COMBUSTION TURBINE LOSS PREVENTION GUIDELINES

INTRODUCTION

This section provides loss prevention guidelines for combustion turbines. PRC.6.1.2.1 explains features, operational concerns and terminology common to most combustion turbines. PRC.6.1.2.3 describes combustion turbine loss prevention inspections. The focus of this section is stationary machines rated 5 MW or more. Combustion turbines for aircraft, marine, rail and other propulsion applications are similar to stationary units, but may have additional features and design and regulatory requirements. Small units could have different design and maintenance philosophies. For information about a specific type of turbine or installation, consult the manufacturer's literature.

POSITION

Maintenance quality is the most important factor in combustion turbine availability and reliability. Maintain combustion turbines in accordance with the manufacturer's recommendations. Use parts, lubricants and other supplies that are approved by the manufacturer. Do not permit unqualified persons to operate or maintain combustion turbines.

Combustion turbines arguably stress their materials of construction more severely than any other commonly-used machines. Exceeding manufacturer-specified limits during operation will rapidly age and may catastrophically damage a combustion turbine unit. Therefore, use all available means, including programmed controller limits and operating instructions, to keep all operating parameters within the window specified by the manufacturer. Log and investigate any operation outside the specified window. Analyze the possible effects of such operation and adjust maintenance schedules as needed.

Because they are such highly loaded, complex systems, combustion turbines are often subject to redesign and corrective action by their manufacturers. Ensure that all manufacturer's bulletins concerning possible problems and recommended solutions are received, reviewed and acted upon.

Fire Protection

Combustion turbine and external fuel system fire protection are discussed in NFPA 850, PRC.17.12 and PRC.17.12.1. For oil hazards, including lubricating and control oil systems, hydrogen and electrical hazards outside the turbine unit enclosure, follow the recommendations for steam turbines. Protect inside the turbine enclosure with a CO_2 system designed in accordance with NFPA 12 and PRC.13.3.1 or with water spray or water mist. Water spray may be hazardous to the turbine and water mist is a developing technology; therefore, arrange for AXA XL Risk Consulting review of these systems early in their planning. Submit plans for all fire protection systems to AXA XL Risk Consulting for review before the systems are installed.

Provide an interlock that shuts down the machine and isolates and vents or drains all fuel sources upon initiation of the fire protection system.

Design and Installation

Installing a combustion turbine introduces several hazards to a facility. Management hazard evaluation and, for newly installed units, management-of-change programs, must identify and control these hazards. Combustion turbines also require highly trained operators and maintenance technicians and a strong maintenance program. Plan ahead.

Specify combustion turbines to provide the needed power output under the conditions that will be encountered. Pay particular attention to ambient temperature because of the strong effect inlet temperature has on available power. Bring any predictable air and fuel contaminants to the turbine supplier's attention and specify blade coatings that will resist the effects of these materials.

For advanced design and upgraded machines, verify that the manufacturer has sufficiently tested the new design or upgrade. Sufficient testing means operation with acceptable availability and reliability at the required ambient conditions, fuel properties, output levels, internal parameters and emission levels. Ensure testing has taken place under similar operating modes, e.g., frequent starts for units intended for peaking service.

Table 1 highlights design features and Table 2 highlights instruments and control devices. Although no combustion turbine should be without any of the features or protective devices noted, neither list is necessarily complete for any particular unit. Apply the manufacturer's recommendations for any additional features and devices. Table 3 suggests testing intervals for various instruments.

TABLE 1
Combustion Turbine Design Details

Location	Detail	Hazard	Consequence avoided
Inlet structure (<40ºF [5ºC])	Compressor recirculation, heaters, etc.	Icing	Surging, foreign object damage (FOD)
Compressor blading	Coating	Corrosion	Pitting (at rest)
Compressor blading	Resonant frequency analysis	Blade vibration (1)	Fatigue failure
Compressor	Surge mapping	Surge	Catastrophe
Turbine blading	Coating	Corrosion	Pitting (at rest)
Turbine blading	Resonant frequency analysis, blade profile adjustment	Blade vibration (1)	Fatigue failure
Overall unit (2)	Borescope ports	Various	Various
Exhaust ducting	Pressure relief	Overpressure	Rupture
Lubrication system	Primary, standby and emergency (3)	Lubrication failure	Bearing damage; machine wreck
Gaseous fuel valving	Double block and vent	Fuel leakage into machine	Loss of machine control, internal fire or explosion
Liquid fuel valving	Double block and drain	Fuel leakage into machine	Loss of machine control, internal fire

Notes to Table 1:

1. Ensure individual blade and blade assemblies are tuned to avoid resonant frequencies that will be excited by any expected vibration. For variable speed units, ensure speeds corresponding to blade resonant frequencies are identified and that operation at those speeds is prohibited.
2. Provide borescope ports to allow inspection of critical compressor, combustor and turbine components without lifting the casing.
3. The emergency lubricating oil source must be powered by a highly reliable energy source such as a dedicated battery bank. See API 614 for more information on lubrication systems.

TABLE 2
Combustion Turbine Instruments

Instrument	Indication	Alarm	Shutdown	Comment
Vibration	x	x	x	
Rotor axial position	x	x	x	All shafts
Overspeed	x	x	x	Two independent overspeed trips for each shaft. One trip may be waived for shafts driving only compressors.
Inlet filter pressure differential (high)	x	x	1	
Compressor surge - machines with steam injection to the power turbine	x	x	x	
Compressor surge - all others	2	2	2	
Compressor discharge pressure	x	x		
Compressor discharge temperature	x			
Compressor performance	3			Clean when indicated; inspect if cleaning does not renew performance
Fuel pressure (low)	x	x	x	
Cooling air flow	x	x	x	Monitor flow rate or pressure differential
Combustor flameout	x		x	Two detectors per combustor; trip fuel valve in less than 750 ms.
Turbine temperature (high)	x	x	x	Average outlet temperature
Turbine temperature (spread)	4	x		Immediately investigate and correct any reading which is more than 100ºF from the mean or abnormal
Lubrication temperature (low)	x		5	
Lubrication system pressure (low)	x	x	x	Also alarm on startup of backup lubrication sources
Bearing temperature (high)	6	x	x	
Guide vane angle	x	x		
Fire protection system	x	7	x	

Notes to Table 2:

1. Required when snow, icing, sand or other substance may suddenly clog the filter.
2. Protect from surge by operating limitations based upon design. Ensure margin-to-surge is maintained by analyzing the daily performance calculations recommended by the manufacturer.
3. Calculate per manufacturer’s instructions.
4. Observe at all times. Some dangerous deviations that are observable during startup may disappear at high power, with potentially catastrophic results.
5. Start up permissive interlock to require minimum temperature.
6. Bearing metal temperature preferred for radial bearings and required for thrust bearings. Oil drain temperature is acceptable for radial bearings.

Transmit fire alarms to a constantly manned emergency response center.

TABLE 3
Instrument Testing Intervals

Backup and emergency lubricating oil pump automatic start; low lubricating oil pressure alarm.	Weekly
Overspeed trip	Exercise quarterly (1) Test annually (2)
All other automatic protective devices and instruments.	Calibrate and test annually or as directed by the manufacturer.

Notes to Table 3:

1. Trip the machine using a simulated overspeed signal if possible or manually using the same mechanism as a mechanical tripping device.
2. Actually overspeed the machine, taking precautions to keep control of the machine speed at all times. Not required for units driving compressors.

Provide a suitable foundation, properly damped and free of external vibration. If possible, locate the turbine where it will not be subject to unnecessary ambient temperature excursions, such as those caused by direct sunlight that will complicate alignment.

Design air inlet structures to provide suitably clean air uniformly over the compressor inlet. Arrange air inlets so they will not ingest wind-blown contaminants such as sand, rain or salt water spray, or combustion products from any source. Provide heat when necessary to prevent icing.

Provide fuel of suitable quality. The attention required varies with the type of fuel. Pipeline natural gas, once its characteristics are established by contract, usually requires only minimal filtering; however, trace contaminants and materials added to adjust the fuel value of the gas may complicate operations, particularly with pollution control equipment. Each delivery of distilled fuels should be sampled and analyzed to avoid problems caused by heavy metals, sulfur, bacteria and other contaminants. Crude oil, waste and process gases and other low-grade fuels need more frequent sampling.

Use noncombustible materials for inlet structures, silencers, sound deadening insulation and filters, or provide fixed fire protection.

Consider using less combustible lubricating and hydraulic fluids. See PRC.9.2.4 for more information. In all cases, periodically analyze fluid samples for lubricant quality control and machine condition. For less combustible fluids, analyze as necessary to ensure continued fire resistance.

For machines in hazardous or remote locations or in locations with limited available fire protection resources, consider magnetic bearings. Where they can be effectively applied, particularly in machines without gears or other large asymmetrical load sources, magnetic bearings can eliminate the need for a lubricating oil system. At the present state of the art, all magnetic bearing installations must be custom engineered.

Units that must start on demand during any conditions require backup ac or dc power for starting, for mechanical, fuel system and electrical controls, and for the following:

- Lubricating oil heating and circulating and control panel heating for low ambient temperature installations.
- Generator and engine compartment heating.
- Fuel oil heating and circulating for units firing heavy fuels or in low ambient temperatures.
- Block or circulating water heaters for diesel starting engines in low ambient temperatures.
- Control compartment air conditioning for high ambient temperature installations.
- Battery charging.

Provide quality control monitors during shop or field assembly of combustion turbines. Witness or review important tests to verify proper performance and setup of all instruments and protective devices and to ensure proper balance and alignment under all anticipated operating and ambient conditions. Also ensure complete benchmark data is collected and recorded. Benchmark data will include at least the following:

- Complete clearance (as assembled), runout, balance and alignment information.
- Complete vibration signature.
- Compressor performance map, with actual operating points plotted.
- Unit performance data, including initial values of all performance indices.

For units in combined cycle or any other service that involves using exhaust gas in a downstream process, determine the importance of the downstream process and of the combustion turbine mechanical output. Where either is important, provide dampers, auxiliary burners and other equipment needed to allow operating the turbine or the process separately.

Operation and Maintenance

Combustion turbines challenge management training programs. These machines require highly qualified operating and maintenance personnel and contractors. Use formal training and qualification programs and document all operating and maintenance procedures. Provide refresher training and requalification annually.

Assign a responsible person to review these programs annually and keep them up to date as technology changes. Maintenance is the most critical factor in combustion turbine reliability. Therefore, a strong management maintenance program is required.

Maintenance often requires hot work and may possibly require fire protection system impairments. Ensure both activities are properly managed. Housekeeping is a vital part of operations and maintenance. Ensure both contractors and employees comply with all management loss prevention programs.

Combustion turbines are complex systems. Subtle changes in operating parameters, clearances or component shapes can have disastrous consequences. Therefore, scrupulous record keeping is required. Use forms recommended by the manufacturer.

Minimize stress by avoiding rapid starts and operation above the nominal rating. If possible, provide a running cool down period after unloading before shutdown.

Provide alternate fire protection at all times when the primary fire protection system is disabled for any reason. After operation and before opening any casings, always purge potentially combustible fumes, generally by isolating all fuel, purging the fuel system, and cranking the unit for at least 5 min.

Match mark piping, fuel nozzles, couplings and casings to facilitate proper reassembly. If possible, keep "symmetrical" parts such as fuel nozzles, combustors and transition pieces as sets. Never replace part of a set of balanced components, such as liquid fuel nozzles or turbine or compressor nozzles or blades, without satisfying all the manufacturer's criteria to be certain the new member(s) of the set match the remaining members.

Do not mark on any combustion system or on turbine components with any compound not certified free of lead, sulfur and other compounds that may attack the alloys used. If certified markers are not available, use tags wired to the parts, but avoid aluminum and other low-melting-alloy wires.

Do not force flanged fittings into alignment. If flanges cannot be moved within ⅛ in. (3.175 mm) of parallel by hand, realign or replace the piping.

TABLE 4

Dismantled Inspection Intervals

Type of Inspection	Type of Fuel	Suggested Interval (hr) 1 start/1000 fired hr	1 start/25 fired hr	1 start/1 fired hr
Combustion	Gas	5000 to 8000	2500 to 4000	500 to 800
	Distillate	4000 to 8000	2000 to 4000	400 to 800
	Heavy	1500	750	150
Hot Gas Path	Gas	18,000 to 22,000	9000 to 11,000	1800 to 2200
	Distillate	14,000 to 20,000	7000 to 10,000	1400 to 2000
	Heavy	8000 to 10,000	4000 to 5000	800 to 1000
Major	Gas	35,000 to 45,000	17,500 to 22,500	3500 to 4500
	Distillate	30,000 to 40,000	15,000 to 20,000	3000 to 4000
	Heavy	20,000 to 25,000	10,000 to 12,500	2000 to 2500

Take clearance readings using standard precautions, including:

- Take axial readings with the rotor positioned toward the compressor inlet. Release any pressure used to position the rotor before taking readings.
- Do not use snap gauges on beveled surfaces.
- Do not use taper gauges for radial clearances or where the gauge may bottom out on an internal or curved surface.

Maintenance Scheduling

Combustion turbine maintenance is strongly influenced by the operating mode. When calculating maintenance intervals, consider the load (as it affects turbine inlet temperature), the starting frequency, rapid vs. normal starts, the ratio of the number of starts to the number of operating hours and the preload warm up interval, the type of fuel, the environment, and maintenance practices.

Consult the manufacturer and consider unit experience when calculating maintenance intervals. The guidelines in Table 4 are typical for an industrial machine operating continuously, with no more than one start per 1000 fired hours.

The effect of fuel type varies widely as shown in the table. Fuel contamination causes further variation.

The number of starts per fired hour generally does not have much influence on maintenance intervals until the ratio exceeds one start per 100 fired hours, however, the intervals shrink rapidly above that value. A machine with 1 start per 25 fired hours is likely to have maintenance intervals one-half those in the table. A machine with 1 start per fired hour is likely to have maintenance intervals one-tenth those in the table. Operating above the base load rating greatly reduces the maintenance interval. Machines operating at their peak load rating may require intervals one-third those shown in the table.

This table is for guidance only. For any particular turbine unit, particularly aero derivative units, contact the manufacturer for specific information.

For any unit not in regular service, operate the lubrication system and run the unit on the turning gear weekly. At least bimonthly, operate the unit at least one hour under load and collect and record operating data.