Gas Turbines

Gas Turbines for power plants are either aeroderivative or industrial type. Aero derivative engines are evolutions of GT's used in aircraft which were slightly modified for fixed applications. GT as used in aircraft are also sometimes used for powerplants. The as standard aircraft GT (then called a gas generator) is used to supply hot and pressurised combustion gases to another turbine called the power turbine. The power turbine is usually running at 3000rpm to match the frequency output of the generator. Within the gas generator the turbines and compressors generally run at much higher rpm as is usual in aircraft engines. Aircraft GT's are usually mutispool, i.e. they have concentric shafts running at different rpm, the number of shafts is normally two or three. However when we refer to aeroderivative engines, these are usually designed for land use and not exact aircraft engines as explained above. Aeroderivative engines usually have a higher efficiency (say 38 to 40%) than the industrial type gas turbine (30 to33%). This comes from the fact that aeroderivative engines have higher turbine inlet temperatures and have higher compression ratios. The pressure ratio for an aeroderivative engine would be around 18 while that of an industrial type would be around 10.

Sometimes in GT and Combined Cycle use, the term Heat Rate is used in stead of efficiency. The units of Heat Rate are kJ/kWh (heat input / power output) , $1kWh = 3600kJ$, hence if we have an efficiency of 40%, for 3600kJ of output we supply $3600kJ \times \frac{100}{40} = 9000kJ$ in fuel. Hence the Heat Rate is 9000kJ/kWh.

Aeroderivative gas turbines have very thin material sections when compared to the industrial type. This comes from the fact that aeroderivatives are close to engines which were meant to fly, hence light weight, while industrial type were designed to be on land with a more conventional approach, hence much heavier. The much thinner sections of an aeroderivative engine leads to a much faster possible start up time for this type of engine. It has to be appreciated that industrial gas turbines, like steam turbines or boilers have quite a long time for starting up and loading because heat has to be allowed enough time to soak into the thick metal sections so that there is very little differential expansion between outside and inside layers. A normal start of an industrial GT is of the order of 20 minutes from standstill to synchronisation and 30 minutes to full load. At synchronisation, the turbine will be at full speed i.e.3000rpm but no load hence the turbine inlet temperatures are low, then the load is progressively increased by increasing the fuel input, hence the turbine inlet temperature increases.

Due to the very high Turbine Inlet Temperatures cooling of the first stages of nozzles and blades is done. Cooling is done by means of high pressure air from the compressor outlet which is directed into passages inside the nozzles and blades so that some heat is taken off and the material temperatures are maintained at acceptable levels.

Combustion chambers:

Gas turbines suffer mostly because of the high temperatures with which they work. This temperature is much higher in gas turbines (1100 to 1200°C at inlet to the turbine) than for steam turbines (500 to 600 °C). Of course the highest temperature is in the combustion chambers were much higher temperatures are reached. In the combustion chamber the temperature reached is a function of combustion and not much to the selection of the designer, i.e. when the fuel ignites the temperature goes very high and then the designer can only control this initially very high temperature by dilution with unburnt air to put down the temperature of the overall combustion products to levels which can be accepted by the gas turbine nozzles and blades. Hence in the combustion chamber there is the primary zone where there is the flame, and then there is a secondary and tertiary dilution zones were the overall temperature is put to acceptable levels. Combustion chambers suffer a lot of thermal stresses and are inspected very frequently to check the amount of deformation and cracks which inevitably form during operation. On a lesser scale the turbine nozzles and blades also have to be occasionally checked for deformation and cracks.

The most common type of fuel used in gas turbines is natural gas, secondly light distillate (diesel) then heavy fuel oils and coal gasification. It has to be appreciated that the combustion products are actually passing from the turbine and hence the amount of dirt and corrosiveness of the fuel and its combustion products are preferred to be as low as possible. (it is good to know that there is high temperature corrosion and low temperature corrosion which are influenced by different contaminants in the fuel). For this reason when natural gas is used the maintenance intervals are the longest and get shorter for "worse" fuels.

The combustion chamber can be one (or two)very large chamber which handle all the fuel and air in the gas turbine, or there can be several smaller chambers situated all around the turbine periphery each handling and equal amount of fuel and air. When one or two burners are used for the whole flow these are sometimes referred to as silo burners as they are big and usually the cylinder is vertical. When several small chambers are used, these are usually referred to as can type combustion chambers or cannular type since all the cans are placed in an annular fashion around the GT.
It is normally expected that when one or two silo burners are used the burner is bigger and more can be invested on it making a better burner than for the several burners in the cannular. Therefore the burning efficiency and pollutants are better for the silo burners, however the spread of the temperature and flow may not be so good over all the annular area.

The cannular type must have good fuel distribution between them to ensure balanced temperatures over all the annular area. Many temperature sensors are placed at the back end of the GT (i.e. at the exit to atmosphere) to measure the temperature over all the periphery of exit. In this way it can be determined whether or not all the combustion

chambers are working together. The temperature in the combustion chambers is beyond the measuring range of normal thermocouples, hence the Turbine Inlet Temperature is determined by calculation within the GT controlling processor.
To aid in the atomisation of liquid fuels, atomising air is used. Atomising air is compressed air at a pressure above the pressure inside the combustion chamber which is injected at the fuel nozzle tip. The purpose is to break up the fuel flow and small fuel droplets are formed.

Recently, due to the awareness raised of the environmentally harmful NO_x gases from combustion processes, modification in combustion chamber were done to minimise the amount of NO_x produced. Since the amount of NO_x produced increases with the combustion temperature, the normal way of reducing NO_x levels is by cooling the flame. Low quality steam is introduced into the combustion chamber, or even water, to cool down the flame and produce less NO_x. The amount of steam introduced can even equal the amount of fuel introduced. When steam is introduced the power produced will increase because the injected steam will expand in the turbine and hence produce power as in a steam turbine. NO_x reduction is also possible in low NO_x burners without steam/water injection or by converters in the stack.

Factors effecting load

The gas turbine as used in a power plant for electrical power generation is operated at a fixed speed corresponding to the frequency of the grid. Power is then mostly a function of the amount of fuel injected in the combustion chamber. However there are other factors outside the control of the operator which also have an effect on the power output and also on the efficiency. The main factors on the power output are:
Ambient temperature, higher ambient temperature results in lower loads and efficiency
Atmospheric pressure
Relative humidity
Pressure drop in exhaust gas duct
Pressure drop across air filters
Compressor fouling, ie dirt attached changes the roughness and profile
Steam or water injection for NO_x reduction
The ambient temperature is by far the factor which normally effects the most. The reason why temperature and pressure effect the GT load is that the specific volume of air is increased at high temperatures and the GT induces less mass flow of air.

Combined Cycles and Gas Turbines

In recent developments of power plants around the world, combined cycle power generation plant has found much favour. This is because
it is much less capital intensive than other conventional plant
it has a higher efficiency
it has a shorter procurement time, hence return on investment start earlier
it is small in foot print size

it is much more flexible, i.e. it is much quicker to start and has quicker response on load changes

Typical efficiencies of combined cycle plants range from 45 to 53% depending on the complexity. Since industrial type gas turbines have a lower efficiency than aeroderivative gas turbines, the industrial has a higher exhaust temperature. In a combined cycle plant, this exhaust gas of the GT is used to generate steam in a HRSG (heat recovery steam generator). Hence what energy is not transformed to work by the GT is left to be recovered by the steam cycle. For this reason, the efficiency of the GT has little or no impact on the overall efficiency of the combined cycle.

The efficiency of the overall combined cycle can be improved by increasing the complexity of the HRSG. The simplest HRSG is one with a single pressure, i.e. one economiser, one evaporator and one superheater. Then there is two or three pressure boilers which replicate the economisers, evaporators and superheaters according to the number of pressure levels. HRSG's based on the single pressure design produce the least efficiency, while HRSG with three different pressure levels produce the better overall efficiency. The bundles of the different pressure levels are intermingled to fit the temperature of the fluid being heated with the dropping temperature of the gas turbine exhaust which is being cooled. The technology of multiple pressure boilers is also used in nuclear reactors so that the reactors outlet temperature is kept to a minimum for safety. HRSG' have only low quality waste heat on which they operate. This is the reason why they have to be more complex and have multiple pressures. An important factor in the design of an HRSG is the pinch point, this it the difference in temperature between the exhaust gas at exhaust gas exit end of the evaporator bundle and the boiling temperature at the pressure inside the evaporator. Typical pinch points are 4^{o} to 12^{o}, the smaller temperature difference is produced by the bigger heat exchange surface.

New GT's are being designed with very large outputs of well over 200MW. These GT are nearly always used in combined cycle operation and on natural gas. The most common type of setup for these big machines would be one generator powered from each side, GT on one side and ST on the other side. Another common setup is two separate GT's powering their own generator and another generator is powered by the ST (the ST would be actually powered by the steam generated from the HRSG's behind each of the GT's). The popularity of this setup is due to the fact that the power recovered by the HRSG and ST is approximately 50% of the GT power. Hence if the steam of two HRSG's is put into the same ST, the power of the ST will be more or less equal to the power of any of the GT's.

HRSG operate in what is called Sliding Pressure. Since the GT's exhaust gas temperature drops with lower loads, the boiler cannot keep on producing steam at the same quality of full load operation. This may be easily visualised by remembering that since we have such a small pinch point, when the exhaust temperature drops, the boiling must be performed at a lesser temperature (and associated pressure) to have an equilibrium. This is a marked difference between HRSG's and conventional boilers which normally produce fixed steam conditions and only vary the mass flow output.