Property Risk Consulting Guidelines

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PRC.6.1.2.1

COMBUSTION TURBINE PRINCIPLES

INTRODUCTION

This section describes features, operational concerns and terminology common to most combustion turbines. 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. Units smaller than 5 MW could have different design and maintenance philosophies. For information about a specific type of turbine or installation, consult the manufacturer's literature.

Combustion turbines present significant exposure to loss caused by mechanical breakdown, fire, explosion and resulting business interruption. This section introduces mechanical breakdown issues and internal fire protection. PRC.6.1.2.2 further develops these issues and offers specific recommendations. External fire protection for combustion turbines and their fuel systems and other fire- and explosion-related issues are discussed in NFPA 850, PRC.17.12, PRC.17.12.1 and PRC.6.1.2.2.

BASIC FEATURES

There are two main types of stationary combustion turbines: "aircraft derivative" or "aeroderivative"; and "industrial" or "heavy duty." Aircraft derivative turbines are based on aircraft propulsion designs. Their performance is generally limited by highly stressed compressor section components. Industrial machines are designed strictly for stationary service. Their performance is generally limited by high-temperature turbine section components.

Nearly all combustion turbines contain a compressor, a combustion section and a turbine. The compressor boosts the pressure of the inlet air. The combustion section mixes fuel with the compressed air and burns the mixture, forming a hot compressed gas stream. The turbine converts the energy in the hot compressed gas stream to mechanical energy by accelerating the stream through nozzles, then transferring the energy of the flowing gases to moving blades. The moving blades are mounted on wheel(s) or disk(s) which rotate the shaft.

Combustion turbines exhaust a mixture of air and combustion products. The mixture is hot enough to be useful. The energy in the exhaust produces steam in a waste heat steam generator or heat recovery steam generator (HRSG). A few processes use combustion turbine exhaust gases directly for heating or drying materials in process. Whether the exhausted energy is used directly or to generate steam, the downstream process can be interrupted if the turbine unit fails. The turbine output can be lost if no alternate exhaust path is provided and the downstream process fails or is not required.

Steam or water may be injected into a combustion turbine unit for three reasons:

- Heavy fuel atomizing, by direct mixing with the fuel.
- Nitrogen emission (NO_x) control, by modifying the combustion reaction.
- Power output boosting, by expanding the steam through the turbine.

Several steam and water injection schemes have been developed. In all cases, high quality steam or water is required to prevent accelerated fouling and corrosion.

Compressors

Nearly all modern combustion turbines use multistage axial compressors. Some units have also been built with centrifugal compressors.

Modern combustion turbine compressors generally have between 10 and 15 axial compression stages which develop approximately 100 psi – 230 psi (6.9 bar – 16 bar) discharge pressure. Compressor blades are made of special high-strength alloys. Blade designs are complex so the blades will resist vibration and perform optimally under varying loads. The blades have special, often proprietary coatings to improve the aerodynamic properties and resist erosion, corrosion and fouling. These coatings at times can be considered exotic and proprietary with the OEM’s very protective of the material make up. All TIL’s (Technical Information Letter) and Bulletins should be strictly followed.

Compressor performance loss is sometimes the limiting factor in combustion turbine unit overhaul scheduling. On-line and off-line compressor cleaning methods are available to reduce compressor fouling, but if cleaning does not restore performance, or if the blade coating fails, dismantling is required.

Combustion Sections

Although combustion turbines have been designed to burn many fuels, including by-product gases, heavy and residual oils, and pulverized coal, the majority are designed to burn natural gas, light oils (“distillates,” such as diesel fuel or naphtha) or a combination of the two. Fuel supply systems for combustion turbines are similar to those for boilers, but combustion turbine fuel systems have additional safety and control inputs necessary for machine protection and operation.

A forwarding system delivers fuel at the correct pressure to one or a series of fuel nozzles. Most modern combustion turbines have an annular group of combustors surrounding the machine between the compressor and the turbine. The fuel mixes with air and burns in combustors, or “cans.” Transition pieces conduct products of combustion to the turbine. Some units, particularly those designed to burn fuels such as pulverized coal, have large combustors mounted alongside the unit. Combustor design is complex, because the combustors must efficiently burn fuels at varying rates in a highly turbulent environment. At the same time, the combustor surface temperature must be controlled to avoid failure. Therefore, the cans are designed to produce a central hot flame surrounded by a thin cooling air layer. NO_x emission controls contribute additional complexity.

Turbines must have nearly uniform circumferential temperature distribution or intolerable stresses result. Blades alternating between the cooler and hotter areas will thermally fatigue and fail quickly. To avoid problems in units with annular combustors, proper fuel distribution and equal nozzle/combustor/transition piece performance are necessary. Monitoring, recording and plotting the “temperature spread” are important trending on-line maintenance tasks. Predefined points should be determined where further investigation must be made.

Turbines

Like the compressor, the turbine consists of one or more sets, or stages, of fixed and moving blades. The turbine converts the energy in the combustion products to useful work. The fixed blades are called nozzles and the moving blades are often called buckets. Because they operate at very high temperatures, turbine blades and nozzles are generally made of exotic alloys or ceramics. Some of these coatings are new or have not been proven as long term materials. Turbine blades often have drilled passages or are entirely hollow to provide a path for cooling air flow. Additional holes are sometimes drilled at nozzle and bucket leading edges to cool the “boundary layer” at the nozzle or bucket surface.

Cooling air flow in hot areas is necessary for long-term operation. Instruments that measure flow rate or differential pressure in the cooling system should be provided.

Turbine nozzles and blading are often the limiting factor in combustion turbine overhaul scheduling. Much of the inspection activity required on these units is focused on controlling conditions in this part of the machine and shutting down for repair before serious failures can occur.

Shaft Arrangements

Most stationary combustion turbines have one or two shafts. Single-shaft machines are simpler and may be more efficient at full load. They are most often used for constant-speed loads such as generators. Figure 1 is a single-shaft combustion turbine. Most single-shaft machines are directly coupled to the driven load; however, reduction gears may be used.

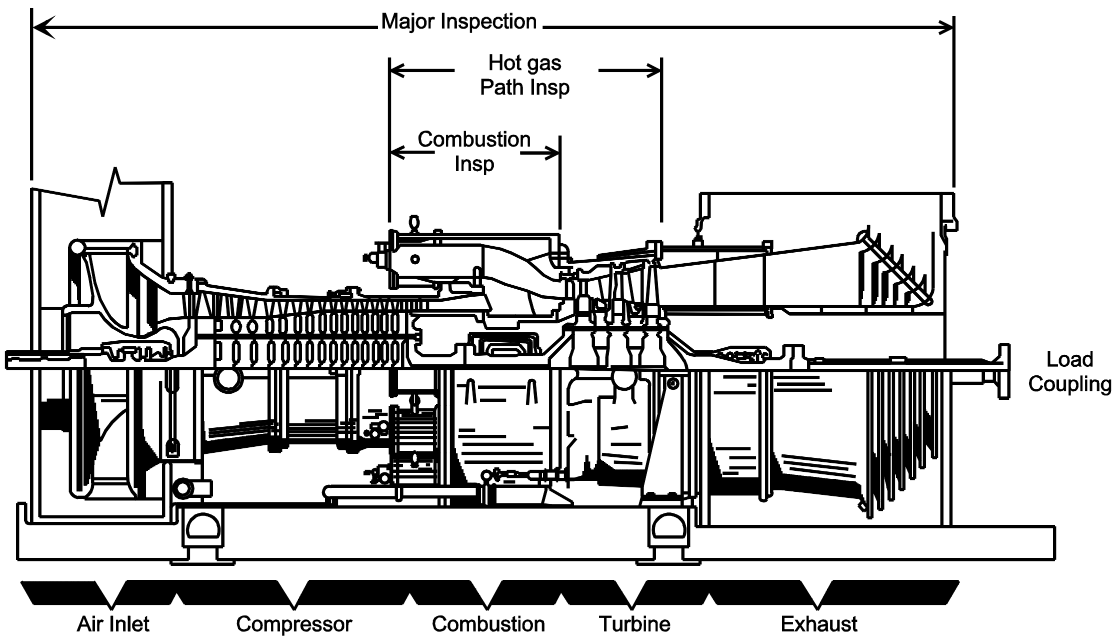

Figure 1. Single Shaft Combustion Turbine, Showing Inspection Scopes.

Two-shaft machines tend to be easier to start and to run more efficiently at partial loads. The compressor and the first turbine stage are mounted on one shaft. The other turbine stage(s) are mounted on another shaft, which is connected to the load. Two-shaft machines are most often used for variable-speed loads such as pumps and compressors.

Two-shaft machines are sometimes assembled from components made by different manufacturers. The unit consisting of the compressor, combustion section and first turbine stage is called a gas generator. The turbine connected to the load is called a free turbine.

Three-shaft machines have occasionally been built. Generally, the first compressor section and the second turbine section are on one shaft, the second compressor section and the first turbine section are on another shaft, and the third turbine section and the load are on the remaining shaft.

Auxiliary Heat Exchangers

Regenerators, recuperators, HRSG’s and other heat exchangers are used in various combustion turbine cycles. All combustion turbine heat exchangers operate at high temperatures, volume flow rates and velocities. The hot fluid often contains particulates and the cold fluid may enter below the dew point. These conditions cause erosion and corrosion; high alloy tubes, coatings and cladding are commonly used to obtain adequate heat exchanger life.

Low water in a HRSG can be a problem. In general, low water in the steam generator must cause a turbine trip to minimize damage. If a low water turbine trip cannot be tolerated, an automatic exhaust bypass with manual backup must be provided or the steam generator must be designed to run dry without damage.

COMBUSTION TURBINE CYCLES

Combustion turbines can be arranged in many ways. A **simple cycle** combustion turbine unit consists of a compressor, combustion section and turbine. The turbine exhausts to atmosphere. Figure 1 is a typical simple cycle combustion turbine.

Efforts to improve efficiency have produced many other combustion turbine arrangements. An **intercooled** combustion turbine has a compressor separated into two or more sections. These sections can be on the same or different shafts. A heat exchanger cooled by an external cooling medium improves compressor efficiency by cooling the air between compressor sections. Figure 2 is a block diagram of an intercooled combustion turbine.

A combustion turbine in a **recuperation** or **regeneration** cycle exhausts to a heat exchanger that heats the compressor discharge air before combustion. Figure 3 is a block diagram of a recuperated combustion turbine.

A **reheated** combustion turbine has a turbine section separated into sections. Fuel added to an additional combustion section located between the turbine sections raises the gas stream temperature at the second stage turbine inlet. Figure 4 is a block diagram of a reheated combustion turbine.

Several combustion turbines have been built using **complex** cycles — cycles that combine more than one of the previously-listed features. Figure 5 is a block diagram of such a combustion turbine.

A **Cheng** cycle is one variation of a combustion turbine cycle using steam injection at the turbine inlet to improve efficiency. The steam expands through the turbine along with the products of combustion from the combustors to produce additional power.

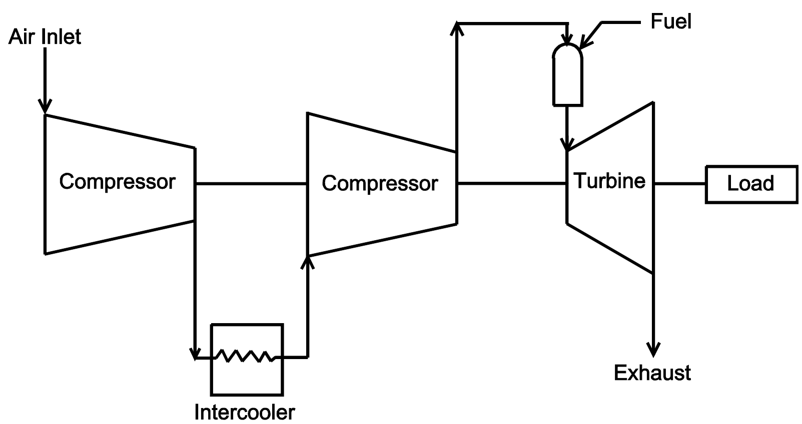

Figure 2. Intercooled.

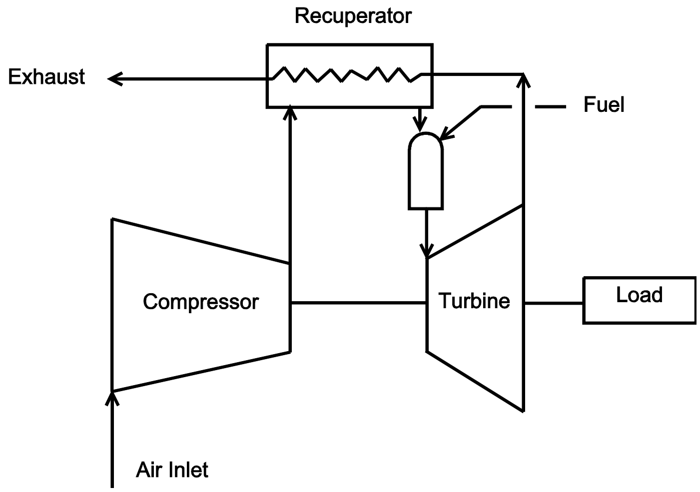

Figure 3. Recuperated.

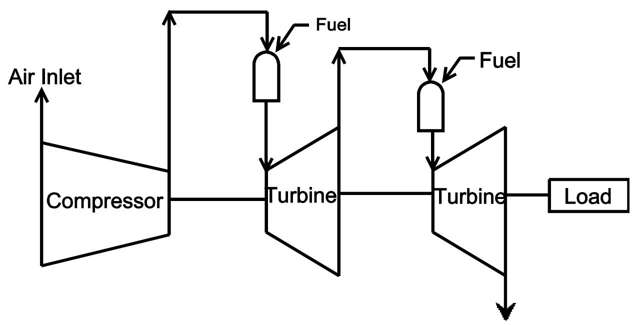

Figure 4. Reheated.

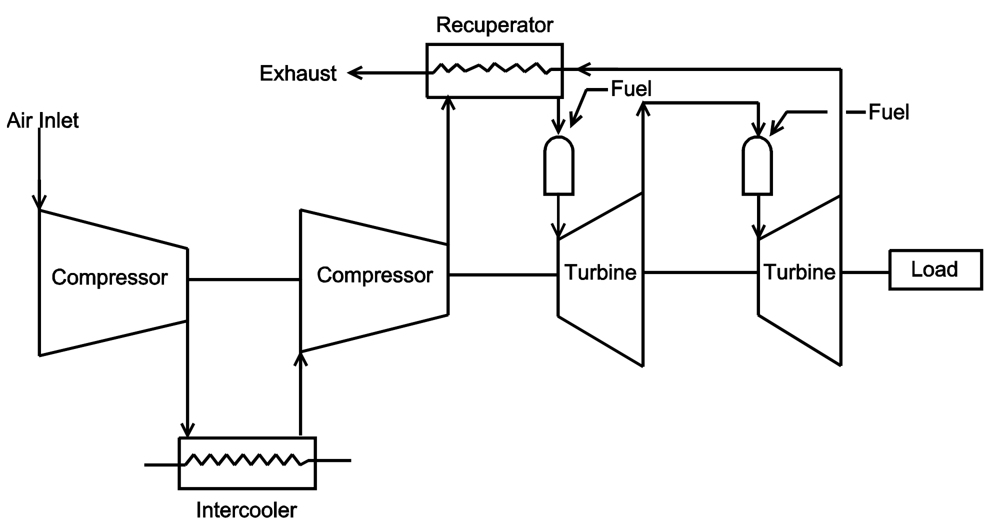

Figure 5. Intercooled With Recuperation And Reheat.

Many variations of the **combined** cycle use steam produced in an HRSG to drive a steam turbine. “Combined cycle” also refers to units that use exhaust heat for a process outside the turbine unit. Some combustion turbines in combined cycle service have dampers that allow turbine operation without the steam generator or downstream process in service. Some HRSG’s and downstream processes have auxiliary fuel burners to support operation without the turbine unit. Combined cycle plants are further discussed in PRC.6.1.0.1.

AUXILIARY SYSTEMS

Bearings

Combustion turbine rotors are supported by bearings. Radial or journal bearings are those through which the shaft passes; they support the shaft and keep it in alignment. Thrust bearings limit endwise shaft movement. Combustion turbines have two or three journal bearings on each shaft. Each shaft will also have a thrust bearing. The thrust bearing may be combined with a journal bearing or mounted on a separate thrust collar.

Most combustion turbines use conventional plain or tilting-pad bearings for both radial and thrust bearings; however, there are ongoing efforts to use magnetic bearings. Magnetic bearings have certain performance advantages, but more significantly, they eliminate the lubricating oil system required for other bearing types.

The rear bearing on a single-shaft machine and possibly the front bearing on a free turbine may be located in the turbine exhaust passage. The high ambient temperature during operation complicates cooling. The temperature differential between shutdown and operation may complicate alignment. The limited space in the area complicates inspection.

Lubricating Oil and Control Oil

Combustion turbine lubricating oil systems have many features in common with the steam turbine lubricating oil systems discussed in PRC.6.1.1.0.5. American Petroleum Institute API 614 contains additional oil system information, including sample diagrams. Briefly, the lubricating oil system must, with extreme reliability, provide clean oil at the correct temperature to the bearings and control system.

Most combustion turbines have a shaft-driven main oil pump, an ac motor-driven auxiliary oil pump and a dc (battery) motor-driven emergency oil pump. The rest of the system consists of coolers, strainers, control devices and protective features. Lubricating oil for bearings located in the exhaust path may be handled by a separate system, because this oil cools and seals the bearings and may be damaged by contact with combustion products.

Combustion turbine lubricating oil sumps generally contain heaters to keep the oil hot enough (at low enough viscosity) for the unit to operate and to keep out moisture. An oil sump temperature interlock prevents unit startup if the oil is too cold.

Most units use mineral oil-based lubricants; however, less combustible lubricating and hydraulic fluids are available. PRC.9.2.4 discusses various alternate fluids. In all cases, periodic analysis of lubricant samples can provide important information about lubricant quality and machine condition.

Vibration Monitoring

Combustion turbine condition can be monitored by observing and analyzing machine vibration. In addition to helping manage machine condition by signaling developing problems such as bearing wear, vibration monitoring is critical for maintaining machine safety. Compressor and turbine blading are susceptible to unbalance caused by uneven wear or fouling. Unless the air inlet is well designed, reliably filtered and adequately heated, the blading may be damaged by ingested foreign objects or ice. Also, turbine blading that operates in the creep range may sustain small failures at the blade edges before failing catastrophically. The resulting unbalance may allow a timely shutdown for repair. Problems, such as combustor failure or transition piece collapse, that have nothing to do with rotating parts can also be detected by vibration monitoring.

Most modern turbine control systems incorporate sophisticated vibration monitoring systems.

Some combustion turbine vibration problems cannot be detected by external monitoring. Compressor and turbine blades may have resonant frequencies that are excited by machine operation. For example, vibrations corresponding to the rotation speed times the number of combustors appear far downstream of the combustion section, often well into the turbine section. Differing points on the same piece of equipment may have readings that are very different with an example being opposite corners may have a large vibration resonance from the other. Resonant frequencies excited by such sources are a design problem; they cannot be detected by external monitoring or controlled by any operating strategy. Long term monitoring with trending is a key component to longevity of the unit and identifying a problem quickly.

Resonant frequencies may also be excited by off-normal conditions. For example, unevenly fouled compressor blades or unequally functioning combustors can induce dangerous downstream vibrations. Overall high quality machine maintenance is the only way to minimize these vibrations.

Starting and Jacking

Combustion turbines must be rotated, possibly more than 1000 rpm (16.7 Hz), to raise compressor discharge pressure enough to operate the turbine. Internal combustion engines, steam turbines, air turbines or electric motors are generally used. The starter is connected to the main turbine rotor using a gear set (if needed) and a clutch.

Combustion turbine rotors, particularly when hot, are easily distorted by their own weight or by uneven cooling. A jacking gear or turning gear may be needed to slowly rotate the rotor during cool down and to rotate it periodically while the machine is at rest. The lubrication system normally must be operating during jacking gear use.

Governor and Control

Modern combustion turbine controls are complex microprocessor-based systems that monitor many parameters to ensure safe and efficient turbine operation. The control system output adjusts the fuel supply, possibly the fuel annular distribution, and the vane angle of any adjustable guide vanes. Inputs may include:

- Ambient and inlet air pressure and temperature
- Pressure and temperature at each compressor stage having adjustable guide vanes
- Adjustable guide vane angles
- Compressor outlet temperature and pressure
- Fuel pressure
- Combustor and turbine inlet temperature and pressure
- Temperature and pressure at each turbine stage
- Turbine exhaust temperature, pressure and annular temperature profile
- Speed of each turbine shaft
- Signals from protective features in systems including lubricating oil, vibration monitoring and fire suppression

Because of the large number of control parameters, manual unit operation is not normally feasible.

Control systems perform many tasks automatically. For example, the “start” command might cause the controller to verify warm lubricating oil, start the auxiliary oil pump, verify its performance and verify fuel properties, measure the ambient conditions and adjust the inlet guide vanes, and test critical protective features before energizing the starter. Purging, firing and operating the unit adds many more variables to measure and control and more actions to take.

Internal Fire Protection

Combustion turbine internal fires or explosions cannot be extinguished; they must be prevented. These events are generally caused by:

- Flameout and reignition
- Fuel valves leaking during idle periods
- Hot restarts

Flameouts can occur because of fuel system and combustion component irregularities. If combustion stops in any combustor for any length of time, trouble is likely unless an immediate fuel valve trip occurs. If fuel continues to flow, hot surfaces will reignite it. If reignition occurs in the combustor, an explosion is likely. If reignition occurs in the turbine or downstream from the turbine, serious local fire damage is likely. To prevent damage, each combustor needs dual flame detectors that will initiate a shutdown within 750 ms of flameout.

Leaking fuel valves are hazardous for many reasons. They can “pool” fuel in the machine, causing fire or explosion upon ignition. Or, on dual-fuel turbines, they can input excess fuel from the standby fuel system and overspeed the machine. Gaseous-fueled turbines require “double block and bleed” fuel valve arrangements. Liquid-fueled turbines, however, may have single fuel isolation valves. Double block and bleed arrangements should be provided for dual-fueled turbines and on liquid fueled turbines that can develop fuel system pressure, for example with an electric fuel pump, while the turbine is not in service. A schematic of a “double block and bleed” can be found in Figure 1 of PRC.4.0.1.

Hot restart fires occur when a turbine is not sufficiently purged of fuel and cooled down after shutdown before a restart. Following the manufacturer’s recommended procedures should prevent problems.

CONSTRUCTION

Most combustion turbines are skid-mounted packaged units. The compressor, combustion section and turbine, and starting, lubricating oil, fuel handling, control and fire protection systems are all contained in a single enclosure. Units driving generators may include the generator and any needed gear set in the package. The operator supplies the following:

- Appropriately cleaned inlet air
- Inlet and exhaust noise suppression equipment
- Fuel at the correct temperature and pressure
- Electricity, except for units having batteries or an auxiliary generator for “black start” capability
- Exhaust duct and stack with a waste heat recovery unit if desired
- Suitable coupling for the connected load
- Energy source for the unit starter
- Properly designed foundation

There are other variations, particularly in the aircraft derivative market. Units with the gas generator and free turbine supplied by different manufacturers are generally packaged before installation.

Combustion turbine rotors are generally “built up;” both compressor and turbine sections consist of individual disks stacked on a shaft. The disks are held in place by keys and shrink fits. Some rotors have through bolts to axially compress the stacked disks.

OPERATION

Operational maintenance is critical to combustion turbine operational reliability. Many incipient problems are detectable only by the subtle changes in performance they cause. Long before a turbine becomes unable to produce rated power or manifests distress in any other way, daily performance measurements can serve warning. The manufacturer's guidelines for logging events and parameters and calculating performance indices should be followed at all times.

Factors Affecting Unit Operation

High ambient temperature limits combustion turbine performance. Power output depends on the air mass flow rate through the compressor. Compressor performance is limited at the high end by stonewalling, which occurs as a function of volume flow rate. Therefore, the warmer the inlet air, the lower the mass flow rate at which stonewalling occurs. Variable guide vane movement may partly compensate, but when the vanes reach their limiting angle, the only other way to compensate for reduced mass flow is to raise the turbine inlet temperature. Higher inlet temperatures more severely stress the turbine, and are limited by turbine material capabilities. As soon as the maximum turbine inlet temperature is reached, further ambient temperature increases reduce the power available at the coupling. At constant turbine inlet temperature, power decreases by approximately 10% for every 20°F (11°C) ambient temperature increase. Turbine units for hot climates must be designed accordingly.

Altitude affects turbine performance. Higher altitude or lower barometric pressure reduces the mass flow of air through the unit and reduces performance. Although altitude is fixed for a given installation, performance measurements need to be corrected for barometric pressure. Inlet restrictions limit performance in the same way as higher altitude.

Exhaust system restrictions increase back pressure. Increasing back pressure reduces the turbine pressure ratio and limits output. Unless the exhaust bath is fouled or damaged, back pressure is constant.

Variable speed unit performance limits are dictated by compressor rotating stall regions and surge limits and by speed ranges which may approach the resonant frequency of some machine part. Restricted operating regions should be programmed into the turbine control system, if possible, or identified in posted operating instructions.

The level and nature of the impurities in the surrounding air determine the inlet structure design and the need for inlet filters to avoid excessive fouling, erosion or corrosion. Air impurity levels can vary with the weather, time of the day, season and operation of adjacent equipment. In addition to the compressor performance problems, dirty air will cause the following problems for a combustion turbine:

- Power output loss because of reduced compressor performance.
- Operating restrictions because of earlier onset of surge.
- Turbine cooling system fouling; accelerated high temperature corrosion.
- Compressor blade pitting corrosion after loss of blade coatings.
- Erosion of turbine blading by flaking deposits from the compressor blades and by the dirt itself.

Noise emission may be limited by municipal codes, OSHA and other regulators or by facility standards. Most units require noise suppressers/baffles in the inlet and exhaust ducts and sound-deadening insulation. If these features are planned in advance, or if there is enough room to retrofit them, they should not affect unit operation.

Emission controls may affect unit operation depending upon the methods used to meet the limits. Sophisticated combustor design may be used; however, some units also use water injection. Water injected into the combustors can help control combustion temperature and, therefore, some emissions. Other approaches have been used and new approaches are being developed.

Facility needs can affect unit operation in various ways. For example, some combustion turbines operate in combined-cycle plants by heating waste heat boilers having no supplemental firing. In such plants, boiler temperature must be maintained even at reduced flows. To keep the combustion turbine outlet temperature up, compressor flow needs to be reduced, pushing the compressor closer to its surge line. In another variation, steam is injected into the unit just upstream of the turbine. This arrangement also needs careful planning; too much steam at a given power level can similarly push the compressor toward surge.

Operating Modes

Combustion turbines, unlike steam turbines, can be started from ambient conditions and can be fully loaded within minutes. Therefore, combustion turbines are useful in peaking and emergency services as well as base-loaded applications. A machine in peaking service operates only during high demand periods. Although the rapid-starting feature is often the reason to select a combustion turbine, rapid starts should be avoided whenever possible because they impose higher thermal stresses on the turbine. Required maintenance interval calculations factor in the number of starts and the number of operating hours. Rapid starts impose a higher penalty than normal starts and must be tracked.

A base-loaded machine runs constantly, usually at full load. Process facilities have always used base-loaded combustion turbines. Traditionally, electric utilities used combustion turbines mostly for peaking. Changes in fuel availability and economics, regulatory philosophies and pollution control politics have led to increased use of combustion turbines in base-load electric utility services. Any change in service requires facility management to carefully analyze the different stresses the new service will impose on the machines and adjust the monitoring and maintenance programs accordingly.

Another factor in operating power generation equipment is the deregulating of power distribution or private grids. Differing types of operation include “Merchant Power Plants” where daily power brokers determine a rate for the next day’s power need. This financial concern can drastically affect the daily operation of a combustion turbine and helps to determine if a unit will be brought on line for generation. This long term approach to financial running of the plant will affect the number of starts and stops of the unit. Planning for maintenance is key in preparing for potential power peaking needs in warmer weather.

MAINTENANCE

Maintenance is the most critical factor in combustion turbine availability and reliability. In addition to undergoing operational maintenance and inspection, combustion turbines are subjected to three types of dismantled inspections: combustion; hot gas path, and major. Early in this document, Figure 1 shows the scope of the three inspections.

During a combustion inspection, the combustor(s), fuel nozzles, transition pieces and associated components are dismantled and inspected. The turbine is visually inspected through its inlet, but is not dismantled unless adverse conditions are found. Combustion inspections occur frequently; they apply to the machine parts most likely to degrade rapidly. Most turbine owners stock “parts kits,” which contain all the parts removed during a combustion inspection. Such kits allow all the parts to be quickly replaced; the actual inspection, restoration and repair of the removed parts are performed at leisure after the machine is back in service.

Hot gas path inspections involve all the activities in a combustion inspection, plus dismantling and inspecting the turbine. Many users also stock parts kits for hot gas path inspections.

Major inspections, or full overhauls, involve disassembling the complete unit, from inlet flange to exhaust flange.

Combustion turbine maintenance is strongly influenced by the operating mode. The amount of load (as it affects turbine inlet temperature), the starting frequency, the ratio of the number of starts to the number of operating hours and the preload warm-up interval all need to be considered when calculating maintenance intervals.

COMBUSTION TURBINE LOSS CONTROL CONCERNS

Combustion turbine parts tend to operate closer to their construction material design limits than most other machines. For example:

- Many parts in the combustion and turbine sections operate at high enough temperatures to be damaged by creep. Creep forms microscopic voids in the material which slowly link up and form crack-like defects. Damage accumulates and progresses over time even in parts operating at design conditions. The damage rate can accelerate dramatically under off-normal operating conditions.
- Compressor section parts may be stressed near their limits by aerodynamic forces.
- All internal machine parts are subject to unusual kinds of corrosion caused or catalyzed by air or fuel contaminants in a high-temperature, high-stress environment.

Mechanical Hazards

Overspeed is the most serious mechanical hazard of turbine operation. A slight overspeed can sufficiently stress the rotating parts to distort them. Hot parts are susceptible to accelerated creep. A more serious overspeed can rub the blade ends against the casing. A severe overspeed may break blades or buckets free of the wheels, loosen disks on the shaft or rupture a disk. Any broken rotating part may rupture the casing with any of these being a catastrophic failure. Combustion turbines require two overspeed protection devices, one of which must be independent of the speed control governor. All shafts of multi-shaft machines require protection.

Vibration is another serious mechanical hazard. Combustion turbines require permanently installed continuous vibration monitoring systems. An alarm and automatic shutdown should be provided for high vibration. A shutdown device is also required for axial position out of tolerance.

Any mass has a characteristic or resonant frequency and will vibrate at that frequency when struck with a hammer. The speed corresponding to a resonant frequency is called the critical speed for that frequency. Excess vibration associated with critical speeds is another turbine hazard. A given rotor may have more than one critical speed; however, the speed corresponding to the main resonance, or “first critical” is normally the most troublesome. Integer multiples of that speed may also be troublesome. Manufacturers take great pains to separate operating speeds from the critical speed. If operational changes or turbine modifications reduce the separation, potentially destructive unstable vibration may result.

Turbine and compressor blades and nozzles also have resonant frequencies. Premature failures associated with these resonant frequencies have been the subject of many manufacturers’ post construction bulletins. There is no corrective action for a blade resonance at required operating speed other than redesign. Further, such resonant frequencies are extremely dangerous, because they cannot be detected by measurements taken on an operating machine.

Lubrication System Hazards

Fire is a lubrication system hazard further discussed in NFPA 850, PRC.17.12 and PRC.17.12.1. Combustion turbine oil systems challenge the fire protection system by continuing to supply oil during the coast down period. Combustion turbines are normally housed in an enclosure which may help contain a spill, a fire and a gaseous agent used to smother the fire.

Turbine oil systems must reliably supply oil to the machine even if the main pump fails during a normal electric power supply outage. The systems should provide devices to warn operators of a drop in oil pressure and shut the unit down if the pressure approaches the minimum for safe operation. Warning devices are also needed for high oil temperature, low reservoir level, backup or emergency source running and high filter differential pressure.

Corrosion

Combustion turbines are subject to various types of corrosion. They are broadly classified as pitting and high temperature corrosion.

Pitting is primarily a problem in the compressor. Because pitting takes place in the presence of moisture, it attacks mainly when the unit is shutdown. However, because the first few compressor stages may operate below the dew point, pitting can also occur during service. Moisture may be present in the later compressor stages during startup. Pitting attacks uncoated blades or blades with worn spots in their coating. Over time, pits can link up and form corrosion fatigue initiation sites. Keeping a shutdown machine warm and dry may help, and a vapor phase inhibitor might be used during a lengthy shutdown, but the only reliable defense against pitting is a suitable coating. Air preheaters may also be needed in cold climates.

High temperature corrosion, in the absence of other problems, is the determining factor in establishing hot part inspection intervals. Although several corrosion mechanisms exist, the most common are those associated with sodium, potassium, vanadium, lead, sulfur and zinc. These elements are found in fuel and occasionally in air.