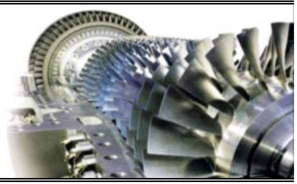

GAS TURBINE FUNDAMENTALS

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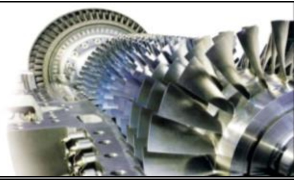


1: INTRODUCTION

The gas turbine is a power plant which produces a large amount of energy for its size and weight. For example, Copper – Rolls Coberra 6000 gas turbine package (using the Rolls Royce RB211 gas generator) produces 26 MW of power and weights approximately 26 tons. The exhaust and inlet air ducts are excluded from this weight, but even so, the power to weight ratio of this package is far less than other self contained drivers such as engines. Steam turbines and electric motors have lower weight but are not self contained. The drivers require steam plants or electrical generation packages.

Gas turbines have other advantages as well. The speed of the turbine can be changed to match the requirements of the driven equipment. This is very useful when driving centrifugal compressors. Gas turbines run "smooth", unlike gas engines which produce vibration due to their reciprocating motion.

This allows much lighter base plates and support structures. Gas turbines can operate on different kinds of fuels – natural gas, LPG, diesel, fuel oil, etc. Also gas turbines have a very high starting torque and can be started up when the driven equipment is loaded. Gas engines and electric motors have poor starting torque.

2: PRINCIPAL OF OPERATION

The gas turbine is a simple device. Figures (1 and 2) show the mechanical arrangement of the basic, simple – cycle gas turbine. A dynamic compressor supplies air to a combustion chamber, where fuel is burned with excess air at constant pressure. The power gas is expanded through a turbine, which drives the air compressor and provides excess power as mechanical output. As the last step, the combustion products are exhausted to the atmosphere.

In order for a gas turbine to be effective a very high efficiency is required for both compressor and turbine. Second, the internal pressure and temperature both must be more than certain minimum levels before any output power can be produced. In general, the higher the combustion pressure and temperature, the more efficient the turbine.

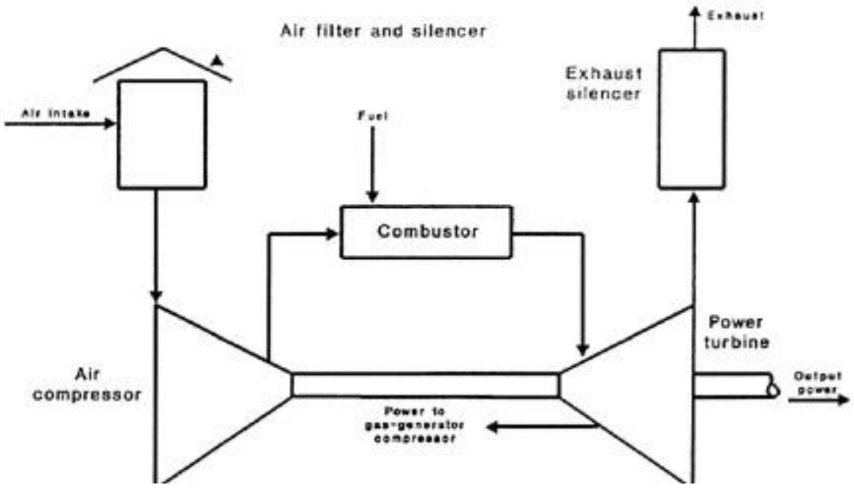


Figure 1: Simple Cycle of Gas Turbine

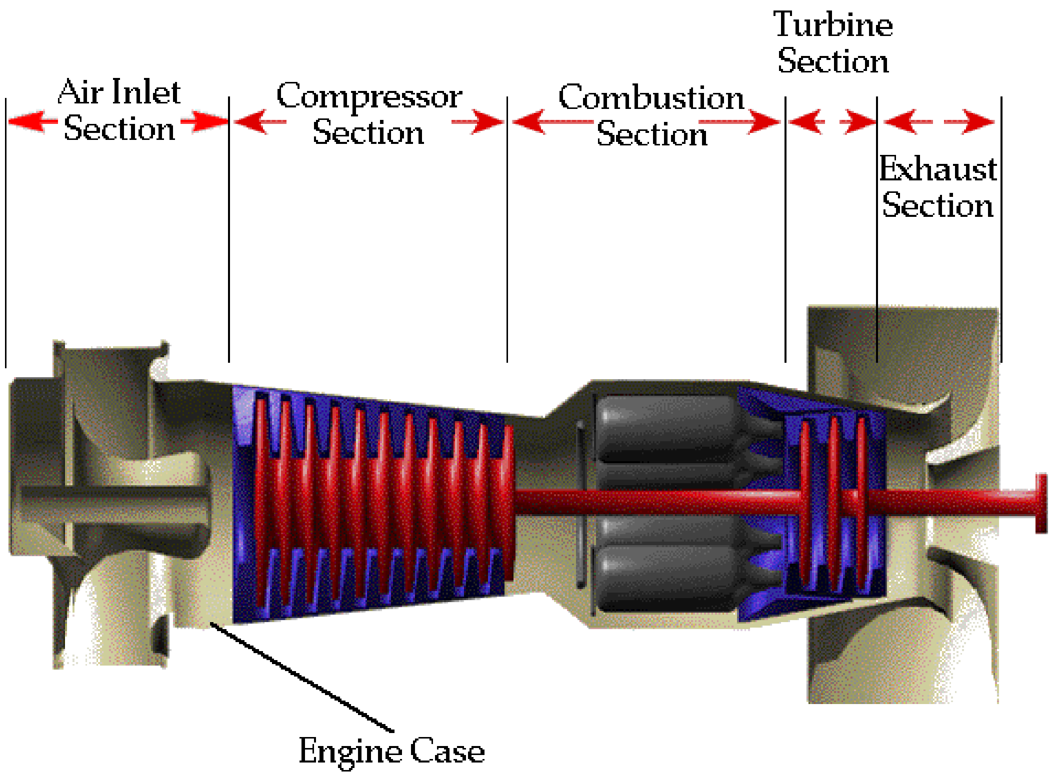


Figure 2: Major Sections of a Gas Turbine

Figure 3 illustrates the possible thermal efficiencies for the simple – cycle turbine as a function of pressure ratio and turbine inlet temperature. For a given pressure ratio, higher temperatures leads to higher efficiencies.

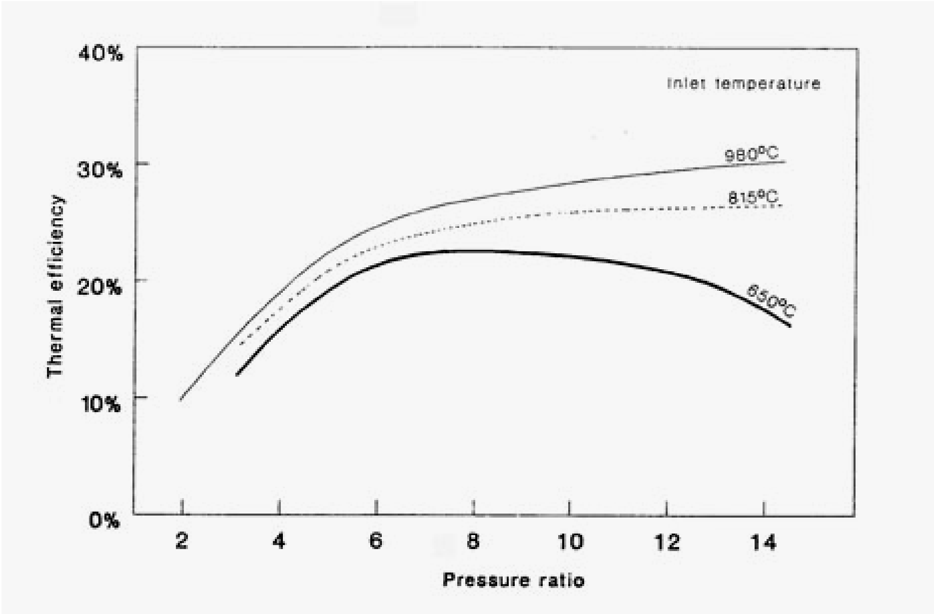


Figure 3: Efficiency of Gas Turbines vs. Compression Ratio and Combustion Temperature

It is important to see that the power turbine must generate enough power to run the air compressor and the driven equipment (gas compressor, electric generator, pump, etc). Typically from 50% to 70% of the total work generated by the power turbine, is required to drive the air compressor. The ratio of net work to total work is called the work ratio. The higher the work ratio, the more efficient the gas turbine. Early gas turbines had work ratios of 0.4 or less. A typical example would be a Solar Saturn which has a compression ratio of 6.2 and a turbine inlet temperature of about 800^0 C. The maximum thermal efficiency of this turbine is about 22%.

3: GAS TURBINES CONFIGURATIONS

Gas turbines may be classified as either industrial or aircraft derivative. Industrial turbines are sometimes called “heavy duty”. These were first introduced in the late 1940’s. Industrial turbines are characterized by heavy horizontally split casings. They utilize axial compressors and annular can combustors. They are typically quieter than aircraft derivative machines. The primary advantage of industrial turbines is their long life, high availability, and long runtimes between major maintenance. Disadvantages include higher weight and space requirements.

Examples of industrial turbines include the GE frame5, Ruston TB5000, Solar Saturn and Centaur.

Aircraft- derivative turbines are basically adapted from jet engines and consist of a hot gas generator (jet engine) and a free power turbine which is connected to the driven equipment.

Aircraft derivative turbines have the advantage of being much lighter than industrial turbines. They are also modular in construction. This allows maintenance to be done quickly with minimal downtime. For example, a major overhaul on a heavy industrial turbine may require 7-10 days. An aircraft derivative turbine may require less than 12 hours since the hot gas generator is simply removed and replaced with a new one. Aircraft derivative turbines typically also use the latest technology and require more sophisticated controls.

Example of aircraft derivative turbines includes the Rolls Avon and RB211 and the GE LM2500.

Recent advances in gas turbine technology have narrowed the differences between industrial and aircraft derivatives. Many so called “industrial turbines” are now built using the lighter modular construction found in aircraft derivative turbines.

Gas turbines may be ***single shaft*** or ***multiple/split shaft***.

Figure 4 shows the available shaft configuration in gas turbines.

In fact, the power turbine is supplied by a different vendor than the hot gas generator. Three shaft machines are used to increase the speed of the final stages of the air compressor. This can improve compressor efficiency. Early industrial turbines were often single shaft design but many industrial turbines today employ 2 shaft design.

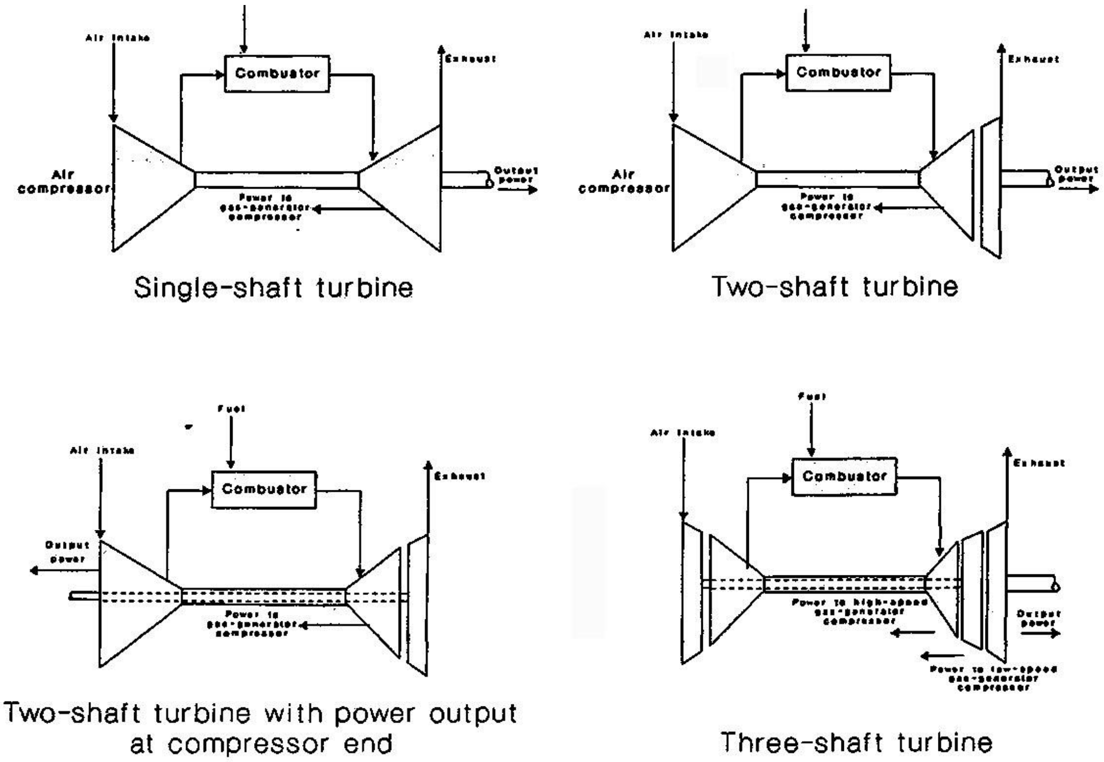


Figure 4: Gas Turbine Configurations

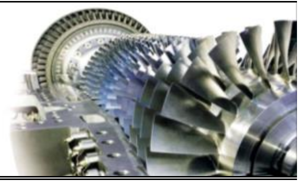
The primary advantage of the split shaft design is the possibility to drive the power turbine at a different speed than the hot gas generator. This allows more flexibility in the operation of the driven equipment and is particularly advantageous for speed control of centrifugal compressors and centrifugal pumps.

4: GAS TURBINE MAJOR SECTIONS

As it was previously illustrated in Figure 2 the major sections of a gas turbine are as follows:

- Air Inlet Section
- Compressor Section
- Combustion Section
- Turbine Section
- Exhaust Section

In the following you will read a brief explanation about them.



4.1: Air Inlet Section

As a gas turbine draws in large quantities of air, atmospheric pollutants take in with the air can coat the air compressor blades, reducing their efficiency.

Regardless of the degree of air filtration, fouling will occur and must be controlled to maintain power output: lessening of compressor efficiency affects the power output by a ratio of about two. This means that a 1% reduction in compressor efficiency decreases the power output by approximately 2%.

Turbine manufacturers provide methods and equipment for cleaning. Two methods are used:

1. Abrasive (Online) cleaning
2. Offline Washing.

The abrasive cleaning can be done during operation and is frequently performed on a regular basis. The cleaning of the air compressor is done by adding nut shells or rice to the air intake. Special equipment is required for abrasive cleaning of the turbine because the nut shells or rice must be injected into the combustors by the use of special nozzles.

Offline Washing is required if the compressor has take in oil vapor or if ash has been laid down on hot-gas-path parts (including fuel nozzles, combustors, transit pieces, turbine nozzles and buckets). Here again, turbine manufacturers provide methods and equipment. The liquid used for washing may be hot water, detergent, or solvent, depending on the characteristic of the fouling.

The air intake package provides a clean, uniform air-flow to the gas generator. It is composed of a filter kit, silencer and an inlet plenum.

Gas turbine filtration systems are carefully designed to suit the operating environment. Onshore sites are different in their filtration requirements, going from single to multiple stages.

A typical system might include a primary vane separator, a secondary multi – density pad and a tertiary high efficiency filter. The vane separator allows large volumes of air to be drawn in with little air pressure drop. Water droplets are collected in the vane and returned to the atmosphere. The second stage filter pad removes intermediately sized particles. Fine filtration to 2 microns is provided by the third stage filter.

Self-clean pulse jet filter systems have in recent years become a popular choice for high dust load environments. Self-clean systems are composed of high efficiency filter cartridges which are periodically and sequentially cleaned by a reverse flow air jet system. These systems have proven to be an effective, low maintenance alternative in onshore applications.

Figure 5: A Self-Clean Filter Element

(Picture Belongs to Unit 106 of Phase 2&3 of S.P.G.C.)

Figure 6: A Filter House Containing Self-Clean Filter (Picture Belongs to Unit 106 of Phase 2&3 of S.P.G.C.)

4.2: Compressor Section

As it is known the compressor is a device which elevates the working fluid pressure. Compressor types come in two main groups:

1. Positive Displacement Compressors
2. Dynamic Compressors

The second group is sub-grouped into:

- Centrifugal Flow Compressors
- Axial Flow Compressors
- Mixed Flow Compressors

Figure 7 illustrates the regions of pressure (head) versus flow rate which are covered by these types of compressors.

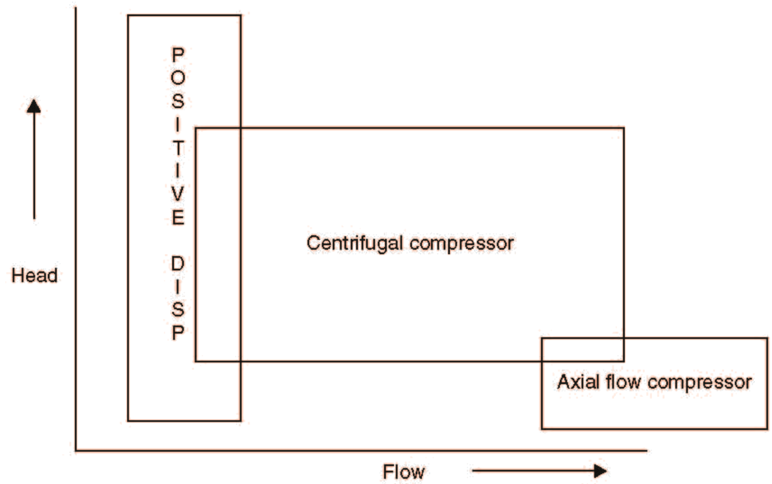


Figure 7: Performance Characteristics of Different Types of Compressors

Positive Displacement Compressors are used when a high pressure (head) and low gas flow rate are required. Centrifugal Compressors provide a medium head and flow rate. Since one of the main factors of power generation in gas turbines is the fluid momentum which means; the higher the momentum, the higher the generated power, the Axial Flow Compressors are applied in gas turbine. There other two other main advantages which worth mentioning that have led to get this type of compressor widely used in gas turbine technology:

- Having a high isentropic efficiency (Commonly 85%)

- Low maintenance activity and cost

The main components of an axial flow compressor are:

- Case
- Rotor
- Stator

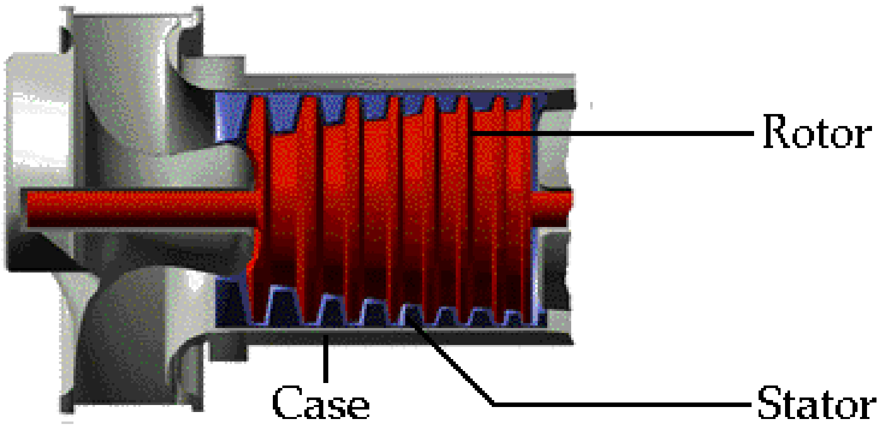


Figure 8: Main Components of an Axial Flow Compressor

The first component discussed is case.

The compressor case contains the rotor and stator. The case is split into halves. The upper half may be removed for inspections or maintenances while bottom half remains in the place. The case of an axial flow compressor has the functions bellow:

- Supports the stator vanes
- Provides the outside wall for axial path of air flow
- Provides means for extracting the compressed air

The next compressor section will be the rotor.

The rotor is the rotating element of an axial flow compressor. The rotor contains blades fixed on a spindle, drum or wheel (Figure 9).

The rotor blades are usually made of stainless steel and they are manufactured corrosion and erosion resistant. They are usually fitted in the rotor's disk bulb-type, fir-tree type or dovetail-type (Figure 10). Then they are locked by means of screws, pins, spacers, keys or lock wires. The clearance between the rotor blades and the case is very critical. These blades are thinner at their tips than at base. This design helps preventing damage to blades, stator vanes, or compressor housing if the blades touch the compressor housing.

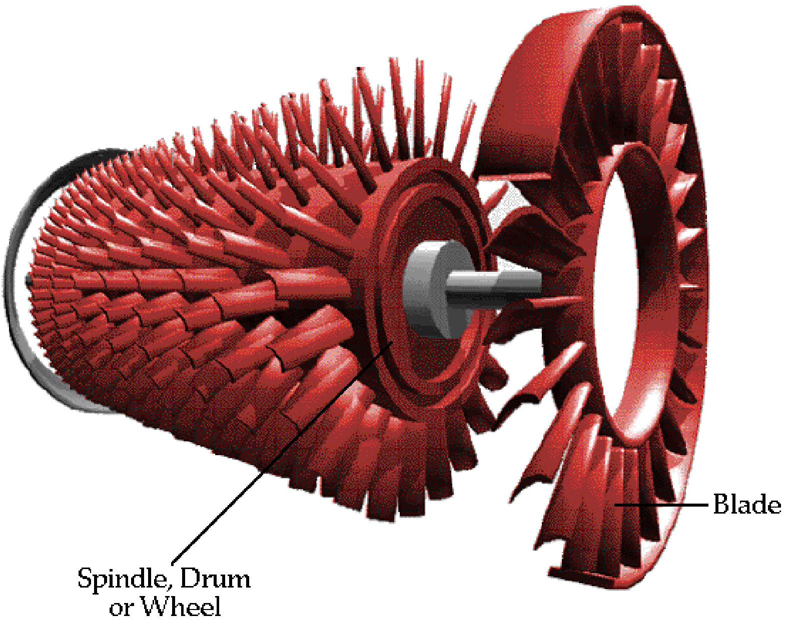


Figure 9: The Compressor Rotor

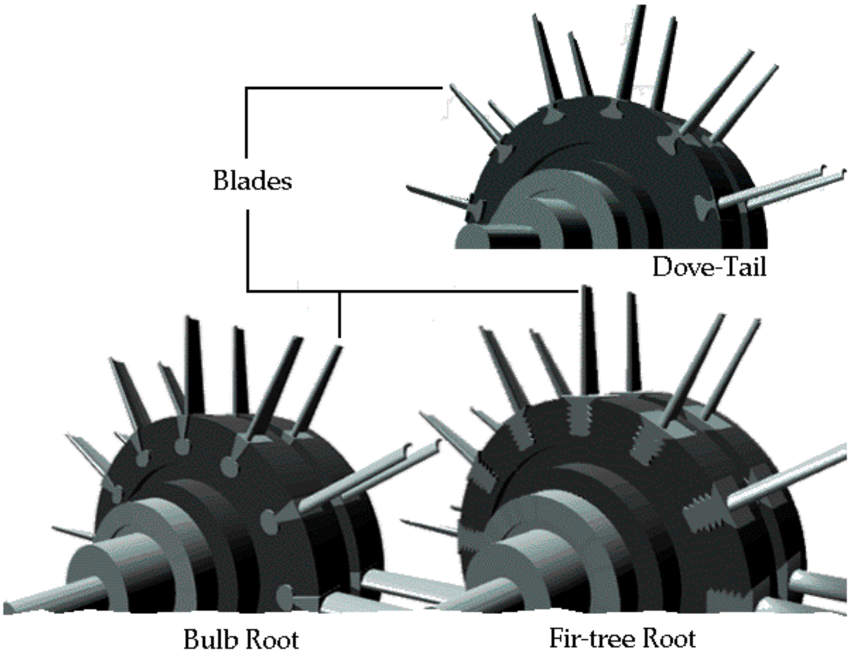


Figure 10: Different Fitting Methods of Rotor's Blades

Stator vanes are non-moving elements of compressor. They are located between each rotor stage. As rotor blades they are made of corrosion and erosion resistant stainless steel.

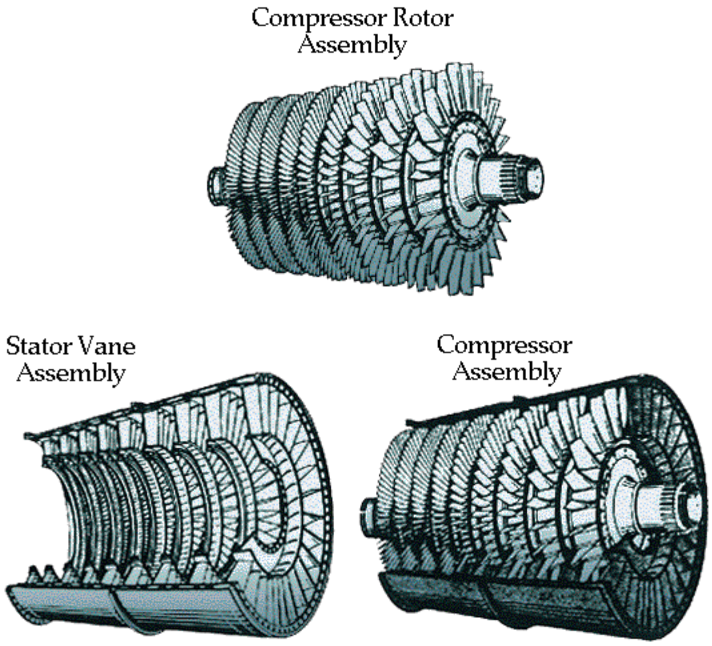
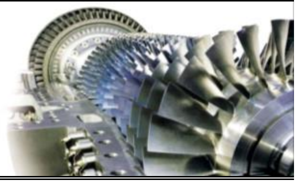


Figure 11: Compressor Assembly

An axial flow compressor compresses its working fluid by first accelerating, then diffusing it to obtain a pressure increase. The fluid is accelerated by the rotor blades and diffused by stator vanes. The stator vanes also make the fluid flow to be introduced to the next row of rotor blades in the best possible attack angle. Actually the stator vanes convert the kinetic energy of the fluid to pressure energy by means of their divergent distance. One rotor blades row and one stator vanes row make up a stage. One additional row of fixed blades (Inlet Guide Vane: IGV) are used at the inlet of the compressor to guide the air flow to the first stage rotor blades at the desired angle. An axial flow compressor comprises of multiple stages (Up to 17 or more stages). Each stage gives a pressure increase about 1.15 to 1.25.

In addition to the stator vanes usually one or two rows of fixed vanes (Exit Guide Vane: EGV) and a diffuser are considered to prevent pressure drop and also for keeping the velocity and laminar flow of fluid from the last stator vane to the entrance



of the combustors (Figure 13).As the air passes through the multiple stages of the compressor, due to pressure increase, its density increases as well. According the Mass Continuity Law the cross sectional area of the fluid must decrease to have a continuous fluid flow, other wise the flow will choke. So the annular working space is decreased (Figure 12) and therefore the blades are shorter at the discharge of the compressor than at the inlet and the compressor wheels diameter changes wise versa.

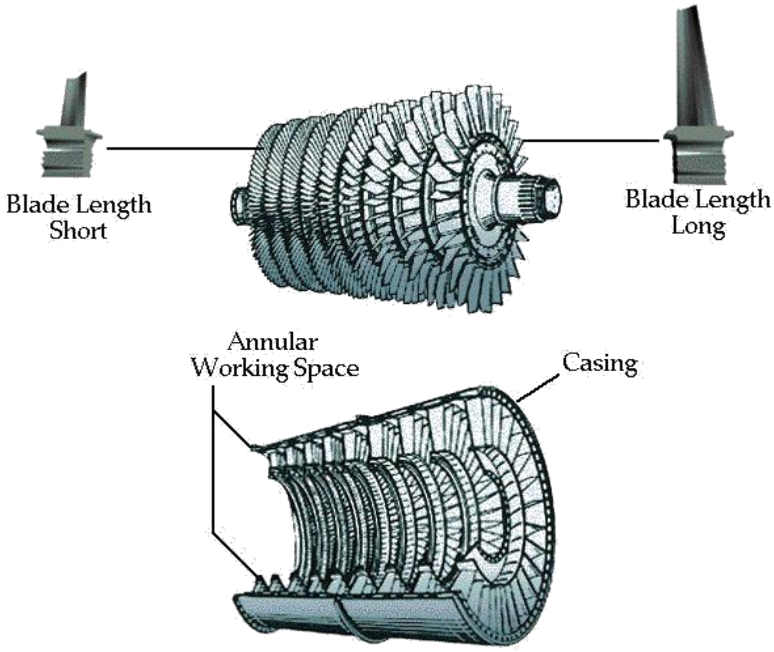
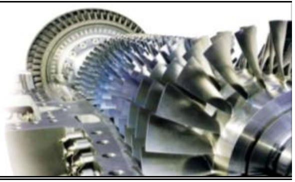


Figure 12: Annular Working Space Decreases



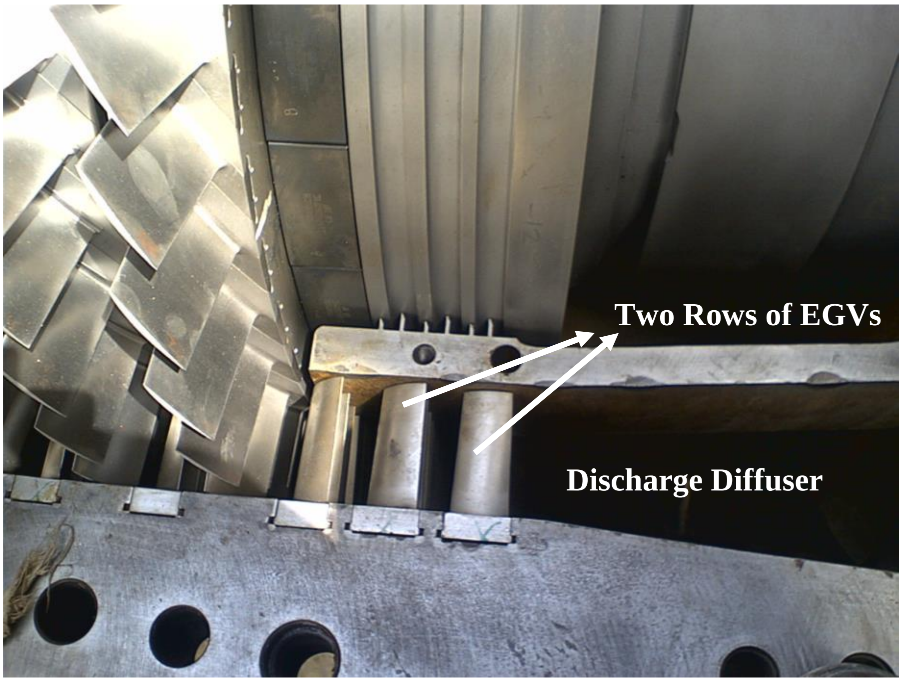


Figure 13: EGVs and Discharge Diffuser of Compressor
(Picture Belongs to Unit 120 of Phase 2&3 of S.P.G.C.)

Figure 14: A Seventeen Stage Axial Compressor Rotor
(Picture Belongs to Unit 120 of Phase 2&3 of S.P.G.C.)

4.3: Combustion Section

All combustors or combustion chambers have the same function. They increase the temperature (Enthalpy) of high pressure gas. They use very little of compressor discharge air (10%) in combustion process. The rest of the air is used for cooling and mixing. New designs of combustors utilize steam injection for cooling purpose.

The combustor is a direct fired heater in which fuel is burnt approximately stoichiometrically with one-third or less of the compressor discharge air. Combustion products are the mixed with the remaining air to reach the temperature that is suitable according to metallurgic characteristics of turbine materials.

Despite of different design styles of combustion chambers, three basic zones are identified in al of them (Figure 15):

1. Recirculation Zone
2. Burning Zone
3. Dilution Zone

The function of the Recirculation Zone is to evaporate (In case of liquid fuel use), partly burn and prepare the fuel for rapid burning in the burning zone. Ideally at the end of the burning zone all the fuel must be burnt, so that the function of the Dilution Zone is to mix and balance the hot gas with dilution air.

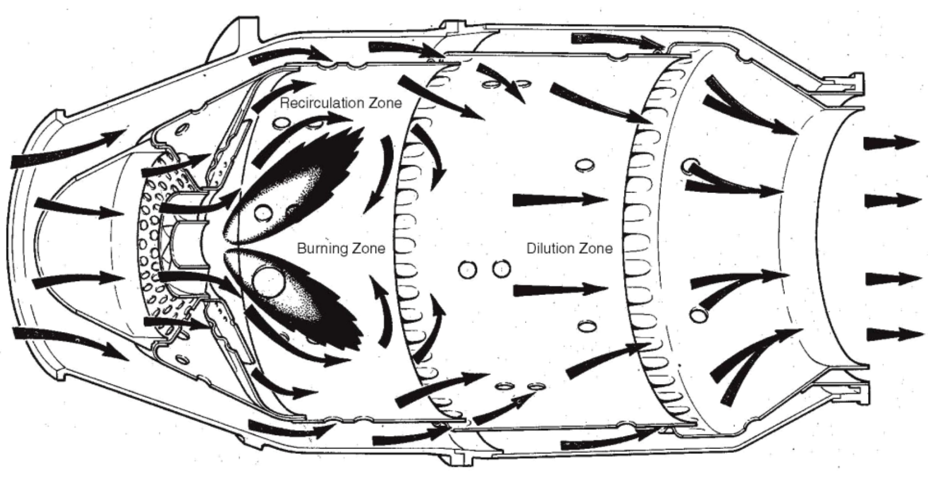
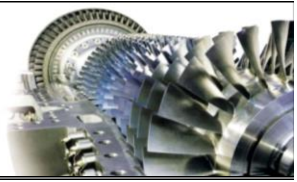


Figure 15 a: Three Distinguished Zones in a Combustion Chamber

The air entering the combustor is divided into two portions:

1. Primary Air



2. Secondary Air

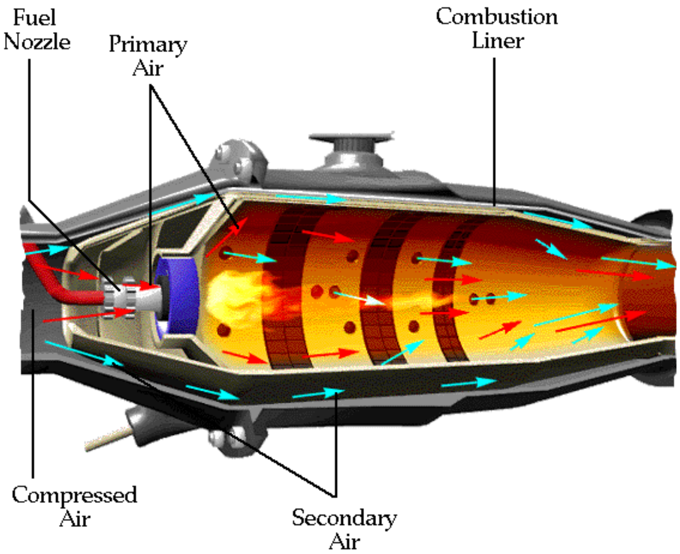


Figure 15 b: Primary and Secondary Air Flow

Primary air is about 18% of air entering the combustor. It is used for burning and initial mixing. The rest of air which is termed as Secondary Air (82%) has the responsibility of dilution and balancing the combustion products flow and cooling the flame tube (liner) and combustion products. About 72% is used for dilution and balancing and 10% for cooling (Figure 16).

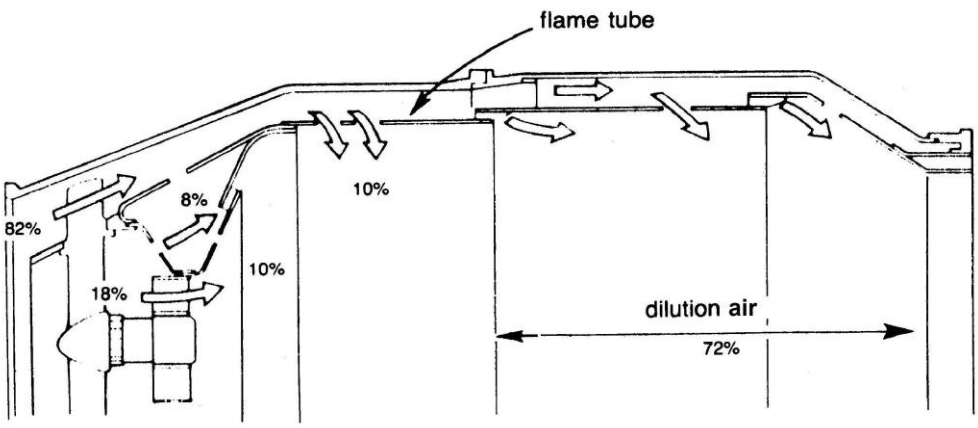


Figure 16: Air Distribution in a Typical Combustion Chamber

The air enters the combustion chamber can be straight flow or reverse flow. Most airo-derivative gas turbines use straight flow types and industrial designs usually use the reverse flow combustors.

A typical combustion chamber comprises of the following main components:

- Fuel Nozzle (To inject the fuel)
- Swirl Vane (To mix the fuel and primary air)
- Spark Plug (Not all of the combustors have)
- Flame Detector (Not all of the combustors have)
- Flow Sleeve (Not all of the combustors have)
- Liner (Flame Tube) (To make a canal for flame)
- Cross Fire Tube Connections (To transfer the flame from the combustor that has the spark plug to the ones that does not have)

Between the end of the combustor and the first stage nozzles of turbine there is another equipment which is called; ***Transition Piece***. The duty of this component is to direct the hot gases to the turbine section at the best possible velocity and angle. In has a convergent shape.

In the Figure 17 the main components of a typical combustor are illustrated in a reverse flow combustion chamber.

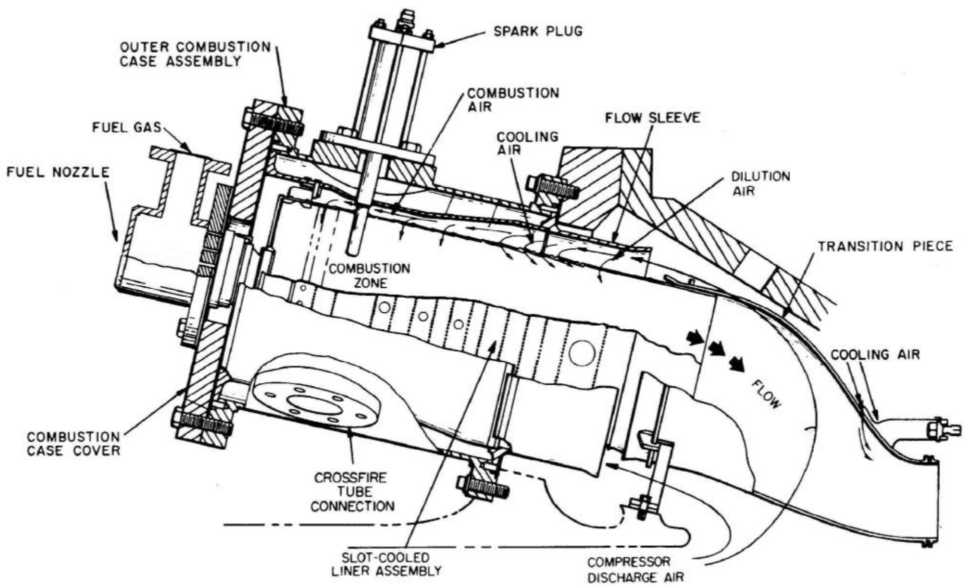
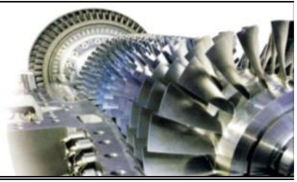


Figure 17: Main Components of Combustion Chamber in a Reverse Flow Design



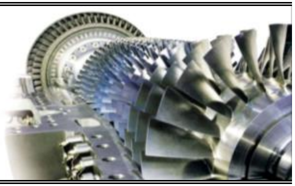
There are different methods for arranging the combustors on a gas turbine. Designs fall into three main categories:

1. Tubular (Figure 18 a)
2. Can Annular (Figure 18 b)
3. Annular (Figure 18 c)

4.4: Turbine Section

On contrary of axial compressor, the role of turbine in gas turbine cycle is to expand the hot pressurized gas to produce power by converting pressure energy to kinetic energy.

Like an axial compressor, a turbine contains Casing, Rotary Blades and Stationary Vanes. In turbine nomenclature the two latter are called Buckets and Nozzles respectively. Hot gases enter the turbine at high pressure and temperature and pass a series of nozzles and buckets (stages) and finally leave it at lower pressure and temperature. Gas expansion and corresponding power generation takes place in several convergent nozzles and buckets. Since hot gas flow is subsonic, when entering the first stage nozzles, due its convergent shape, its pressure drops and its velocity increases. Entering the first stage buckets this high velocity hot gas makes them rotate and this process is repeated till the gas leave the turbine (Figure 19).



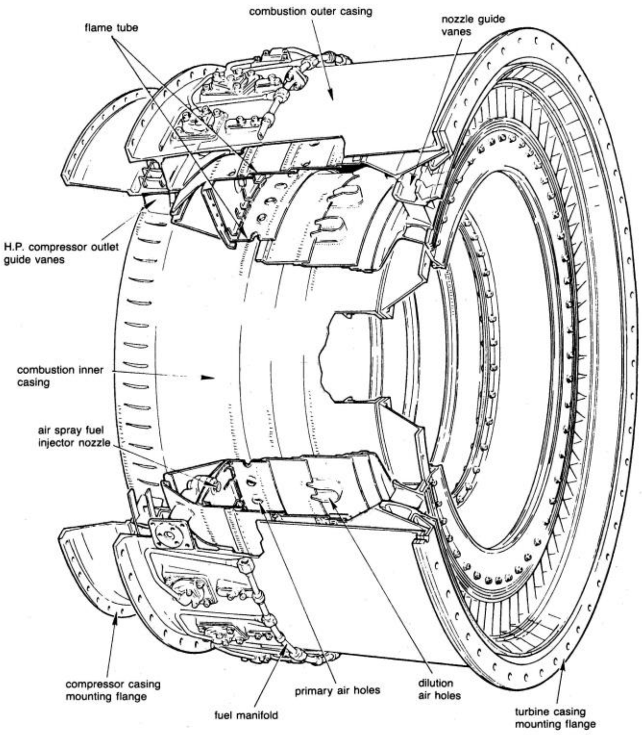


Figure 18 a: Tubular Combustion Chamber

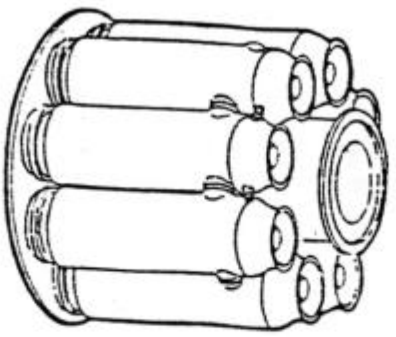
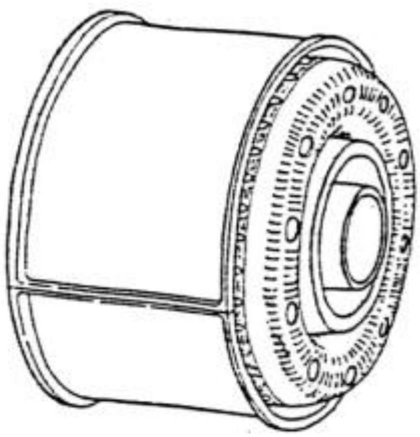


Figure 18 b: Can Annular Combustion Chamber

Figure 18 c: Annular Combustion Chamber



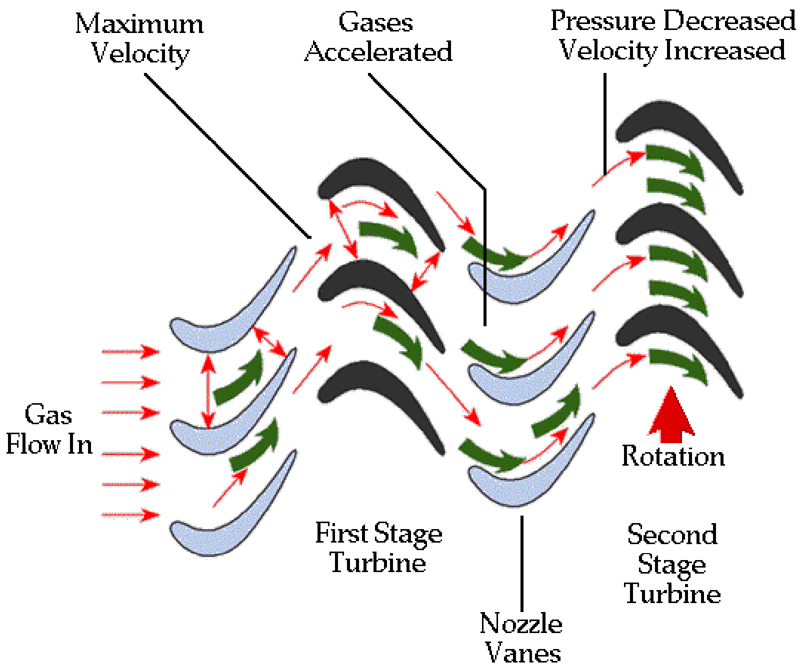


Figure 19: Gas Flow Pattern in Turbine Section

There are two power generation methods in turbines:

1. Impulse Power Generation
2. Reaction Power Generation

In Impulse Power Generation the buckets are nor divergent neither convergent and the distance between two buckets from inlet to outlet remains constant. So power generation is only based on changing in the direction of velocity vector (Figure 20).

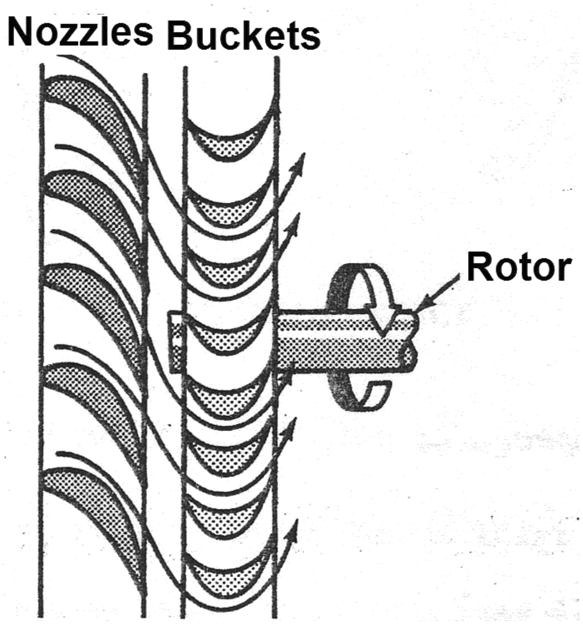


Figure 20: Schematic of Pure Impulse Power Generation

In Reaction Power Generation method buckets are convergent as same as nozzles; therefore the generated power is the consequent of changing in direction and size of the velocity vector.

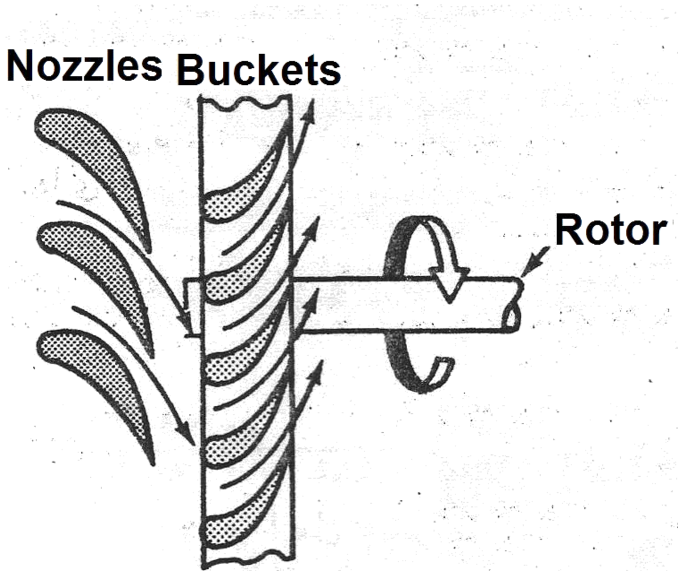


Figure 21: Schematic of Pure Reaction Power Generation

Since Impulse method needs high pressure and such pressure is not achievable in gas turbines, a combination of Impulse and Reaction is used and the buckets are manufactured in a way to be effective and applicable in this compound method (Figure 22).

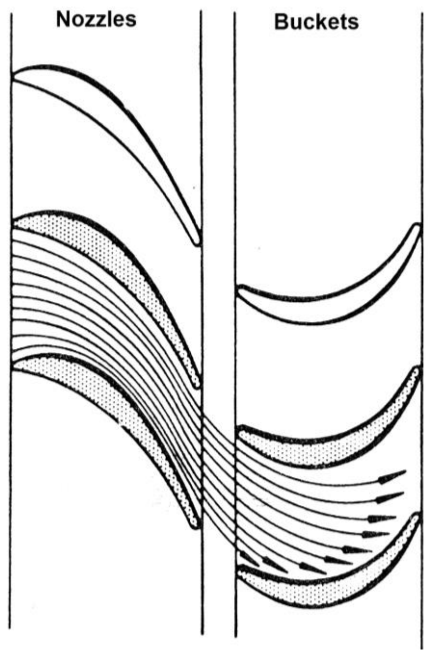


Figure 22: Schematic of Impulse/Reaction Power Generation

Figure 23 illustrates the Temperature, Pressure and Velocity changes of air flow through a typical gas turbine while entering the axial compressor and passing combustors and leaving the turbine section.

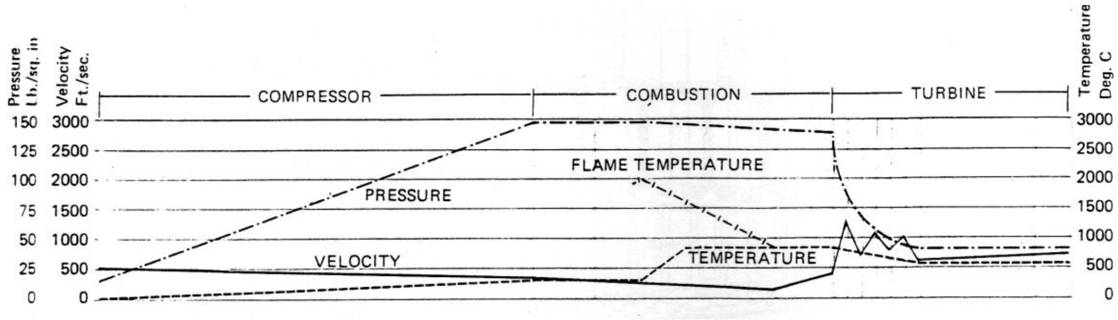


Figure 23: Temperature, Pressure and Velocity Changes through a Typical Gas Turbine

Improvements to the performance of gas turbines are achievable by operating the engine at as high possible turbine entry temperature. However, the maximum practical turbine entry temperature is limited by the capability of the blade materials to withstand high gas temperatures. Over the last four decades, a progressive improvement in material technology has led to an increase in the turbine entry temperature. However, an effective cooling technique in addition to improved blade material and manufacturing technology allows higher temperatures at the entry to the turbine to be achieved.

Cooling Techniques

Convection cooling, impingement cooling and film cooling are the main cooling techniques in turbine blades. These methods can be employed to maintain the skin of the blades at acceptable temperatures. Air is the main coolant fluid which has been used as it is widely available. It can be extracted from the compressor, and used as a coolant. All different cooling techniques can be categorized as either **External** or **Internal** cooling techniques.

- ***External cooling***

External cooling involves the injection of a coolant air into the boundary layer of the hot gas flow. This is also known as film cooling. The coolant air absorbs heat from the blade as it passes inside the blade before it is ejected onto the external surface. The ejection can be done from rows of holes on the pressure side or suction side of the blade. Its purpose is to form a relatively cool insulating film and to reduce the heat transfer from the hot gas to the outside surface of the blade. A typical film cooling arrangement is shown in Figure 24.

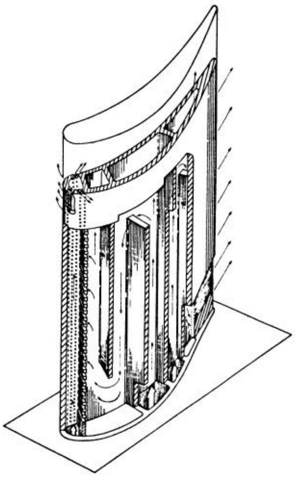


Figure 24: Film Cooling

- ***Internal cooling***

Convection cooling is one method of internal cooling. This technique involves air flowing through internal passages within the blade and absorbing heat from the metal. In order to provide a large amount of cooling, a large internal surface area is required. Therefore, this method is not very effective for cooling the thin trailing edges of turbine blades. Another form of internal cooling is impingement cooling. In this technique, coolant air is passed through a series of holes in such a way that it impinges on the inside of the blade. The impingement technique is very efficient in targeting specific areas and is easily adapted to nozzle guide vanes.

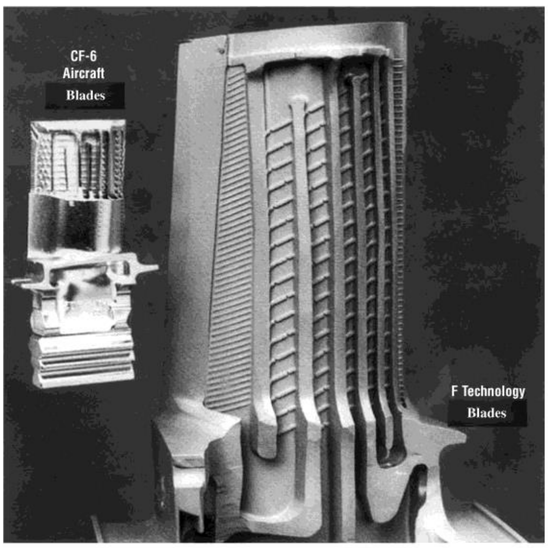
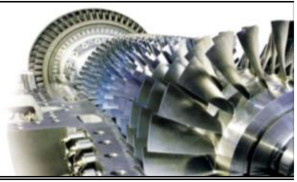


Figure 25: A Nozzle with Internal Cooling



4.5: Exhaust Section

After the hot gases leave the last stage of the power turbine they enter the exhaust duct (1) and are sent to atmosphere. Exhaust temperature vary but typically run from 400-500^{0}C.Pressure drop in the exhaust duct is usually 5-10 mbar. A considerable amount of waste heat energy is available in this exhaust stream due to high flow rate of exhaust. If this escaping energy is used to heat a process fluid, the overall efficiency of the gas turbine installation will be increased.

5: BEARINGS AND SEALS

Bearings and seals in a gas turbine are similar to those found in centrifugal compressors. Radial bearings are typically sleeve or tilting pad although some designs use ball or roller bearings. Thrust bearings are usually tapered land or tilting pad. Ball bearings are used in some applications. Labyrinth seals are widely used in gas turbine applications. The labyrinth is one of the simplest of sealing devices. It consists of a series of circumferential strips of metal extending from the shaft or from the bore of the shaft housing. Labyrinth seals leakage is greater than that of contract seals so they are utilized when a small loss in efficiency is acceptable.

In single shaft turbines usually there are two Journal Bearings and which are installed at the forward and afterward ends of the rotor. Two Thrust Bearings are also used. Active and Inactive thrust bearings. Both are installed next to the journal bearing of the forward end of the rotor.

Labyrinth seals are usually used to seal the sealing air which seals the lubricating oil in journal bearings and also at the compressor discharge end.

6: LUBRICATION SYSTEM

The purpose of gas turbine lubrication oil system is to provide clean and cool oil to engine parts that are subject to the friction. Lube oil:

- Reduces the Friction
- Cushions (Damps the Vibrations)
- Cools
- Cleans

The primary purpose of any lubricant is to reduce the friction between moving parts. The oil films slide against each other instead of metal to metal contact.

Oil pressure actually lifts the shaft up from journal bearing and as the shaft rotates the oil layer prevents any physical touches and also it cushions. It means the pressurized lubrication system it capable to absorb operational shocks as the result of load changing on the shaft or any bad contact between gear teeth.

Lube oil cools the internal parts of machine by absorbing the heat and transferring to the cold outside medium to reject the heat.

Also oil cleans internal elements of machine. As it is circulated, collects any foreign matters and dirt or metal particles and carries them to the oil reservoir to be settled down there or to be removed while passing the lube oil filters.

A typical gas turbine lube oil system consists of the following main components:

- Lube Oil Reservoir
- Lube Oil Pumps
- Lube Oil Filters
- Lube Oil Coolers
- Control Devices

Figure 26 illustrates a typical lube oil system of a gas turbine.

The lube oil supply is stored in the oil reservoir. Main, Auxiliary and Emergency lube oil pumps draw the oil under pressure from oil reservoir to the bearings. Control devices like a three way temperature control valve regulate the oil temperature. The oil is then routed through the filters to remove the suspended contaminants. Then the oil is sent to the main lubrication manifold. Commonly some instrument devices such as; pressure and temperature gauge, indicator and transmitter, pressure and temperature alarm and shut down switches are installed on main manifold. After lubricating all bearings, the lube oil is returned to the oil reservoir. An oil mist separator has the role of separating any oil droplets from the oil vapor which is generated over the liquid in the reservoir and is drawn out of it by means of an induced blower. What was described here is the principle of the lube oil system. The details may vary from one manufacturer to another one. In following the details are described.

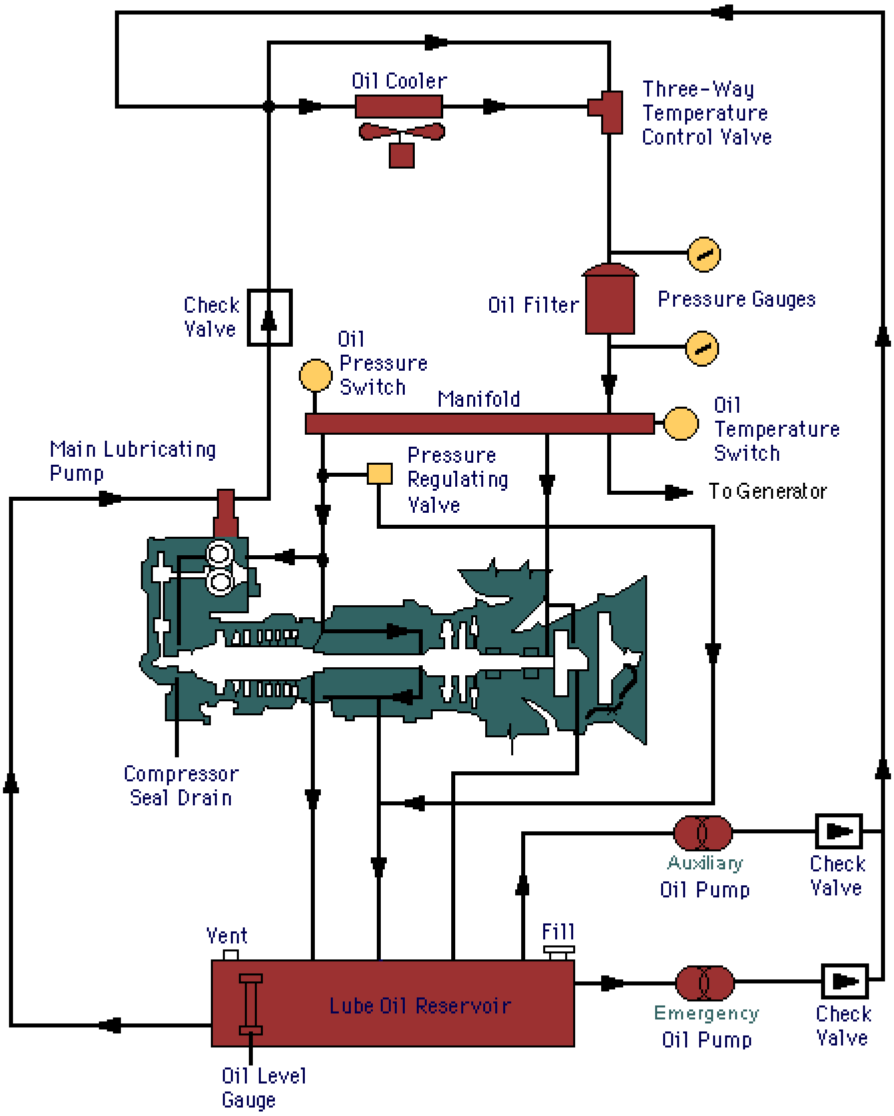


Figure 26: A Typical Lube Oil System of a Gas Turbine

6.1: Lube Oil Reservoir

The purpose of the oil reservoir is to contain a supply of the lubricant for gas turbine, accessory drive system, gearbox and driven equipment. It also provides the oil for starting, control, positioning the inlet guide vanes and trip oil circuit. Lube oil temperature is usually measured in the reservoir. In some designs an immersion heater is installed to provide the proper oil temperature especially is cold seasons. Reservoir may have both level sight glass and level indicator to indicate oil level. A sealed floating device operates level transmitter (LT) and level indicator (LI) and high level switch (LSH) and low level switch (LSL) to initiate turbine shut down due to high or low oil level in the reservoir.

The vapors generated inside the reservoir are vented to the atmosphere through a previously described system (Oil Mist Separator) to maintain an even pressure and level in the reservoir. A flame arrestor is installed in the vent to prevent entering any source of ignition. A Pressure Control Valve (PCV) is also installed to control supply oil pressure by returning the excess oil to the reservoir. System protection is provided by mounting a Pressure Safety Valve (PSV) located on each Main, Auxiliary and Emergency pumps with a return to the reservoir (Figure27).

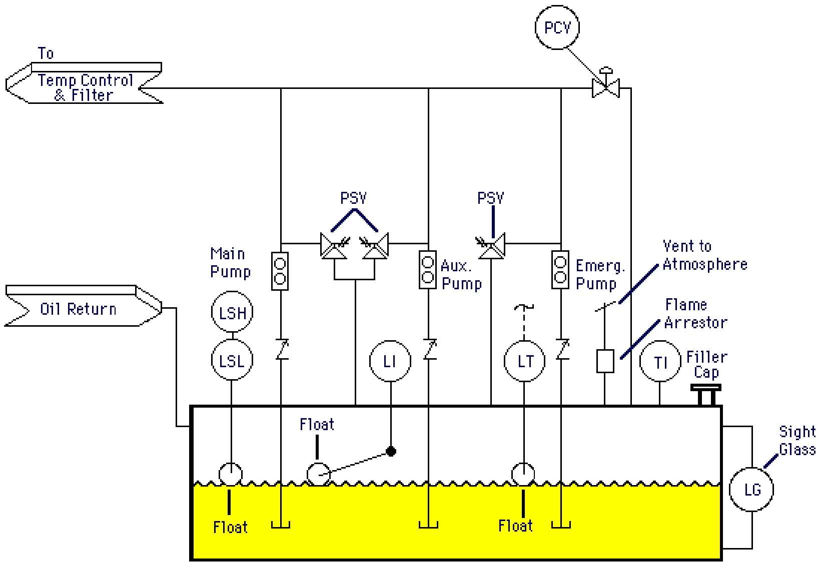


Figure27: Oil Reservoir and its Typical Components

6.2: Lube Oil Pumps

As mentioned above, the purpose of lube oil pumps is to provide lube oil under the pressure to lubricate the engine and its associated components. Lube oil pumps which are found in a gas turbine package fall into three:

- Main Lube Oil Pump
- Auxiliary Lube Oil Pump
- Emergency Lube Oil Pump

Three common types of main lube oil pump are as follows:

- Vane
- Gerotor

- Gear

These pumps are positive displacement type (Figure 28).

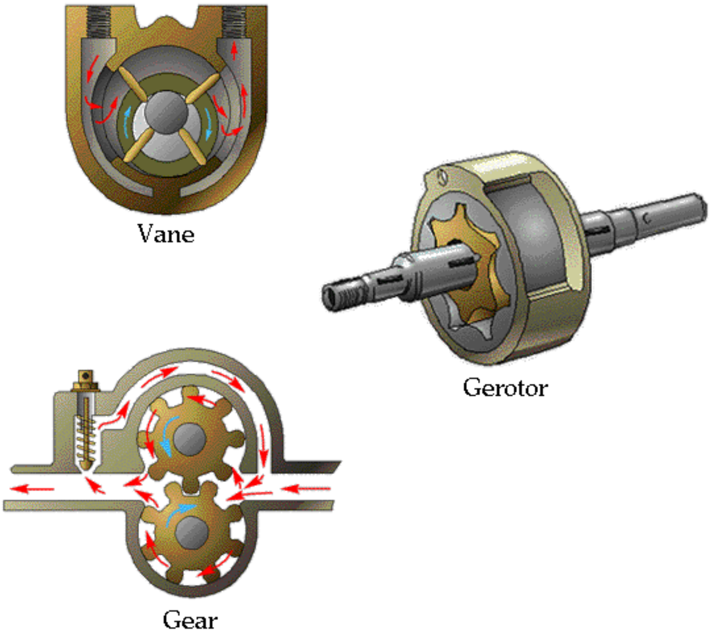


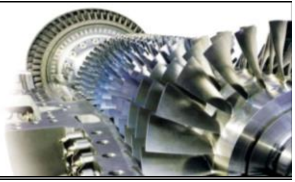
Figure 28: Three Common Types of Main Lube Oil Pumps

First of all the Auxiliary Pump is preferred to be described. The purpose of this pump is to supply oil:

- During gas turbine start up
- During gas turbine shut down and cool down time
- Any other time that main lube oil pump can not provide the lubricant

Before the gas turbine starter is engaged this pump comes in service and operates and keeps running till the moment that the provided pressure by the Main Lube Oil Pump is adequate (Approximately up to 90% of rated speed of machine.). This pump is AC-powered. During gas turbine trip or normal shut down this pump is engaged again (when shaft reaches about 80% of its rated speed) and continues operation till the moment that cool down time passes. A vertical centrifugal pump is sometimes used as an Auxiliary Lube Oil Pump.

Main Lube Oil Pump is attached to the accessory gearbox and is driven by the power generated by the main shaft of the gas turbine. That is why it is call as Main Lube Oil



Pump. This pump comes in service when the turbine reaches to such speed that is enough to provide sufficient oil pressure for lube oil system.

The Emergency Lube Oil Pump has been considered to supply oil during an emergency shut down if the Auxiliary Lube Oil Pump does not come to service or is not able to provide adequate oil pressure. This pump is similar to the Auxiliary Lube Oil Pump. The difference is that Auxiliary is AC-powered but Emergency is DC-powered.

6.3: Lube Oil Filters

The purpose of lube oil filter is to remove suspended particles that collect in the oil. If not removed these particle lodge in the tiny closed spaces between bearings and seals and also the friction will increase between moving parts, resulting in excessive wear and bearing failure. Gas turbine lube oil filters have micron scale meshes. Contaminants in lube oil system are mainly from the sources below:

- Small carbon particles from lube oil brake down
- Metallic particles from engine wear and corrosion
- Particles entering by the air through bearing seals
- Dirt or any foreign matters from oil reservoir

According the usage times numbers lube oil filter can be categorized into two groups:

- Disposable Filters
- Cleanable Filters

Disposable filters are usually cartridge type and able to remove the contaminants as small as 5 microns. They are usually smaller than the Cleanable type and commonly used as multiple filters in filter case (Figure 29). They must be disposed after removing and new ones must be replaced.

Figure 29: Disposable Lube Oil Filters (Picture Belongs to Unit 106 of phases 2&3 of S.P.G.C.)

Cleanable filters are multi usage and can be removed, cleaned and reinstalled. They are wire mesh type.

Two types of lube oil filter assemblies are utilized in gas turbines:

- Simplex Lube Oil Filters
- Duplex Lube Oil Filters

Simplex assemblies contain only one filter, so when the filter element needs to be cleaned or replaced the gas turbine must be shut down (Disadvantage). So many gas turbines are benefiting duplex assembly. Each filter comprises of the following main components (Figure 30):

- Filter Case
- Plumbing
- Differential Pressure Gauge
- Differential Pressure Alarm Switch
- Balance Line
- Transfer Valve

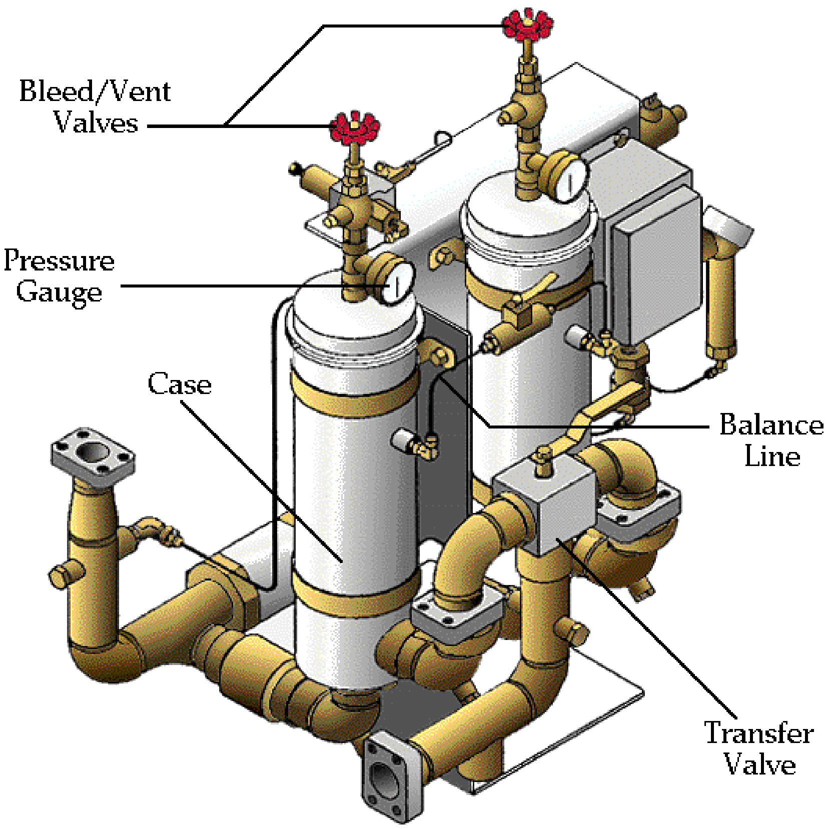


Figure 30: A Duplex Filter Assembly and its Components

The filter case is cylinder shape and contains the replaceable filter element(s). The plumbing comprises a drain port used to drain oil while replacing filter elements and bleed/vent valve to bleed trapped air during filling the filter case by the oil.

At the moment only on filter must be in service. A handle transfer valve is used to change over the filters. Before doing the change over the filter cases oil pressure must be equalized. This is done by opening the balance line valve.

Differential pressure alarm switch alarms when outlet and inlet pressure differential exceeds a pre-determined set point.

6.4: Lube Oil Coolers

The purpose of lube oil coolers is to remove the absorbed and transferred heat by oil from the engine and reject it to cold medium which can be water or atmospheric air so that the lube oil temperature is maintained at a proper point. Therefore the lube oil coolers are categorized into two types:

- Water Cooled

- Air Cooled

The water cooled system employs a water to oil heat exchanger. The water cools the oil and heats up so it is routed to an air cooler to be cooled to be reused.

The air cooled system utilizes a finned type air cooler which the induced or the forced air flow in blown on it by means of an electrically powered fan.

The lube oil cooler is one of the components which needs less operational checking. Mainly the leakage of oil or water must be checked.

Figure 31 shows a diagram of an air cooled system. Lube oil from lube oil pump either bypasses the air cooler or enters one of them by means of correct operation of Transfer Valve (FCV) and Temperature Control Valve (TCV).

If the oil temperature is less than the system's set point, the TCV opens port B to port A and the oil air coolers are bypassed, but if the oil is heated up the TCV begins to close port B and open port C, and oil will undergoes the air coolers.

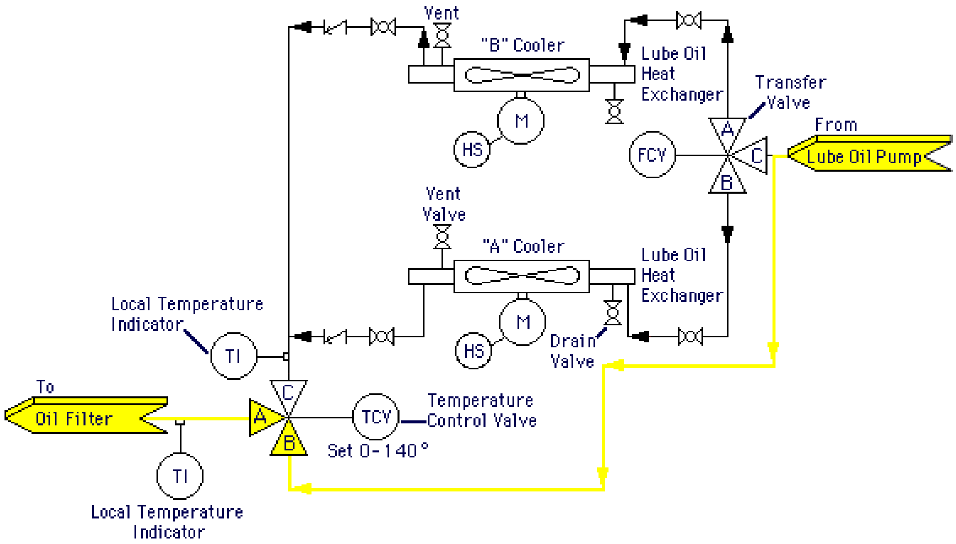


Figure 31: TCV Operation in an Air Cooled System

7: FUEL SYSTEM

The purpose of a fuel system is to provide the exact amount of fuel to the gas turbine in different operational conditions. The fuel amount is based on the load and the turbine speed and the fuel pressure is a function of the compression ratio. The higher the compression ratio the higher the amount of fuel is needed. Almost any combustible fluid, either gaseous or liquid can be used. Some gas turbines can operate on both fuel types. The fuel gas and liquid fuel must meet some necessary requirements as the following tables:

Table 1: Fuel Gas Requirements

Requirement	Specifications
Lower Heating Value	900-1400 BTU/SCF
Supply Pressure	140-425 psig
Gas Temperature	32-160^o F
Fuel Quality	Water free
	No more than 1-3% H_2S
	Maximum HC droplets : 5 microns
	Below 10 microns solid particles
	Less than 20 ppm total solid and liquid HC
	Less than 1 ppm sodium

Table 2: Liquid Fuel Requirements

Requirement	Specifications
Fuel Temperature	32-140^{o}C
Fuel Viscosity	Less than 10 cs
Pour Point	10^{o}F below ambient temperature
Fuel Quality	Less than 1% sulfur
	Less than 0.01% total ash
	Less than 0.5 ppm vanadium
	Less than 1 ppm sodium and potassium
	Less than 1 ppm lead
	Less than 2 ppm calcium

1: Fuel Gas System

The main components of a typical fuel gas system are as follow:

- Fuel Shutoff Valve (SOV)
- Vent Valve
- Pressure Control Valve (PCV)
- Pressure Indicator Controller (PIC)
- Pressure Safety Valve (PSV)
- Filter Separator

- Control System

The purpose of the Fuel Shutoff Valve is to allow/prevent the fuel gas to be delivered to the turbine. The purpose of the Vent Valve is to release the extra possible pressure or trapped gas in the fuel gas lines.

The position of these two valves is controlled pneumatically or by hydraulic system.

The first device located after the SOV is the Pressure Control Valve. This equipment regulates the fuel gas pressure to the turbine according to the instrument air signal from Pressure Indicator Controller (PIC). PIC measures the fuel gas pressure, compares this pressure to the set point and modulates the PCV to maintain set point pressure. A Pressure Safety Valve is mounted between the PCV and PIC to vent excessive fuel gas pressure to the flare due to PCV malfunctioning. Two other instruments that receive the fuel gas pressure from the PIC line: Pressure Indicator (PI) and Pressure Transmitter (PT). The PT signals the fuel gas pressure to DCS. PAL alarms for low pressure of fuel gas and PAH for high pressure.

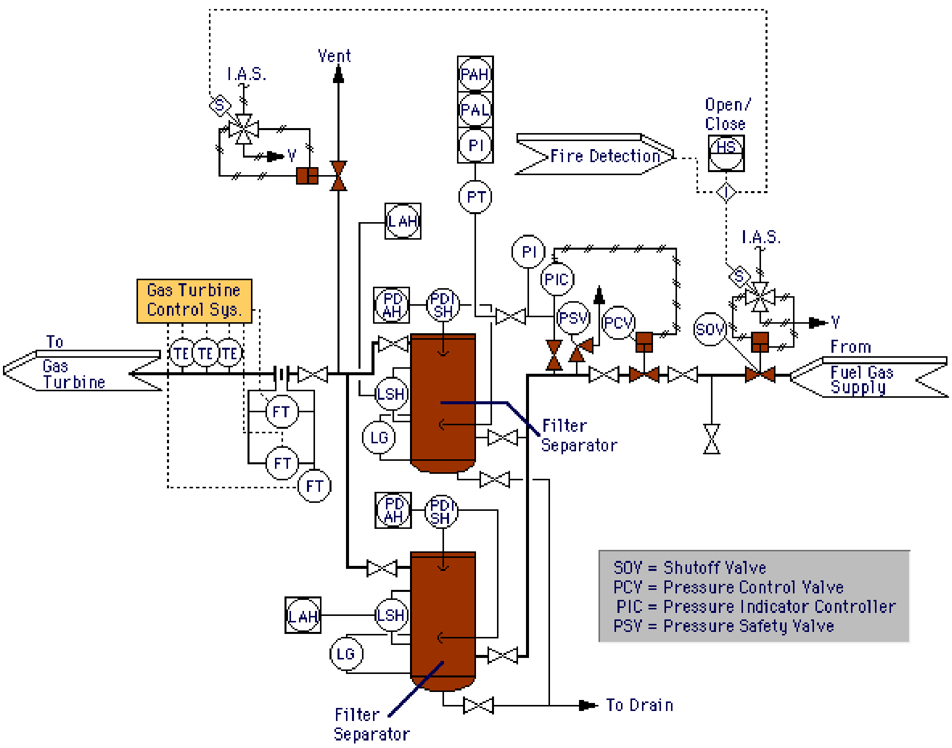


Figure 32: Fuel Gas System Components

The purpose of the Filter Separator is to provide filtration and separation the fuel gas prior entering the fuel gas Control System. The fuel gas must be relatively clean and dry. Operator should periodically check the separator sight glass for any evidences of accumulated liquid (if available). Any liquid accumulation must be drained off. Like the lube oil filters are equipped with Differential Pressure Indicators and Alarms. The system shown in Figure 32 contains a high differential pressure indicator switch (PDISH) and a differential pressure alarm (PDAH).

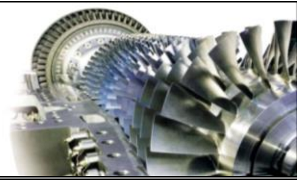
Fuel gas flows from the filters to the gas turbine Control System. Several measuring devices are located between the filter separator and the gas turbine.

- Pressure Transmitter (PT)
- Flow Transmitter (FT)
- Temperature Measurement Elements (TE)

These devices provide information to control system. The information is analyzed and computed by the Control System to schedule fuel flow to the engine as needed according to the speed and load.

2: Liquid Fuel System

As the fuel gas system the purpose of the Liquid Fuel System is to deliver measured amount of the fuel at the correct pressure to the engine in different operational conditions. Gas turbines liquid fuels are liquid hydrocarbons similar to Kerosene. Almost any combustible fluid can be used for turbine fuel, although high viscosity fuels bring about some special problems. The Figure 33 shows a typical liquid fuel system and highlighted main components.



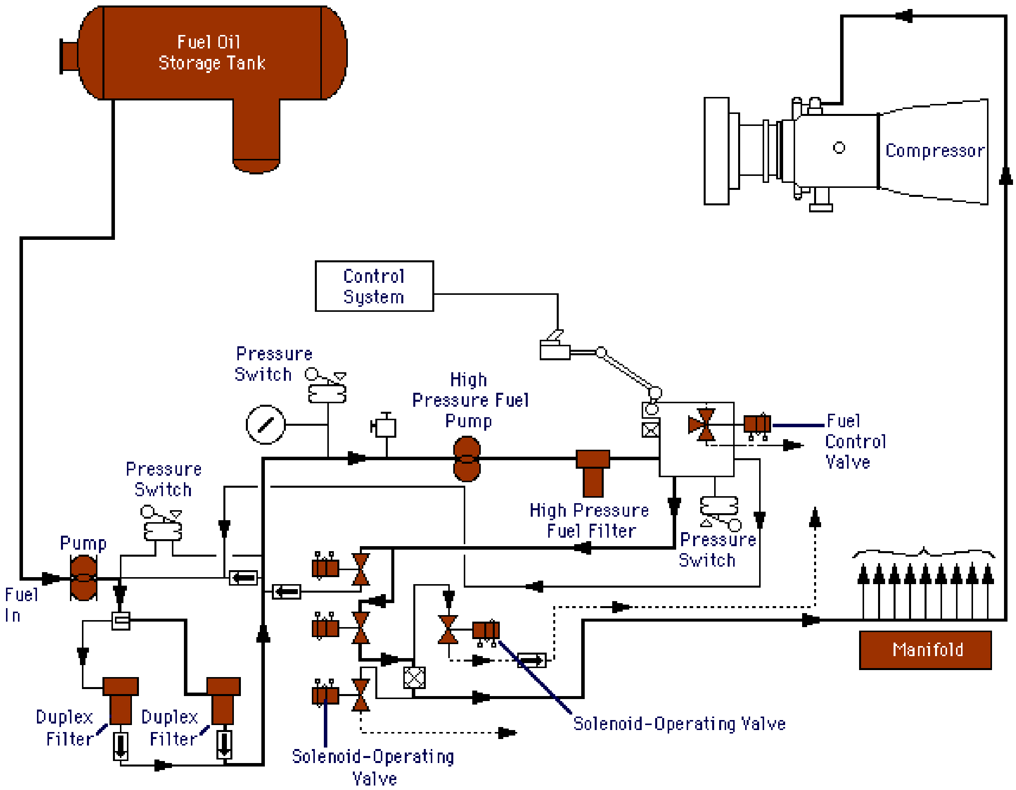


Figure 33: Main Component of a Typical Liquid Fuel System

The main components of a liquid fuel system are as follows:

- Fuel Storage Tank
- Fuel Pumps
- Pressure Switches
- Fuel Filters
- Manifold
- Nozzles
- Fuel Control Valve
- Solenoid Operated Valves
- Control System

The purpose of the Fuel Storage Tank is to store the received fuel from outside source. Storage tanks usually store enough fuel for 24 hours of gas turbine operation.

That is why they are sometimes called Day Tanks. They are often equipped with the following devices:

- Relief Valve
- Pressure Control
- Pressure Indicator
- Temperature Indicator
- Level Indicators
- Level Controls and Alarm

Fuel pumps deliver under pressure fuel to gas turbine control system. They are started and stopped by a local HOA hand switch. HOA stands for Hand/Off/Automatic.

When the hand switch is on the H position, the liquid fuel is under the manual control. When on the O, the pump is off. When both pumps switches are on A, the running pump plays the role of main pump and the other pump will remain stand by and will start automatically at the moment of main pump failure and the fuel flow will go on without any interruptions.

There are two types of fuel pumps:

- Fuel Boost Inlet
- High Pressure Fuel

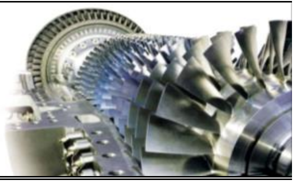
The purpose of the Fuel Boost Inlet pump is to elevate the pressure to the pressure which is required for proper fuel system operation. It is installed upstream the low pressure duplex fuel filters. It is a rotary positive displacement gear type pump, driven by an electro motor. The High Pressure Fuel pump is also a gear type positive displacement type driven by electro motor or by the engine itself.

The low fuel pressure switches senses fuel pressure to the high pressure fuel pump. This switch initiates engine shutdown if the fuel pressure in lower than the pre determined set point.

In a liquid fuel system there are two types of filters:

- Low Pressure Duplex Filters
- High Pressure Fuel Filter

The duplex filter assembly contains two parallel- mounted filters equipped with a selector valve, filter check valves, and a differential pressure switch. Each filter



contains two replaceable filter elements with 10 micron nominal rating, connected to the fuel system through the control valve, so that fuel flow may under goes through either filter. This arrangement serves two purposes:

- Servicing of the inactive filter during operation
- Transferring the fuel flow to the clean filter without engine shutdown

The high pressure fuel filter is installed in the fuel line between the high pressure fuel pump and the fuel control valves. It contains a replaceable filter element rated at 40 microns nominally.

The Manifold has been considered to divide the fuel flow between fuel nozzles via connections to the Injectors.

The fuel nozzles are located in the inlet of combustors. They deliver a highly atomized fuel in a controlled spray pattern to the combustors. The fuel nozzles fall into three types:

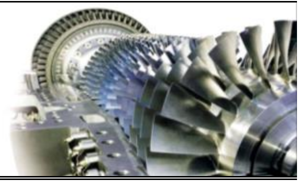
- Simplex
- Duplex
- Air Blast

The simplex Fuel Nozzle has a small orifice that provides only on spray. It has a set of vanes, called as flutes, which act as a swirl vane to mix the fuel and the primary air as best as possible (Figure 34).

Duplex fuel nozzles are divided to:

- Single Line
- Dual Line

The single line duplex fuel nozzle receives the fuel at one inlet port. A flow divider inside the nozzle distributes the fuel through two sprays. The primary fuel tube sprays the fuel at a wide angle and the outer fuel tube (secondary) opens at a present pressure which narrows the spray pattern to prevent any touches to the combustors liner (Figure 35). The dual line duplex fuel nozzle is similar to the single line except it does not have a flow divider to separate sprays. There is an independent inlet port for primary and secondary orifices. It also contains cooling air holes and flutes (Figure 36).



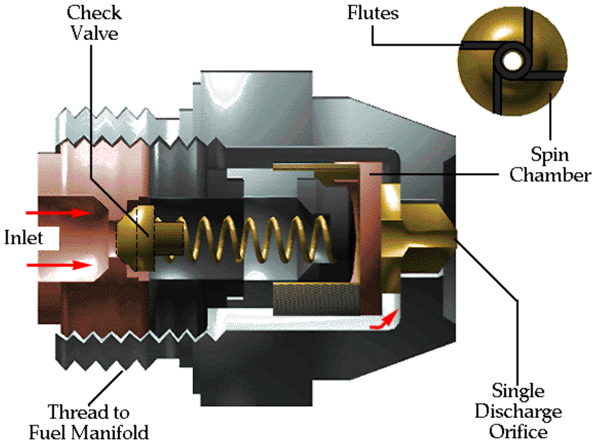


Figure 34: Simplex Fuel Nozzle

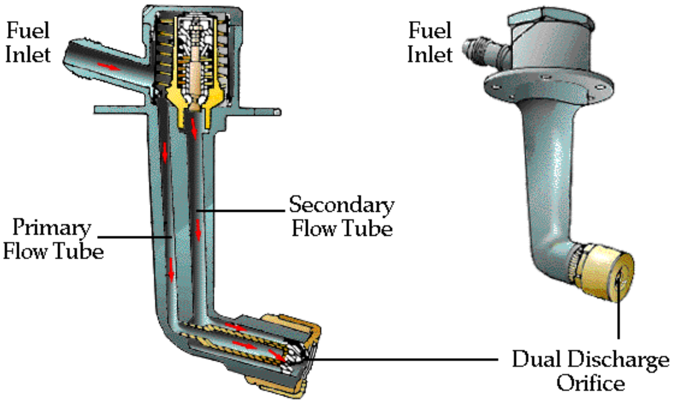


Figure 35: Single Line Duplex Fuel Nozzle

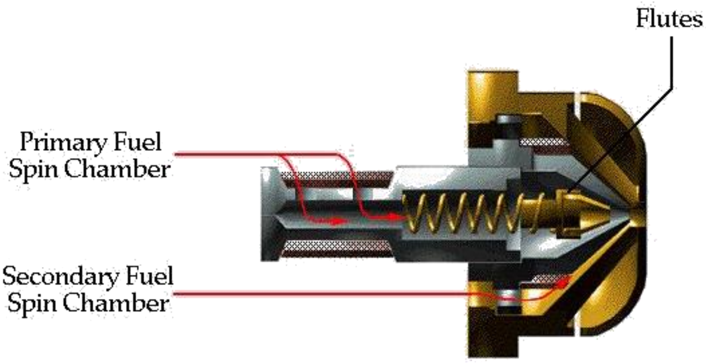
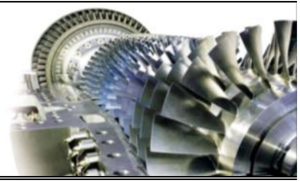


Figure 36: Dual Line Duplex Fuel Nozzle

The Air Blast Fuel Nozzle enhances the atomization process and finer fuel droplets. This nozzle is more effective during start up when low fuel pressure causes problems. By using high velocity airflow, these nozzles atomize more completely than it can be accomplished by only pressurized fuel. This type also comprises of two main types:

- Simplex
- Duplex



Figures 37 shows an air blast fuel nozzle and its two types.

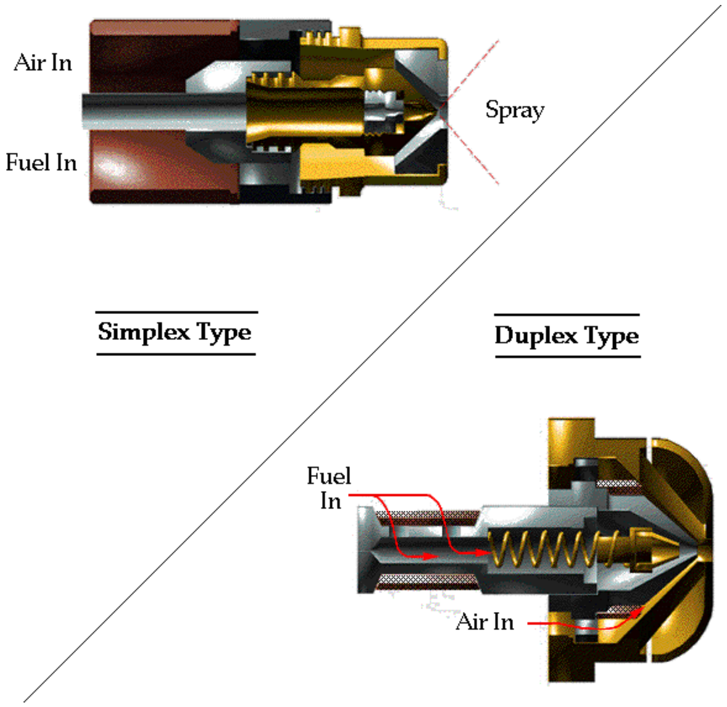


Figure 37: Air Blast Fuel Nozzle

Turbine speed is controlled by the fuel control valve. So it is supposed to:

- Provide the proper fuel/air ratio to combustors
- Regulate the fuel flow to control the engine speed and exhaust temperature

The turbine speed is measured by two methods:

- Flyweight Governor
- Magnetic Sensors

The Flyweight Governor consists of a pair of weights, a tension spring and a governor rod. As the turbine rotates the weights are moved apart and step by step the rod closes the throttle valve to decrease the shaft rpm in case of over speed.

Magnetic pick up sensor consists of a permanent magnet, wrapped with a coil in a sealed case. The sensors are mounted around a gear wheel on gas turbine shaft. Each sensor generates an electrical signal proportional to the engine speed. A signal is sent each time to a gear tooth that is passing under the sensor and rotational speed is measured.

8: ACCESSORY EQUIPMENTS

In industrial frame gas turbines there is compartment which is called Accessory Compartment. The equipments below are the main possible present devices in this compartment:

- Accessory Gearbox
- Auxiliary Lube Oil Pump
- Auxiliary Hydraulic Oil Pump
- Emergency Lube Oil Pump
- Ratchet System

Auxiliary and emergency pumps were previously described.

An Accessory Gearbox provides enough space to contain some diver shafts. At start up step the shafts of the gearbox is driven by the starter, which can be electrical, pneumatic or hydraulic. The following equipments attached to the Accessory Gearbox are driven by the main shaft of the engine in self sustaining condition.

- Main Lube Oil Pump
- Main Hydraulic Pump
- Liquid Fuel Pump (In case of liquid fuel system)
- Atomizing Air Compressor (In case of liquid fuel system)
- Cooling Water Pump (In case of water cooled lube oil cooling system)

All of these equipments absorb their power from the main shaft (No.1 shaft) and adequate power is distributed among all driven equipments via gears.

When the turbine trips or it is shutdown normally, due to heavy weight of the shaft. It must be rotated during cool down time to prevent shaft bending and the system which does that is termed as the Ratchet System. Usually every 3 minutes it makes the shaft rotate for 30 seconds which would be equal to 45^{o} of rotation. It is a one direction clutch that is engaged and again disengaged according to the explained sequence. The pressurized hydraulic oil enters two of four cross mounted cylinders and pistons and generates the torque to rotate shaft. The two other cylinder and pistons are filled in the second half of each 30 second sequence. Figure 38 shows a cut view of an accessory gearbox that also contains the ratchet clutch.

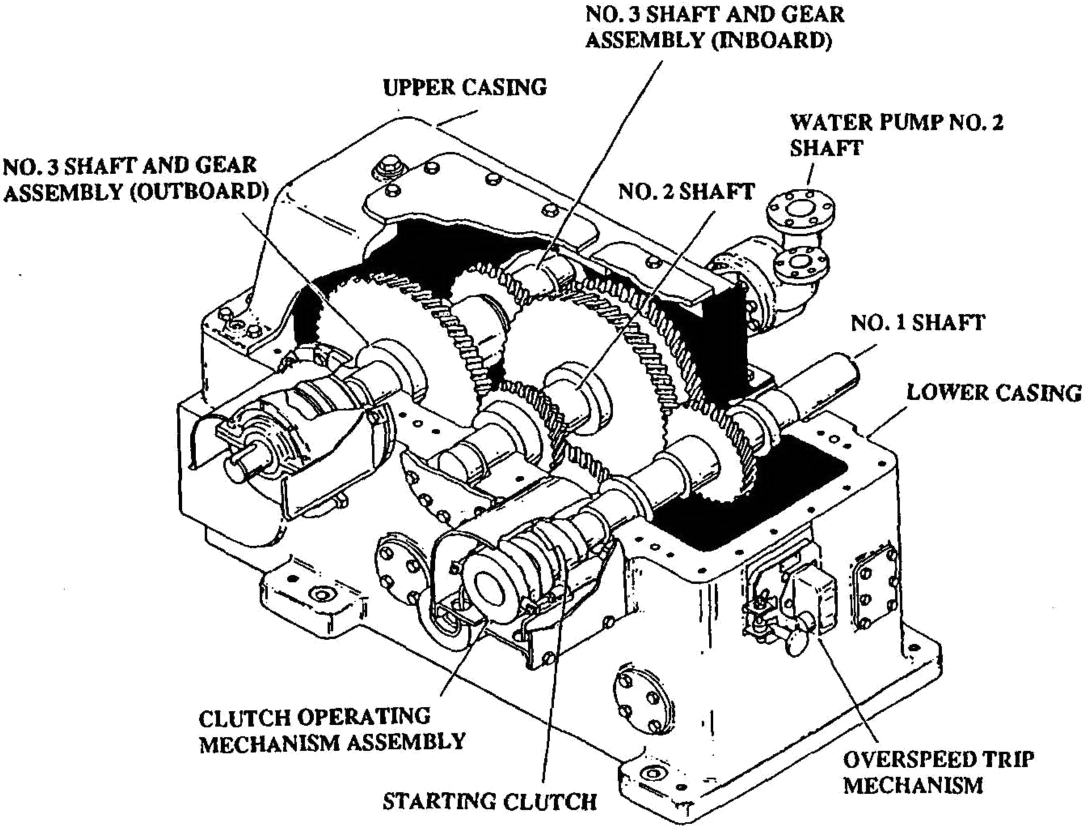


Figure 38: A Cut View of an Accessory Gearbox

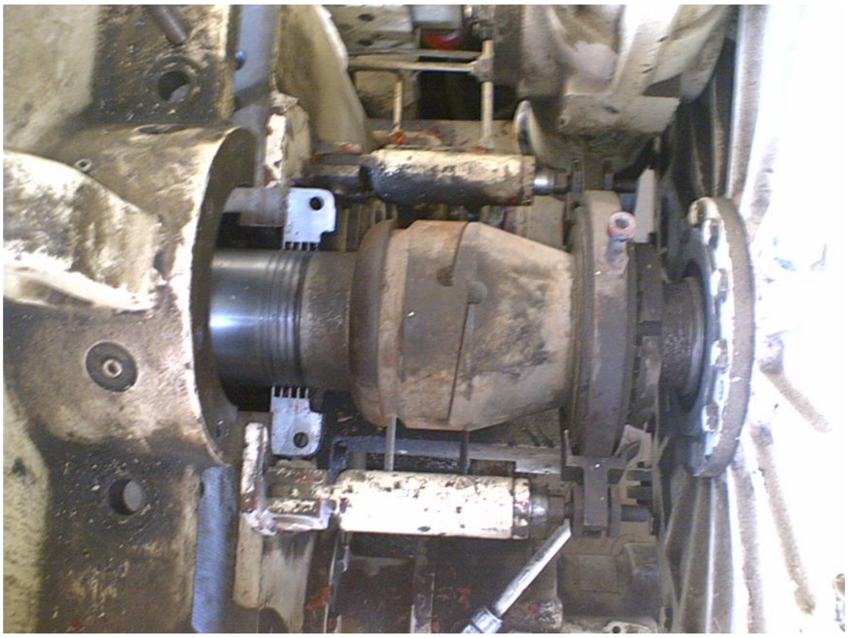


Figure 39: A One Direction Ratchet Clutch (Picture Belongs to Unit 120 of Phase 2&3 of S.P.G.C.)

9: START UP SEQUENCE

As the primary action the auxiliary systems are switched on:

1. Compartment cooling fans
2. Exhaust fans
3. Auxiliary lube oil pump
4. Auxiliary hydraulic oil pump

The main starter is energized. After a programmed delay time, the hydraulic oil is introduced to pump assembly of torque convertor. Gradually the IGV of torque convertor opens more and consequently more oil is entered the turbine assembly of torque convertor. At this moment the turbine rotor begins rotating via power transmission through the accessory gearbox and coupling.

The turbine must run for a period of time so that the inside of the engine is purge by the air drawn via air intake filters. Purging limits ant threads of explosions because of presence of any residual of combustion products.

The spark plugs are energized by means of a high voltage DC transformer. SRV and GCV are opened and fuel is introduced to combustors. The flame is generated and distributed among all combustion chambers through cross fire tubes.

However the turbine is warming up it could not accelerate because no more gas is entering to combustion chambers.

Flame detectors must approve the presence of the flame. An ultraviolet sensor that is sensitive to the ultraviolet radiation of combustion products approves the presence of the flame and let the VIGV and GCV open more. Since the air mass flow and fuel flow increase, the speed is elevated and turbine accelerates.

At this moment because the turbine rotor speed is more than starting means one, the clutch is decoupled and turbine begins running is self-sustaining mode.

Already the pressure made by main lube and hydraulic oil pumps is enough high to satisfy the system requirements so a pressure switch commands the auxiliary lube and hydraulic oil pumps are switched off.

By means of the signal that is generated by magnetic pick up gear the GCV regulates the gas entering the engine and control the speed.