Mechanical Equipment - Course 230.1

GAS TURBINES

Two of our nuclear plants, Pickering G.S. and Bruce G.S. rely on open cycle gas turbines for standby power.

The Pickering G.S. unit was previously discussed in Level 3 Mechanical Equipment, are modified jet engines, with a free power turbine added to drive the generator. There are six units each rated at 5 MV, capable of peaking to 7 MW.

The purpose of this lesson is to discuss in more detail than was given in Level 3 the theory of operation of gas turbines, and some of the operating characteristics of these particular units.

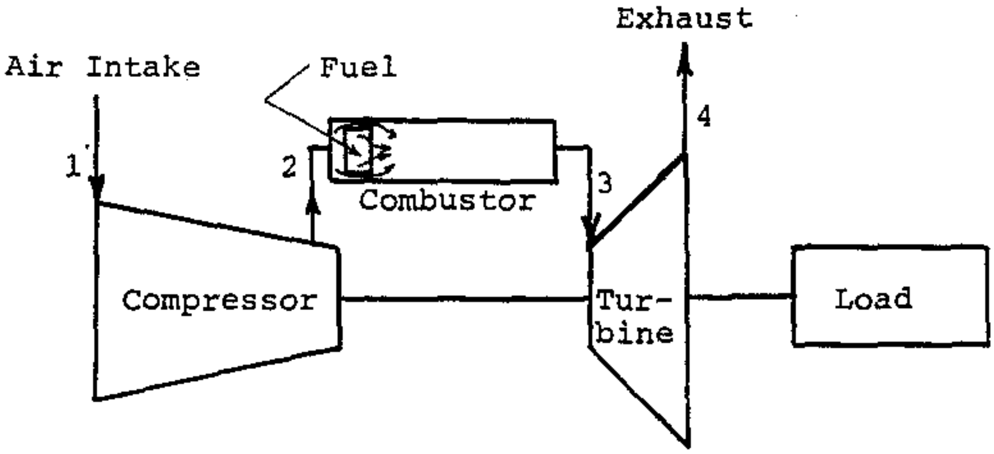
Gas Turbine Cycle

The theoretical cycle for the gas turbine is the Brayton cycle illustrated in Figure 1. It consists of isentropic compression, constant pressure heat additions, isentropic expansion, and constant pressure heat rejection.

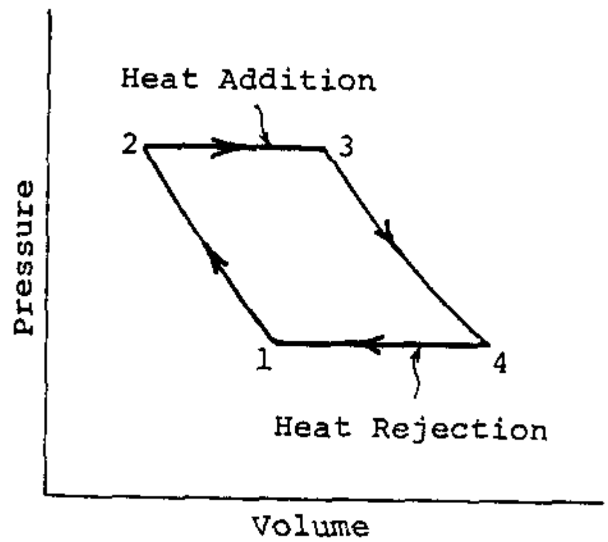
At this point it is well to distinguish between the open and closed cycle. The flow diagram of Figure 1 shows gases discharged to atmosphere from the turbine, and air entering the compressor from atmosphere. This is the open cycle. In the Brayton cycle diagram the point of exhaust (4) is connected to the point of intake (1) by a constant pressure process indicating that the gases leaving the turbine are cooled and then returned to the system. This is the closed cycle and requires an expensive heat exchanger between the turbine exhaust and the compressor intake and large amounts of air or water as the cooling medium.

Basic equipment for a simple gas turbine system includes a compressor, combustor, and turbine. A rotating compressor draws in atmospheric air, pressurizes it, and forces it into the combustor in a steady flow.

Fuel injected into the air burns, raising the temperature of the mixture of air and combustion products. This high energy mixture flows through the turbine, dropping its temperature and pressure as it does work on the moving blades. It leaves the turbine at high temperature and atmospheric pressure. The turbine drives the compressor and an external load such as a generator. The turbines at Pickering illustrated in Figure 2 consist of a ten stage axial flow



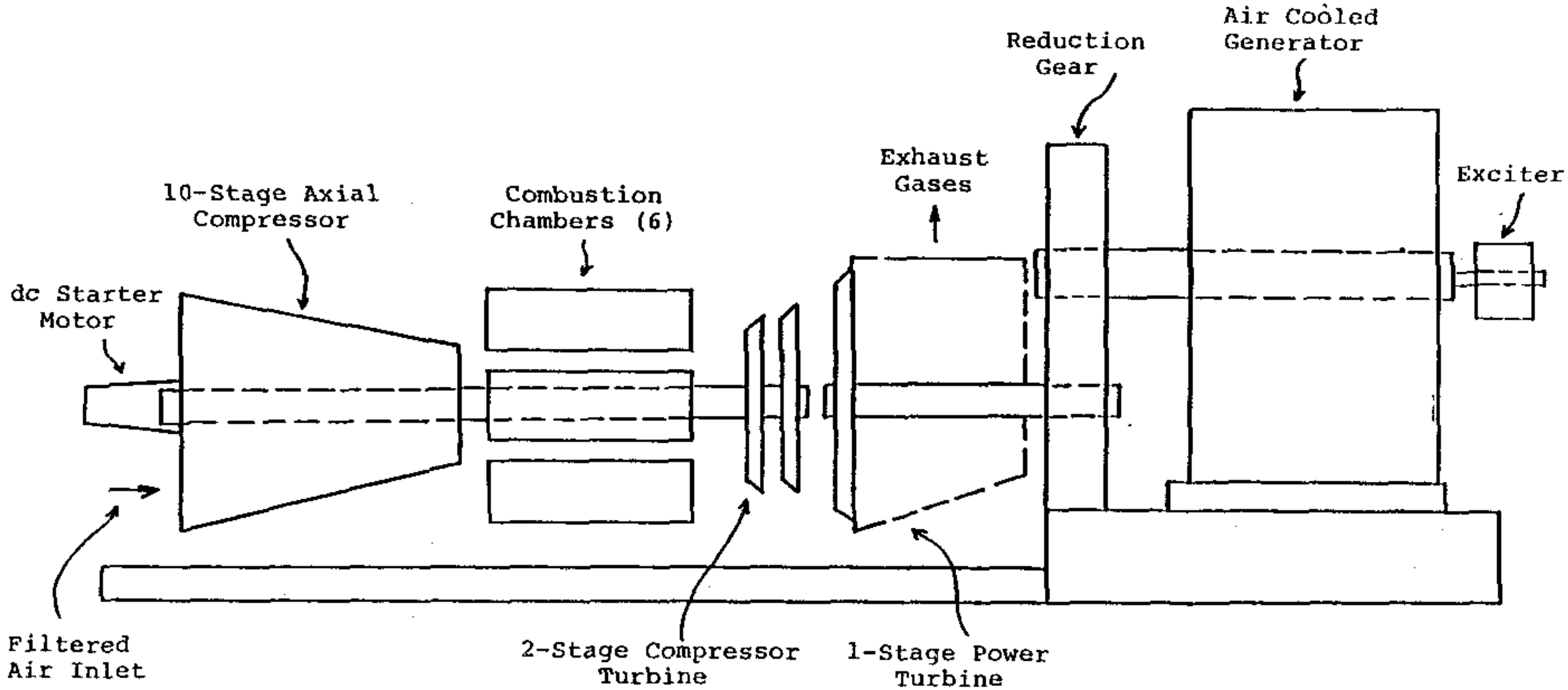
(a) Open Cycle Gas Turbine



(b) Brayton Cycle

Gas Turbine Cycle

Figure 1



<u>Gas Turbine Generator Basic Components</u>

<u>Figure 1</u>

compressor, six combustors, two stage compressor turbines and a single stage power turbine. The gas turbine consists of two shafts, one between the compressor and the compressor turbine and one between the power turbine and gear reducer driving the generator.

Compressor

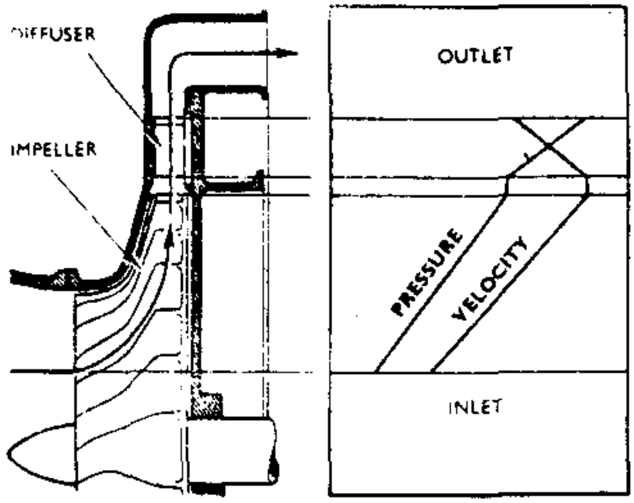
Efficient compression of a large volume flow of air is the key to a successful gas turbine cycle. This is achieved in two types of compression, the centrifugal (Figure 3) and the axial flow (Figure 4). The centrifugal compressor is a single or two-stage unit employing an impeller to accelerate the air and a diffuser to produce the required pressure rise. The axial flow compressor is a multi-stage unit employing alternating rows of rotating and stationing blades, to accelerate and diffuse the air until the required pressure rise is obtained.

With regard to the advantages and disadvantages of the two types, the centrifugal is usually more robust than the axial and is also easier to develop and manufacture. The axial, however, consumes far more air than a centrifugal of the same frontal area and can also be designed for high pressure ratios much easier. With the higher pressure ratios there is a higher engine efficiency due to an improved specific fuel consumption and thrust. The Pickering gas turbines use 10 stage axial flow compressors.

Each stage of a multi-stage compressor possesses certain air flow characteristics that are dissimilar from the adjacent stage. Therefore to design a workable and efficient compressor the characteristics of each stage must be matched. This is relatively simple to do for one set of conditions (design mass flow, pressure ratio and rotational speed) but it becomes more difficult if reasonable matching is to be retained when the compressor is operating over a wide range of conditions.

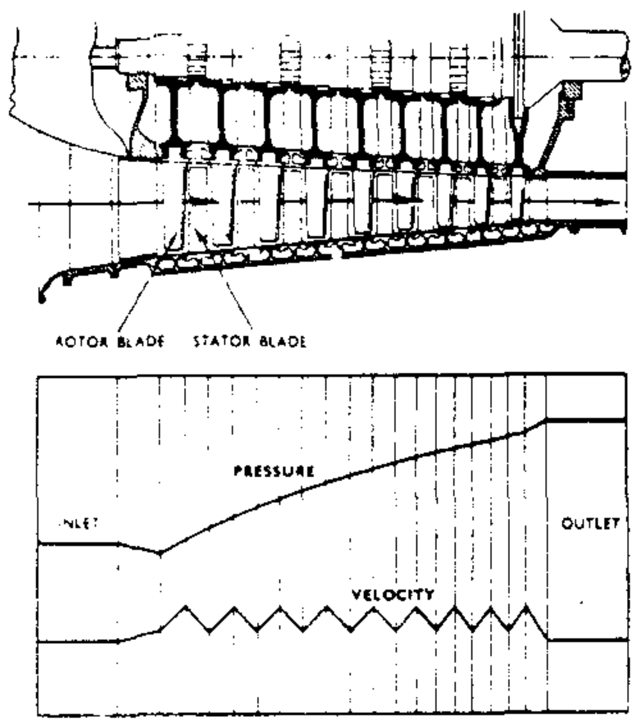
Outside the design conditions the flow around the blades tend to degenerate into violent turbulence and the smooth pattern of flow is destroyed. This condition is commonly referred to as stall or surge. A stall may affect only one stage or a group of stages, whilst a compressor surge generally refers to a complete flow breakdown through the compressor.

At low engine speeds a slight degree of blade stalling invariably occurs in the front stages of the compressor. This condition is not harmful or noticeable on engine operation. A more severe compressor stall is indicated by a rise in turbine gas temperature, vibration or coughing of the compressor. A surge is indicated by a bang of varying severity from the engine and a rise in turbine gas temperature. The rate of airflow and pressure ratio at which a surge occurs is termed the surge point. A line which gives all the surge points called the surge line (Figure 5) defines the minimum stable airflow which can be obtained at any rotative speed.



Pressure and Velocity Changes Through a Centrifugal Compressor

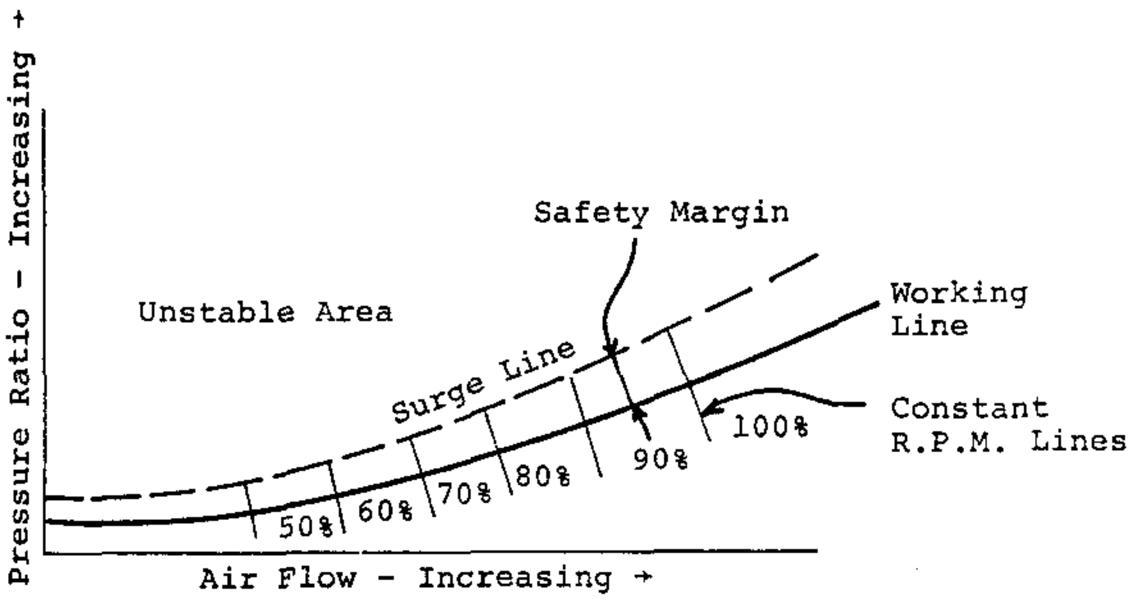
Figure 3



Pressure and Velocity Changes Through an Axial Compressor

Figure 4

A compressor is designed to have a good safety margin between the airflow and the compression ratio at which it will normally be operated and the airflow and the compression ratio at which a surge will occur.



Limits of Stable Air Flow

Figure 5

Combustion Chambers

The combustion has the difficult task of burning large quantities of fuel with extensive volumes of air, supplied by the compressor, and releasing the heat in such a manner that that the air is expanded and accelerated to give a smooth stream of uniformly heated gas at all conditions required by the turbine. This task must be accomplished with the minimum loss in pressure and with the maximum heat release for the limited space availab˙e.

In a typical gas turbine engine such as that used at Pickering the combustion chamber consists of a two piece steel outer casing enclosing a flame tube fabricated from nickel-chrome sheet. An annular cooling air space is provided between the flame tube and the outer casing. Holes in the flame tube head admit the required amount of air for primary combustion and swirl vane incorporated in a diffuser impart a whirl velocity to the air entering around the burner.

Additional air is admitted through holes along the flame tube to cool the inner walls and dilute the products of combustion before entering the turbine. Figure 6 and Figure 7 illustrate combustion chambers similar to that found in the Pickering unit. Figure 7 illustrates the airflow pattern in a combustion chamber.

The liquid fuel system at Pickering consists of six duplex burners which deliver fuel to the combustion chamber in a finely atomized form. Each burner has two inlet passages, one a primary passage for low fuel flows (starting and idling) and the other a main passage for large flows at normal operating conditions.

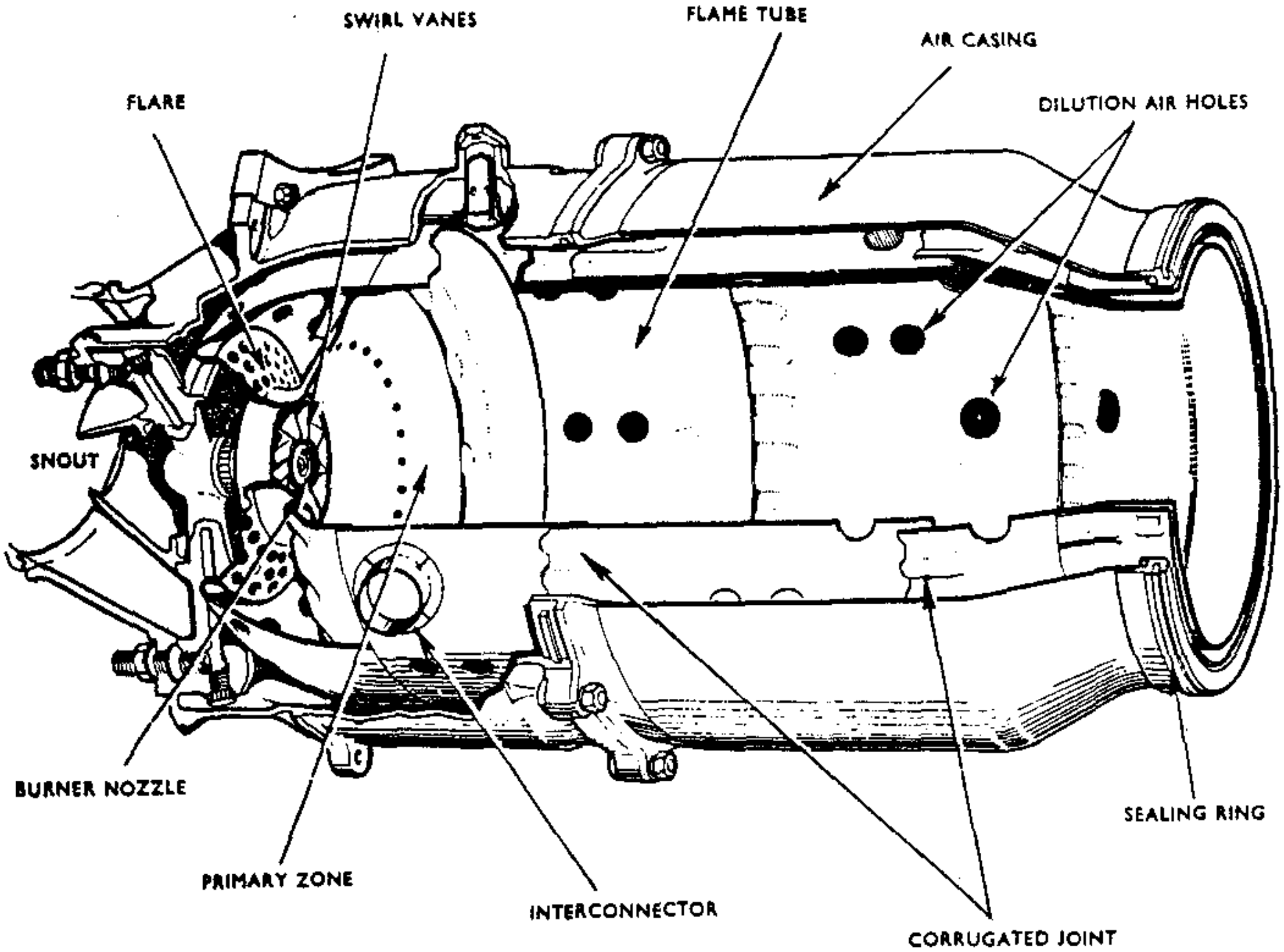
The temperature of the combustion gases released by the combustion zone could reach temperatures of 1800 to 2000% which is far too hot for entering the turbine. The air not used for combustion which is about 60 to 75% of the total airflow, is therefore introduced progressively into the flame tube. This dilution reduces the temperature of the gaseous mixture to approximately 1200°F and also keeps the temperature of the walls down.

The Gas Turbine

The gas turbine like steam turbines use familiar impulse and reaction principals. Because they work with lower pressure drops they have fewer stages, and less change in blade height from inlet to exhaust.

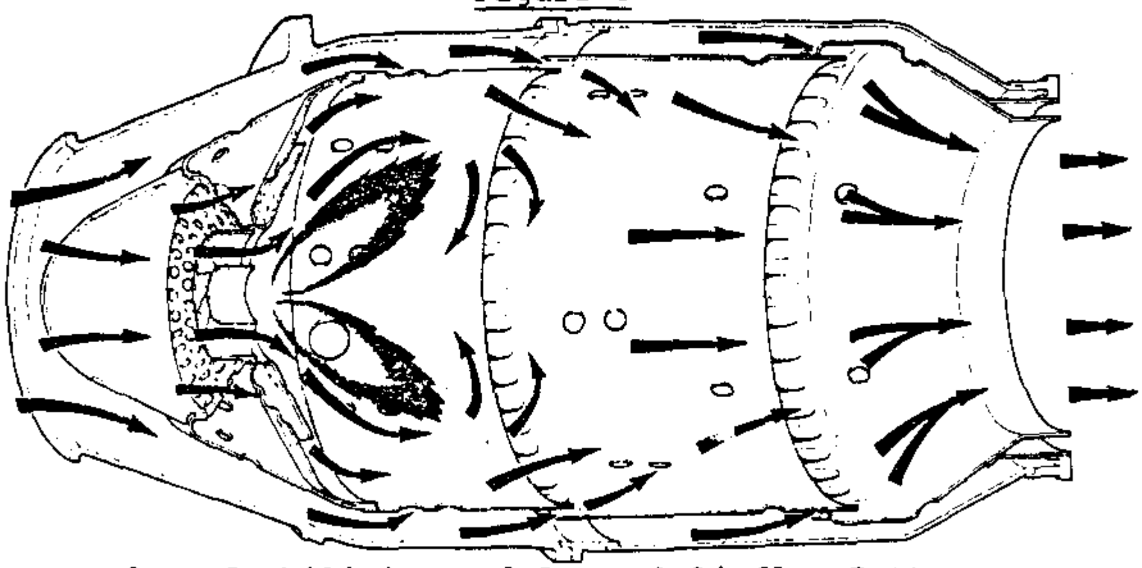
For best performance the gas turbine must work with high inlet gas temperatures. This poses service material problems that must be overcome by design. One approach is to cool the part subjected to highest temperatures and highest stresses. The most critical are the first stage moving blades and the disks carrying them. In one design air is bled from the compressor outlet and led over disk surfaces and blade roots to give film cooling, protecting the metal from the main gas flow temperature which would severely damage the rotor.

The turbine depends for its operation on the transfer of energy between the combustion gases and the turbine. The transfer occurs at approximately 90 percent efficiency, losses being due to thermodynamic and mechanical losses. The torque or turning power applied to the turbine is governed by the rate of gas flow and the energy change of the gas between the inlet and outlet of the turbine blade, thus if the energy is absorbed efficiently the induced whirl upon leaving the nozzle will be removed from the gas stream so that the flow at exit from the turbine will be straightened out. Excessive residual whirl reduces the efficiency of the exhaust system and also tends to produce vibrations.



A Typical Combustion Chamber

Figure 6



Flame Stabilizing and General Airflow Pattern

Figure 7

The degree of twist along the nozzle and blade is to make the gas flow from the combustion chambers do equal work at all positions along the length of the blade and to insure that the flow enters the exhaust system with a uniform axial velocity. The degree of reaction varies from root to tip, being lowest at the root and highest at the tip, with the mean section having a chosen value of about 50 percent.

Gas Turbine Performance Data

One major characteristic of any gas turbine is the variation of output with ambient inlet air temperature. With all other conditions and limits remaining constant a considerable increase in output results from a decrease in ambient air temperature. If the design point rating is at a relatively high temperature (27°C), a considerable increase in output is permissable over most of the year when the temperature is below the design temperatures. This characteristic is a major advantage for many power applications where winter load requirements are higher than summer loads. Figure 8 illustrates the variations in output with ambient air temperature.

The heat rate shown in Figure 8 is the criteria used to express unit efficiency. It is the energy input to the plant for each hp hour of output or kilowatt-hour of output.

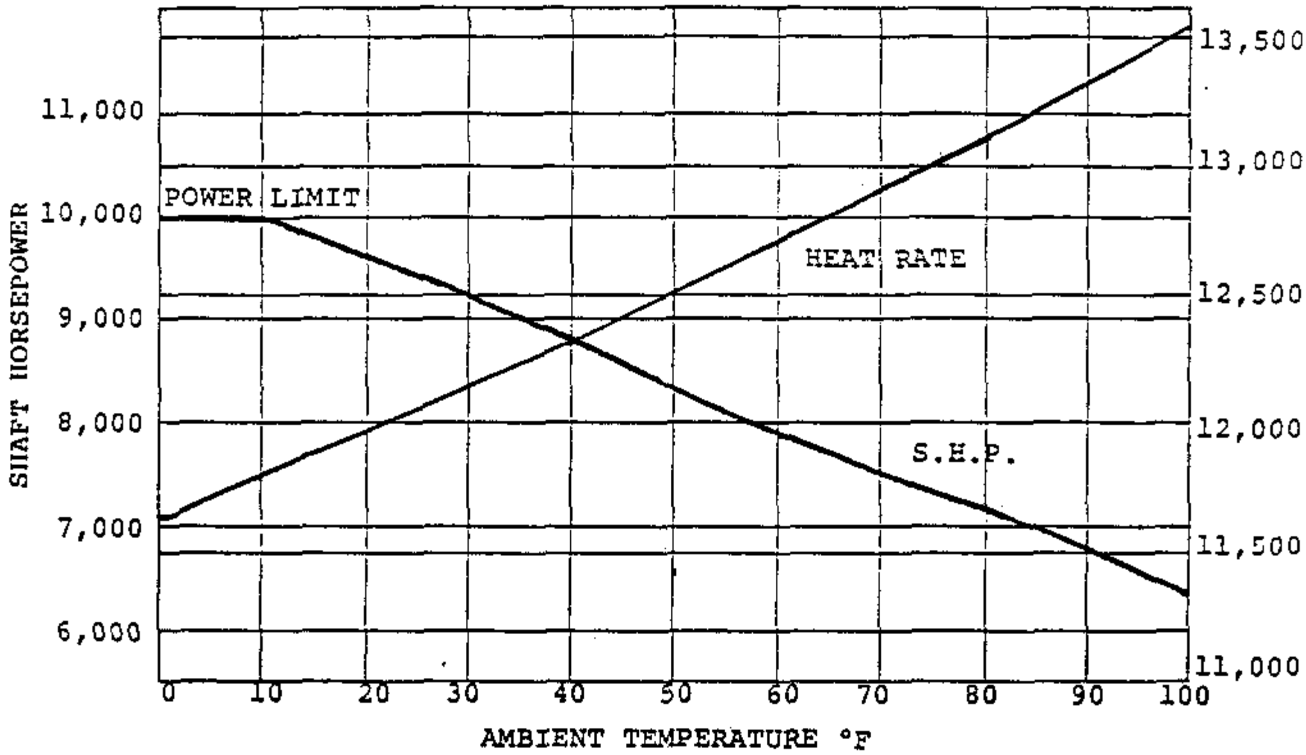
The output of a gas turbine also varies with ambient or inlet air pressure. As air pressure changes with altitude the output of a gas turbine will therefore change as well. As the inlet air pressure decreases or altitude increases, the output of the gas turbine will decrease as shown in Figure 9.

Such items as pressure losses in the intake and exhaust duct with affect the engine performance. For every one percent loss in total pressure in the intake ducting, the air flow and fuel flow will decrease by one percent, while the horsepower output of the power turbine will drop 2.6 percent.

For every one percent pressure loss in the total pressure in the exhaust ducting and stack there will be a decrease in power output of 1.6 percent.

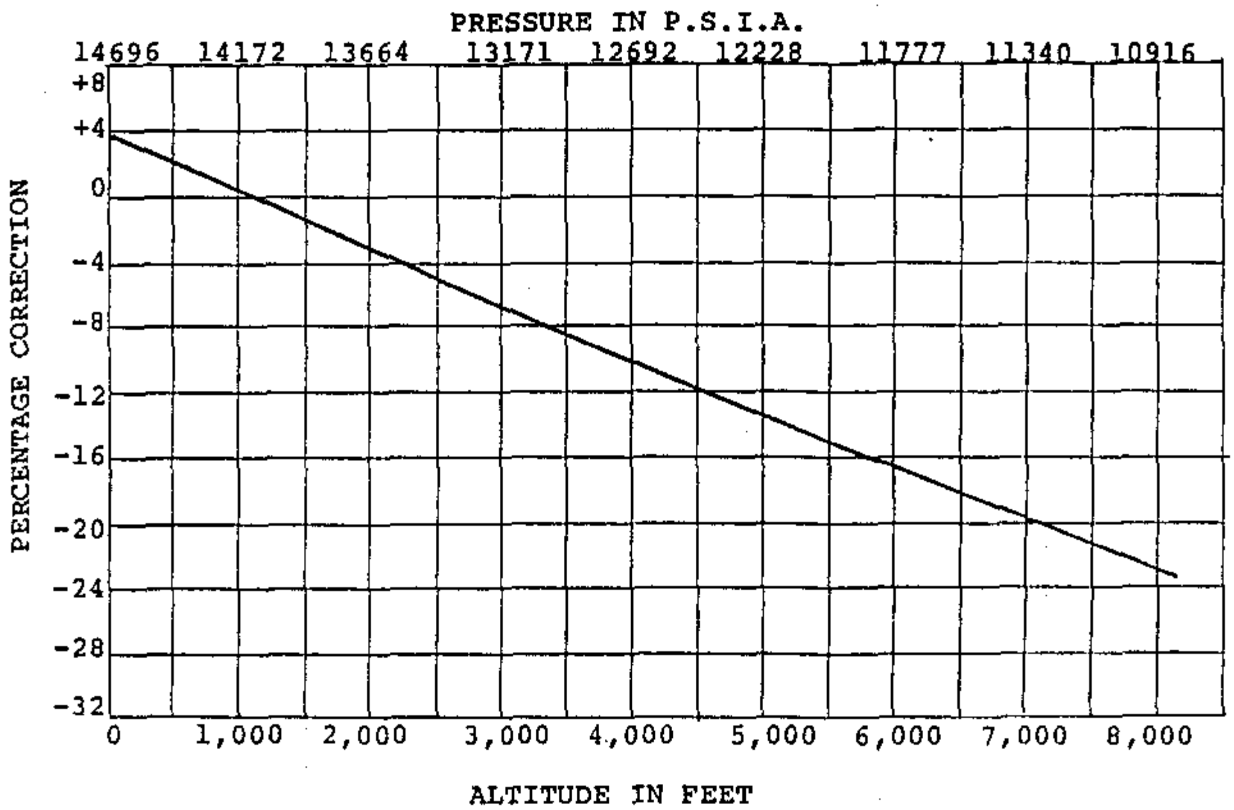
Operating Procedures

An outline of the Pickering gas turbine operation when call upon to start is given in Appendix A. The reader wil not be held responsible for the information contained in the appendix. It is only for those who are interested.



Variation of Power Output with Ambient Temperature

Figure 8



Variation of Power Output with Ambient Pressure

Figure 9

APPENDIX A

Control System

Each gas turbine generator has a separate control cubicle and is completely independent of other units in regard to auxiliaries and control equipment except for the common bulk fuel storage and the remote control centre in the main control room.

The units can be started and controlled from either the local or remote control centres.

Droop and isochronous governing facilities are provided with the selection of mode determined either by the operator or the emergency transfer system.

Auto and manual synchronizing equipment is provided for each unit.

The following is a general outline of the gas turbine operation when a unit is called to start.

1. Pre-start conditions such as: equipment temperatures, power supplies, control air pressures and governor position have to be in their correct state.

2. The power turbine lubrication system starts and establishes proper lubrication pressures. The starter motor starts to rotate the gas producer and speed builds up to an ignition speed of 800 RPM.

3. Following ignition the gas producer continues to accelerate to a self sustaining speed of 3000 RPM during which time the starter motor will have de-energized. Acceleration rate is controlled by a bias signal from the governing system and a limiter on the governing valve controlled by the gas producer discharge pressure since the electrical governor electrical signals are not yet available.

4. Rotation of the power turbine and the generator starts and voltage builds up to 4.16 KV with speed regulated for a generator frequency of 60 cycles.

Depending on the starting signal origin, the unit can be automatically or manually synchronized to the sytem following breaker selection by the operator or the unit will close in on a "dead bus" and start picking up loads sequentially as controlled by the emergency transfer system.

Following a successful start the units will be ready to accept load approximately 60 seconds from initiation of the start signal.

During unit operation of the following automatic limiting devices are effective to control unit output and override increase load signals.

1. High exhaust temperatures.
2. Gas producer speed (limited at 7500 RPM with overspeed trip at 7700 RPM).

Protective System

The follwing items are monitored and will automatically trip the units and lock out the start circuit:

1. Power turbine or gas producer overspeed.
2. Fire.
3. Generator fault.
4. Governor pump failure.
5. 125 V dc power failure.
6. Inverter ac failure (battery supplied).
7. Manual trip.

Lock out of the start circuit requires manual resetting.

The following items may or may not automically trip the unit depending on mode of operation (ie, peaking or emergency class 3 service) and the finalized design.

1. Low lube oil pressure.
2. High exhaust temperature.
3. High vibration.
4. High bearing drain oil temperature.
5. Fuel and lube oil temperatures low.
6. ac failure.

During start-up of the units, various sequences are timed and if they exceed a time limit, the unit will automatically shutdown but will not lock out. This allows a second start attempt. If the second start fails the start circuit is then locked out.

These sequences include the following:

1. Oil pressure in power turbine lube system fails to be established within 15 seconds.

2. Gas producer fails to reach self sustaining speed within 58 seconds.

3. ac power to auxiliaries must be established within 6 minutes.

4. Ignition has to occur within 20 seconds following switch on of fuel and ignitors.

L. Laplante

ASSIGNMENT

1. What is the advantage of an open cycle gas turbine over a closed cycle gas turbine?

2. Briefly describe the principle of operations of an open cycle gas turbine.

3. Explain the difference between compressor stall and compressor surge.

4. What are the symptoms of a stall or surge?

5. Explain why only a small percentage of the total air flow through a combustor actually undergoes combustion.

6. Why are there so few stages in a gas turbine compared to a steam turbine as found in our plants?

7. What effect does inlet air temperature have on gas turbine power output?

8. What effect does inlet air pressure have on gas turbine power output?