply with all loss prevention programs.

The following management loss control programs apply to turbines:

New Construction - Submit plans to AXA XL Property Risk Consulting for installing new turbines or substantially reworking existing units. Installing a large steam turbine is obviously a major undertaking. The probable life-cost of the unit can be significantly reduced if various loss prevention and control features are designed and built into the machine. API Standard 611, API Standard 612, and ASME PWR - Vol. 8, *Guidelines For Preparation Of Specifications For Steam-Turbine Generators* should be consulted. PRC.1.5.2 also contains recommendations.

Hazard Identification - Consider hazard analysis early when designing facility modifications and expansions. Update the analysis periodically to incorporate operating experience and aging effects. While turbine hazards are fairly well established, the turbine itself may be only a small part of the exposure. Extraction steam flow to and from the turbine and driven equipment performance can strongly influence the rest of the plant. Support system reliability influences the turbine hazards. Unit failure probability can change significantly because of changes in operating conditions and unit aging.

Employee Training - Steam turbines and their associated equipment are large, complex and expensive machines that are often critical to a facility's operations. Provide an ongoing formal training program for management, operation, maintenance and repair personnel.

Maintenance - Maintenance is the most important aspect of successful turbine operation. A properly designed and protected turbine that undergoes continued quality maintenance may require fewer overhauls. Maintenance programs are discussed in PRC.1.3.0.

Insurance Company Recommendations Provide a procedure for documenting and reporting evaluation of, and compliance with, insurance company recommendations. Insurance company surveys examine the effectiveness of loss control programs. Loss experience of turbines in many industries supports such recommendations.

Pre-Emergency Planning - Provide a pre-emergency plan for each facility. Steam turbines are usually vital to facility production. A turbine loss can severely upset the facility energy balance. A large turbine rotor can require a year to replace; a complete machine can possibly require longer. Spare rotating elements are one part of pre-emergency planning for turbines. This subject is discussed in PRC.6.0.1.0. Explore alternate means of production and ways to make temporary repairs.

Proper Housekeeping - Housekeeping and maintenance are strongly related. Sloppy plants seldom have good maintenance; plants with good maintenance are seldom sloppy. Turbines require cleanliness, corrosion control and minimal clutter.

Loss Prevention Inspection - Monitor loss prevention programs. Although properly trained equipment operators continuously inspect equipment, a trained inspector who periodically monitors the actual performance of the various loss prevention programs "on the ground" provides a more direct line to management. Property Risk Consulting Guidelines is designed to help a technically oriented person perform meaningful loss prevention inspections. When a turbine needs inspection, a larger facility might consider a specialty inspector; a smaller facility might consider a contract service.

Turbine Loss Prevention Inspection

A loss prevention inspector performing a turbine inspection reviews, records and witnesses selected operations and tests to determine that a turbine has been properly designed, constructed and installed and that it is being properly operated, maintained and repaired. A facility's loss prevention inspector may be an employee, a corporate staff member or a consultant under contract. AXA XL Risk Consulting clients may contact the AXA XL Risk Consulting Area Office to help set up an inspection program or audit an existing program.

Inspection Guidelines

Turbines need several kinds of inspections. Each should be performed under a program that produces suitable reports to management. The types of inspections are:

- Routine inspections by operators.
- In service inspections.
- At rest inspections.
- Dismantled inspections.

Specialized inspections, such as accident investigations, are not discussed in this section.

The following recommendations apply to any inspection:

- Provide the loss prevention inspector with access to a master maintenance data file for each piece of equipment. Even if the necessary information is not in one place, it should be readily accessible. PRC.6.1.1.0.2.A lists data that should be available. Any needed information which does not exist should be generated over a reasonable period of time. Additional maintenance systems which are needed should be recommended.

- Observe and report on housekeeping. This is a good indicator of facility personnel and management attitude toward the equipment.
- Review operating logs and records from the last inspection through the current date. There should always be a properly maintained written system. This may be supplemented where appropriate by electronic data systems. The condition and contents of the operating logs or records tell much about the attitude toward loss prevention.
- Audit the written operating procedures. Operators should have written procedures covering normal and emergency conditions. Normal operations include:
  - Startup and normal shutdown.
  - Transition between hot standby and other operating modes.
  - Steady state and transient operation at full and part load.
- The emergency conditions to be covered are site-specific, however, cover at least the following at all facilities:
  - Loss of the normal electric power or lubrication source.
  - Load rejection.
  - Overspeed or other loss of control.
  - Abnormal noise or vibration.
  - Activation of other installed alarms and protective devices.
  - Weather emergencies, including above- or below-normal temperatures (where applicable).
- Verify the condition of major spare parts. If parts are not on the premises (pool spares, those held by the manufacturer or in contract storage, etc.), confirm the arrangements.
- Review vibration monitoring and analysis programs; where applicable, audit data. Look for adverse trends that might have been missed.
- Audit the following additional items on an as-needed basis, periodically or as suggested by history.
  - Lubricating oil system reliability during any upset or utility outage. See PRC.6.1.1.0.5.
  - Trip valve, extraction valve and reheat intercept valve exercising and overspeed trip testing. See PRC.6.1.1.0.3.
  - Compliance with the ASME standard practice on water/cool vapor induction protection. See PRC.6.1.1.0.4.
  - Life extension analysis or activity for:
    - Major equipment more than 15 years old.
    - Reheat piping over 10 years old.
    - Other piping over 25 years old.
- Provide the loss prevention inspector with a checklist or a report guideline for each inspection tour. PRC.6.1.1.0.2.B suggests items to consider for in service or at rest inspections and PRC.6.1.1.0.2.C suggests items for dismantled inspections.

Routine Inspections by Operators

Routine inspections include most operator actions needed to monitor and control the machine. Document all important activities and periodic observations in a log. Promptly and formally report abnormal conditions to management. Operating specifics are outside the scope of this section, however, the following operator and support staff activities are recommended:

- Measure unit steam consumption. Changes in steam consumption under constant load usually indicate deteriorating conditions. A slow increase may indicate accumulated deposits or erosion damage. A sudden increase may indicate blade failure or foreign object damage. If

possible, measure steam consumption for the unit and for each casing, because problems in one casing may be compensated by altered conditions in other casings.

- Calculate unit efficiency. If steam flow measurement is not practical, calculate unit and casing efficiencies using inlet and outlet temperatures and pressures.
- Measure stage pressures. Changing stage pressures also indicate changes in the blading condition.
- Conduct casing temperature scans. Casing temperature changes may indicate internal leaks, which may be caused by damaged seals or distorted casings.
- Measure and analyze unit vibration. Vibration analysis can reveal more about machine condition than any other on-line technique. Operators must report any change in the nature or amount of machine vibration. Management must promptly respond to reported changes by providing analytical support.
- Measure shaft and casing differential movement. Carefully tracking the differential expansion between shafts and casings may reveal flexibility loss that may cause casing distortions and rubs. Flexibility loss may be caused by seized expansion joints or sliding feet.
- Inspect foundation bolts. Loose foundation bolts may indicate serious problems which will adversely affect the machine alignment. Promptly investigate any foundation looseness or insecurity.
- Closely monitor bearings. Constant attention to bearing temperatures and lubrication temperature differentials is needed to detect deteriorating bearings. Subtle changes in the lubrication system pressure balance may indicate bearing deterioration before bearing temperature increases occur. Wear particle analysis may signal deterioration before any other symptoms appear.
- Perform the following inspections during jacking gear operation:
    - Listen for clanking or scraping noises, particularly near shaft penetrations. These noises may indicate misalignment or shaft or casing distortion.
    - Check the power required by the jacking gear and compare it to the power required during previous jacking gear operation. An increase in power consumption may reveal binding or rubbing in the unit. Readings may need to be adjusted for different unit temperatures or other factors.
- Perform the following inspections during shutdown:
    - Check rotor axial and radial position and shaft runout. This is most effective on machines that have borescope ports at suitable measuring points. Some measurements can be taken at coupling flanges by using a dial indicator.
    - Inspect the internals through borescope ports, drain connections and other casing penetrations. Modern instruments can provide a reasonably thorough internal inspection without the casing having to be lifted. Examining internal parts such as nozzles and blading provides information that is critical to overhaul decisions. Therefore, machines which require long intervals between overhauls should have borescope ports retrofitted to allow the most complete internal inspection possible. Consult the turbine manufacturer concerning the size and location of borescope openings.
    - Take bearing measurements. Depending on the bearing design, bearing inspections may also be possible if necessary.

In Service, At Rest and Dismantled Inspections

Turbines should be periodically inspected and their operating and maintenance records reviewed by a trained person from outside the operating department. All turbines should have a monthly in-service or at-rest inspection.

Turbine overhaul frequencies depend upon their size, age, service and history. It is recommended that turbines be overhauled:

- Every two years for turbines under 1000 hp (750 kW).
- Every three years for turbines 1000 hp (750 kW) to 10,000 hp (7,500 kW). If units are monitored as described below, and they have no known adverse conditions, the interval for machines in continuous service may be increased to five years.
- Every 50,000 equivalent operating hours (T_e) for turbines over 10,000 hp (7,500 kW). T_e is determined by the following formula:

$$T_e = T_a + 25n_s$$

Where: $T_e =$ equivalent operating hours

$T_a =$ actual operating hours

$n_s =$ number of starts, including cold and hot starts

If full monitoring is performed and there are no known or suspected adverse conditions, the interval for machines in continuous service may be increased to seven years. The overhaul interval should never exceed seven years. Full monitoring includes:

- Installed vibration monitoring equipment including alarms and automatic shutdown for high vibration and rotor axial position out of limit.
- All recommended protective devices in service.
- Wear particle analysis performed.
- Inspections conducted at least annually after three years of operation through borescope openings that permit all nozzles, blading and throttle valves to be inspected.

STEAM TURBINE UNIT LOSS PREVENTION DATA

The master maintenance data file for each facility should include the following information. The information suggested is minimal. Every installation will require additional site-specific data.

FACILITY INFORMATION

- A sketch or drawing of the steam system which identifies major steam sources and loads. Show all reducing stations and cross connections. The following information should be available:
  - Capacity of each steam source, including steam turbine extraction, under all conditions.
  - Amount of steam required by each load under all conditions.
  - Priority of steam loads for emergency load shedding.
  - Capacity of reducing stations and cross connections, considering all required desuperheaters or attemperators.
- Copies of the facility pre-emergency plans which involve the turbine(s) and auxiliary equipment. Where applicable, include a plan for cold start or emergency restart without the normal outside power source. List the type, capacity and fuel availability for all backup engine or gas turbine-driven emergency generators on site and for all available outside or emergency power sources.
- Copies of the normal and emergency operating procedures.
- The vibration analysis program manual, which should include descriptions of all unusual or advanced techniques being used, such as remote condition analysis or on-line rotor crack monitoring.
- Other maintenance program documentation, including:
  - Copies of all loss prevention inspection reports.
  - A summary of required activities and their frequencies.
  - Predictive maintenance parameters and the levels at which they require attention.
  - A list of time-based activities and the dates they were last performed.
  - An up-to-date file of contact persons for all maintenance contractors.
- A description of the instrumentation calibration and testing program.
- The manufacturers' recommended temperature rate-of-rise curves and the procedures to ensure that they are being used.
- Measures being taken for equipment over 15 years old to monitor age-related conditions, such as stress cracking, fatigue hardening or creep, that may signal the end of life.
- A copy of those portions of the facility hazard evaluation dealing with the turbine(s), driven equipment and associated processes.
- A file showing the status of all insurance company recommendations involving the turbine(s) and related equipment.

UNIT INFORMATION

Each unit file should identify the components associated with the unit, including the turbine, the driven object, any gear set and all auxiliary systems. A description of the production exposure for the unit is useful. A description of all hazards resulting from unscheduled shutdowns of the unit is essential.

The unit file should also contain:

- An up-to-date set of prints for all unit systems, such as lubricating oil and cooling.
- Coupling data and data on all clutches, turning gear or other accessories.
- Location and plan for installing spare or alternate drivers or driven equipment.
- Details of foundations, piping flanges and other connections.
- A list of derates and forced outages. For each event, provide the date, components involved, cause and resolution.
- Copies of all inspection and overhaul reports, including information concerning all modifications, upgrades and major repairs.
- Log of overspeed, low oil pressure, vibration and other alarm and trip tests and results.
- Setpoints for all alarms and protective devices. Provide the data used to support current setpoints for devices whose settings may be modified in response to operating experience, such as vibration alarms and trips.
- Copies of inspection and test reports for valve exercising.

STEAM TURBINE INFORMATION

Each turbine file should include:

- Unit Number.
- Nameplate data, including the manufacturer and all ratings.
- Dates the unit was built, installed and commissioned.
- An up-to-date set of prints, including all modifications, alterations and repairs, and all manufacturer's instructions.
- All steam and auxiliary fluid temperatures, pressures and flow rates.
- Prints and manuals for the governor, trip valve lubrication system and other accessories, including the condenser, if applicable.
- List of major spare parts and their locations.
- Log of performance (heat rate) tests.
- Schedule and performance log for exercising and testing extraction and nonreturn valves.
- A record of any history of difficulty because of steam contaminants, and a description of the monitoring performed or other action taken.
- An evaluation of the unit water/cool vapor induction protection.
- Records of borescopic or other partial internal inspections performed between overhauls.
- Complete records of all casing or rotor cracks and actions taken.
- Copies of all applicable manufacturer's suggested modification reports (TIL's, etc.).

GENERATOR INFORMATION

Each generator file should include:

- Unit Number.
- Nameplate data, including the manufacturer; all ratings and exciter data.
- Dates the unit was built, installed, commissioned and, if applicable, rewound.
- An up-to-date set of prints, including all modifications, alterations and repairs, and all manufacturer's instructions.
- All auxiliary fluid temperatures, pressures and flow rates, including lubricant, cooling medium, and, if applicable, hydrogen.
- A list of installed electrical protective devices provided and a log of all tests and results.

- Log of electrical tests.
- List of major spare parts and their locations.
- Complete information concerning any retaining ring cracks.
- Records of borescopic or other partial internal inspections performed between overhauls.
- Copies of any applicable manufacturer's suggested modification reports (TIL's, etc.).

OTHER DRIVEN EQUIPMENT INFORMATION

The file for each piece of driven equipment should include:

- Unit Number.
- Type of object.
- Nameplate data, including the manufacturer and all ratings.
- Dates the unit was built, installed and commissioned.
- An up-to-date set of prints, including all modifications, alterations and repairs, and all manufacturer's instructions.
- Temperatures, pressures and flow rates for all process and service fluids.
- Prints and manuals for protective systems such as surge control for compressors.
- Log of performance tests.
- Records of borescopic or other partial internal inspections performed between overhauls.
- List of major spare parts and their locations.

GEAR INFORMATION

Each gear set file should include:

- Unit number.
- Nameplate data, including the manufacturer and all ratings.
- Dates the unit was built, installed and commissioned.
- An up-to-date set of prints, including any modifications, alterations and repairs, and any manufacturer's instructions.
- Temperatures, pressures and flow rates for externally supplied coolants and lubricants.
- Records of borescopic or other partial internal inspections performed between overhauls.
- List of major spare parts and their locations.

STEAM TURBINE LOSS PREVENTION DATA IN-SERVICE OR AT-REST INSPECTION

The following information should be gathered or observed during a steam turbine loss prevention inspection. See PRC.6.1.1.0.1. A for a list of data that should be available to the inspector. Note that the information suggested is minimal. Every installation will require additional site-specific data.

Reviewing logs and records is necessary for any inspection. The activities listed below apply to in-service inspections. An at-rest inspection should involve similar observations. At-rest inspections should, if possible, be scheduled to coincide with borescope inspections or other maintenance activities.

Before conducting the inspection, review the operating and maintenance records collected since the last inspection. The following items, as applicable, require particular attention:

- The most recent dismantled and inservice inspection reports.
- Records of all unscheduled maintenance outages, forced outages and derates since the last inspection.
- All notices of overdue inspections, maintenance or testing.
- Records of adverse conditions found by loss control programs, including but not limited to:
  - Vibration monitoring.
  - Safety device testing.
  - Lubricating oil wear particle analysis.
- The list of outstanding insurance company recommendations.

Walk down the unit, noting visible deficiencies. The following suggestions may help to develop an inspection checklist.

- Note the steam pressure(s), temperature(s), speed(s) and the load. If possible, calculate the thermal efficiency of the whole turbine and each section. Compare the value(s) to previous data.
- Examine exhaust or condenser overpressure protective devices. Verify proper test or inspection procedures and frequency.
- Inspect the governor system for leaks, looseness, binding, or other adverse conditions.
- Verify the machine speed for preset governors; verify machine speed, responsiveness and control limits for variable governors.
- Verify proper frequency and procedure for testing overspeed protection devices.
- Inspect the lubrication system; note bearing temperatures and oil flows and compare them with previous readings. Test the backup oil pump(s) automatic start and the low oil pressure alarm and trip.
- If possible witness, or otherwise verify written records of trip valve, control valve and extraction valve exercises.
- Review records of all control system testing.
- Collect vibration readings to compare with previous data. If vibration monitors are not installed, obtain a set of manual readings. Also, listen carefully for any abnormal noise.
- Examine piping systems for suitable support. Look for loose, damaged or “bottomed out” hangers, and freedom of expansion. For steam systems in service, check for proper drain operation.

- Review written operating instructions, operator training records and results of all drills.
- Review the maintenance program and report all overdue activities or other deficiencies.
- During the tour, note all housekeeping deficiencies, including damaged insulation, improperly stored materials, temporary structures of any kind or leakage of any substance.

STEAM TURBINE LOSS PREVENTION DATA DISMANTLED INSPECTION

The following information should be gathered or observed during a steam turbine loss prevention inspection. See PRC.6.1.1.0.2.A for a list of data that should be available to the inspector. Note that the information suggested is minimal. Every installation will require additional site-specific data.

Reviewing logs and records is necessary for any inspection. The activities listed below apply to dismantled inspections. One inspector will probably not make all the suggested observations; therefore, make records of activities available for review.

Before conducting the inspection, review the operating and maintenance records collected since the last inspection. The following, if applicable, require particular attention:

- The most recent dismantled and in-service inspection reports, particularly any list of items deferred from the last dismantled inspection.
- Records of all unscheduled maintenance outages, forced outages and derates since the last inspection.
- All notices of overdue inspections, maintenance or testing.
- Adverse conditions found by loss control programs, including but not limited to:
  - Vibration monitoring.
  - Safety device testing.
  - Lubricating oil wear particle analysis.
- The list of outstanding insurance company recommendations.

Walk down the unit, noting any deficiencies. Several visits will be necessary. Also, most dismantled inspections are coordinated or supervised by a manufacturer's representative. Loss prevention activities should be coordinated with this individual. These suggestions may help to develop an inspection checklist.

- Witness lifting of the turbine casing. Visually examine and describe in writing or photograph any obvious problems, including rubbed spots, foreign objects or foreign object damage, missing parts, corrosion or deposits.
- Inspect the rotor "as-removed." Make sure samples of deposits are taken for analysis before the rotor is cleaned for nondestructive examination. Nozzle diaphragms should also be examined after they are removed and before they are cleaned.
- Inspect the steam chest, nozzle block and all associated valves, linkages and other components, including the main steam stop, the trip throttle valve and its mechanism, nonreturn valves, reheat valves, the governor and the overspeed trip(s).
- Visually and nondestructively examine the steam strainer.
- Witness the testing or review the nondestructive test reports of all blades, blade attachments, shrouds, lacing wires, nozzles, disks, and valve parts.
- Verify weld repairs of cracks and removals of minor damage by grinding or straightening.
- Inspect all bearings and measure clearances; inspect seals and packings.
- Examine the shaft adjacent to shrink-fit disks for any evidence of axial or radial movement or fretting corrosion. Examine all keyways for cracks.
- Inspect all lubrication system components while dismantled, including main, auxiliary and shaft-driven pumps and their prime movers, the sump and coolers.

- For condensing units, inspect the condenser or review the inspection reports.
- During reassembly, check clearances between moving and stationary parts. Compare readings with those on file.
- Witness or review the records of alignment checks.
- Examine piping systems for suitable support, loose, damaged or “bottomed out” hangers, and freedom of expansion.
- Review the maintenance program and ensure all noted deficiencies are included in the scope of work.
- During the tour, note all housekeeping deficiencies, including damaged insulation, improperly stored materials, temporary structures or equipment or any leakage. Verify all tools and materials in the work area are under control.
- Witness the initial startup of the unit and the overspeed trip test.