CHAPTER 4

GAS TURBINES

4-1. Applications of gas turbines

Gas turbines, also known as combustion turbines, are common prime movers for many applications. Their historically high fuel consumption, especially for small units (less than 10,000 kW), as well as at part load, and at high inlet air temperatures has made them less desirable than diesel engines for prime power plant applications. They have been utilized extensively in standby and peaking applications where their relatively low installed cost outweighs other factors. Open or simple cycle gas turbines are used in virtually all power plant applications and only this type will be addressed in this chapter. Combined cycle systems, where heat is recovered from the gas turbine exhaust and used to make steam which then drives a steam turbine, have become much more common in recent years, but they will not be discussed here.

4-2. Gas turbine operating characteristics

Gas turbines are based on the Brayton or Joule cycle which consists of four processes: compression with no heat transfer, heating at constant pressure, expansion with no heat transfer, and in a closed cycle system, cooling at constant pressure. In open cycle gas turbines, the fourth step does not exist since inlet air is taken from the atmosphere and the exhaust is dumped to atmosphere. Due to its higher temperature, there is more energy available from the expansion process than is expended in the compression. The net work delivered to drive a generator is the difference between the two. The thermal efficiency of the gas turbine is a function of the pressure ratio of the compressor, the inlet temperature of the power turbine, and any parasitic losses (especially the efficiency of the compressor and power turbine). Practical limitations on thermal efficiency due to losses and materials technology yield a maximum of about 40 percent at pressure ratios of 30 to 40 and temperatures of approximately 2,500°F. These temperatures and pressure ratios are found only in recently developed, large gas turbines. Typically pressure ratios of 5 to 20 and turbine inlet temperatures from 1,400 to 2,000°F are common in gas turbines for this application, resulting in efficiencies from 20 to 33 percent. As improved materials and cooling technologies are introduced to smaller units, the efficiencies can be expected to improve if the cost is not prohibitive.

4-3. Gas turbine system major components

Gas turbines can be divided into three major components or sections; these are the compressor, the combustor, and the power turbine. Air enters the compressor and is pressurized to a level from 10 to 50 times that of the entering air. The compressed air then passes into the combustor where fuel is introduced and ignited, producing temperatures in the range of 1,400 to 2,000°F. The hot gases are then directed to the power turbine where they are expanded to atmospheric pressure and in turn provide power to drive both the compressor and the driven equipment such as a generator. Gas turbine auxiliary systems/components include starting, fuel supply, lubrication, governor/controls, speed reduction gear, inlet air, and engine exhaust.

a. Configuration. Gas turbines are lightweight in comparison to diesel engines, are very compact, and due to their small, well-balanced rotating mass are able to operate at very high speeds (from 10,000 to 25,000 rpm in sizes from 900 to 10,000 kW). Smaller gas turbines are usually single-shaft design, that is the compressor and power turbine are mounted on the same shaft. Larger gas turbines are frequently two-shaft machines in which the power turbine is divided into two sections, one of which drives the compressor and the other which drives the generator. The two-shaft design allows the compressor section to be operated at a variable speed (within limits) thus varying the flow to the power turbine section as a function of load.

b. Starting system components. Gas turbines utilize a variety of starting systems based on size of the unit and other considerations. Common starting methods include compressed air, direct current (DC) electric motors with dedicated batteries, or a hydraulic pump driven by an alternating current (AC) motor, small gas turbine, or diesel engine, which in turn drives the hydraulic motor on the gas turbine. Where used, an auxiliary gas turbine or diesel engine also requires a starting system, usually a DC motor and batteries. Regardless of the equipment used, the starting system brings the unit up to a minimum speed at which the burners may be ignited and the turbine is then brought up to operating speed.

c. Fuel system components. Although gas turbines are capable of burning either gas or liquid fuels, only liquid fuels are addressed in this chapter since they are preferred for standby power generation. The following fuel system components are commonly provided as part of the gas turbine package: motor driven booster pump, low-pressure duplex fuel filter, main turbine driven fuel pump, high pressure filter, main fuel control valve (regulated by the governor), fuel manifold and injectors at the combustor, and igniter.

d. Lubrication system components. Most gas turbines are provided with complete lubrication systems which include a cooler (air cooled), filter, pre/post lube pumps, engine driven main lube oil pump, alarms, oil storage tank (located in engine skid), and heater. The system is usually packaged with the gas turbine and only the lube oil cooler is remotely located. The lube oil system may supply the speed reduction gear and generator in addition to the gas turbine.

e. Governor/control. The gas turbine speed and fuel flow are controlled by the governor in response to load changes. Typically two types of governors are used on gas turbines driving electric generators: self-contained mechanical-hydraulic type or remote electronic governor with separate engine mounted actuator. Electronic governor systems with load sharing capability are the usual choice for multiple engine plants. Plants with multiple engines must have compatible governors to ensure proper operation of engines in parallel. Other control/safety alarm and shutdown indications are summarized in table 4-1.

f. Speed reduction gear. The high operating speeds of most gas turbines require that a speed reduction gear be installed to drive the generator at the appropriate synchronous speed, usually 1,200 to 1,800 rpm. The reduction gear is typically an epicyclic design that permits a straight-through shaft arrangement, thus simplifying alignment. A variety of epicyclic designs are used and depending on the speed of the gas turbine, a two-stage reduction may be required. Two common designs are the standard planetary system and the star compound system. The reduction gear is typically lubricated by the main lube oil system.

g. Inlet and exhaust components. Gas turbines require significantly more combustion air than diesel engines. Flows are typically four to five times as much as that required by a diesel engine of the same capacity. This leads to much larger air filters, intake ducts, and exhaust ducts. Proper air filtration is critical to gas turbine performance. Deposits on compressor and turbine blades can significantly reduce efficiency.

Table 4-1. Typical alarm and shutdown requirements for gas turbines

Indication	***Alarm Only***	***Alarm and Shutdown***
Engine System		
Impending High Blade Temperature	X	
High Blade Temperature		X
Impending High Engine Temperature	X	
High Engine Temperature		X
High Gas Producer Thrust Bearing Temperature	X	X
High Power Turbine Thrust Bearing Temperature	X	X
Fail to Crank		X
Fail to Start		X
Ignition Failure		X
Starter Dropout Failure		X
Backup Overspeed Power Turbine		X
Overspeed Power Turbine		X
High Vibration – Engine	X	X
High Vibration – Accessory Gearbox	X	X
Lube System		
High Oil Temperature	X	X
Low Oil Pressure	X	X
Low Prelube Oil Pressure		X
Low Oil Level	X	X
High Oil Level	X	
Lube Filter High Differential Pressure	X	
Fuel System		
Liquid Fuel Filter High Differential Pressure	X	
Low Liquid Fuel Pressure	X	X
Gearbox Systems		
High Gearbox Output Bearing Temperature	X	X
High Vibration – Gearbox	X	X
Generator Systems		
High Generator Bearing Temperature	X	X
High Generator Winding Temperature	X	X
High Vibration – Generator	X	X
Ancillary Systems		
Low Battery Voltage	X	
Battery Charger Failure	X	
Inlet Air Filter – High Differential Pressure	X	X

4-4. Gas turbine system interfaces

Gas turbines interface with the following supporting systems.

a. Generators. Generators are the primary driven equipment for gas turbines. The gas turbine and the generator must be properly aligned and coupled, either directly or by a flexible coupling. It is critical that the engine and generator are properly matched.

b. Fuel oil systems. The gas turbine is dependent on the fuel oil system to provide fuel to the engine skid. The fuel oil must have the proper characteristics required for the specific engine installation. In general, gas turbines can utilize a wider range of liquid fuels than diesel engines. Most facilities use kerosene, No. 1 fuel oil, or No. 1 diesel, but some use No. 2 fuel (if acceptable to the manufacturer) since it is less expensive than the lighter grades of fuel.

c. Lube oil systems. The proper lubrication of the moving parts inside a gas turbine is critical to obtain satisfactory operation of the engine and maximum life of its components. The lube oil must be approved by the engine manufacturer and analyzed on a regular basis to determine the optimum interval for changing the lube oil. Lube oil change intervals are much longer than those for diesel engines, since the oil does not become contaminated by products of combustion. Lube oil systems cool and filter the lube oil to provide both proper lubrication and cooling of critical components within the engine.

d. Engine air system. The engine intake and exhaust systems provide filtered air to the engine and remove products of combustion from the engine room. These systems may be very simple or relatively complex, incorporating such features as preheating or precooling of the intake air, or hardened design. Restrictions or blockage of either the intake or exhaust systems will severely impact engine performance.

e. Engines starting system. Gas turbines installed in power plants may be started with compressed air, DC motors, or an engine driven hydraulic system. Dedicated compressors typically provide starting air at pressures from 150 to 500 psig, depending on the specific requirements of the gas turbine. The system must provide adequate storage of compressed air to allow multiple attempts to start the engines. DC motors are driven from batteries located at the engine skid, which are charged by a dedicated battery charger. Hydraulic systems are composed of a prime mover, usually a diesel engine or small gas turbine, hydraulic pump, drive motor, and accessories, including hydraulic reservoir, air cooled heat exchanger, and filter.

f. Engine control systems. The basic control of the engine is maintained by the governor during operation and the control is independent for each engine. The overall control of a multiple engine power plant can be relatively simple or very sophisticated. Possible control options range from local or manual starting and synchronization of each engine to automatic starting, synchronization, and load sharing of the engine generators.

g. Instrumentation. Collection of operating data is critical to planning maintenance and evaluating problems which may occur. In the past (and still the case at most facilities), all data was recorded by operating personnel from instrument panels at each engine. Many newer plants now have automated data logging systems that can also provide warnings for out-of-tolerance conditions and histories of unusual events which can improve the operation of the facility. Regardless of the type of system, data collection provides the basis for trend analysis that can indicate potential problems before they become severe.

h. Ventilation systems. Gas turbines operate at high temperatures and therefore reject large amounts of heat to the surrounding space. Power plants are typically ventilated to remove this heat and to maintain temperatures within acceptable limits for both personnel and equipment. Proper operation of ventilation systems is required to avoid excessive temperatures, reduced equipment capacity, and potential equipment failures.