1.STEAM TURBINES

A steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts it into rotary motion. [1]

1.1.TIMELINE OF DEVELOPMENT

The first device that can be classified as a reaction steam turbine is the aeolipile proposed by Hero of Alexandria, during the 1st century CE. In this device, steam was supplied through a hollow rotating shaft to a hollow rotating sphere.[2]

Another steam-driven machine, described in 1629 in Italy, was designed in such a way that a jet of steam impinged on blades extending from a wheel and caused it to rotate by the impulse principle. Starting with a 1784 patent by James Watt, the developer of the steam engine, a number of reaction and impulse turbines were proposed, all adaptations of similar devices that operated with water.[2]

None were successful except for the units built by William Avery of the United States after 1837. In one such Avery turbine two hollow arms, about 75 centimetres long, were attached at right angles to a hollow shaft through which steam was supplied. Nozzles at the outer end of the arms allowed the steam to escape in a tangential direction, thus producing the reaction to turn the wheel. About 50 of these turbines were built for sawmills, cotton gins, and woodworking shops, and at least one was tried on a locomotive. [2]

In 1884 Sir Charles Algernon Parsons, a British engineer, recognized the advantage of employing a large number of stages in series, allowing extraction of the thermal energy in the steam in small steps. Parsons also developed the reaction-stage principle according to which a nearly equal pressure drop and energy release takes place in both the stationary and moving blade passages.[2]

Figure 1:*Parson turbine from the Polish destoyer ORP Wicher*[1]

During the 1880s Carl G.P. de Laval of Sweden constructed small reaction turbines that turned at about 40,000 revolutions per minute to drive cream separators. Their high speed, however, made them unsuitable for other commercial applications. De Laval then turned his attention to single-stage impulse turbines that used convergent-divergent nozzles, such as the one shown in Fig 2.

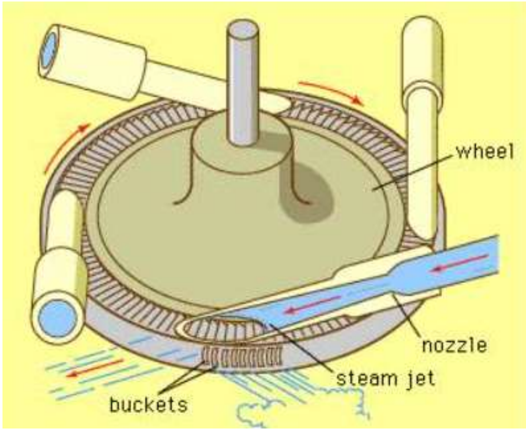

Figure 2: *De Laval turbine, showing how the steam is formed into a jet by a specially shaped nozzle and is then deflected by the buckets or vanes on the wheel, causing the wheel to rotate.*[2]

By 1900 the largest steam turbine-generator unit produced 1,200 kilowatts, and 10 years later the capacity of such machines had increased to more than 30,000 kilowatts. This far exceeded the output of even the largest steam engines, making steam turbines the principal prime movers in central power stations after the first decade of the 20th century. Following the successful installation of a series of 68,000-horsepower turbines in the transatlantic passenger liners *Lusitania* and *Mauretania*, launched in 1906, steam turbines also gained preeminence in large-scale marine applications, first with vessels burning fossil fuels and then with those using nuclear power. [2]

Steam generator pressures increased from about 1,000 kilopascals gauge in 1895 to 1,380 kilopascals gauge by 1919 and then to 9,300 kilopascals gauge by 1940. Steam temperatures climbed from about 180 °C (saturated steam) to 315 °C (superheated steam) and eventually to 510 °C over the same time period, while heat rates decreased from about 38,000 to below 10,000 Btus per kilowatt-hour.[2]

By 1940, single turbine units with a power capacity of 100,000 kilowatts were common. Ever-larger turbines (with higher efficiencies) have been constructed during the last half of the century, largely because of the steadily rising cost of fossil fuels. This required a substantial increase in steam generator pressures and temperatures. Some units operating with supercritical steam at pressures as high as 34,500 kilopascals gauge and at temperatures of up to 650 °C were built before 1970.[2]

Reheat turbines that operate at lower pressures (between 17,100 to 24,100 kilopascals gauge) and temperatures (540–565 °C) are now commonly installed to assure high reliability. Steam turbines in nuclear power plants, which are still being constructed in a number of countries outside of the United States, typically operate at about 7,580 kilopascals gauge and at temperatures of up to 295 °C to accommodate the limitations of reactors.[2]

1.2.PRINCIPLE OF OPERATION

The steam energy is converted mechanical work by expansion through the turbine. The expansion takes place through a series of fixed blades (nozzles) and moving blades each row of fixed blades and moving blades is called a stage. The moving blades rotate on the central turbine rotor and the fixed blades are concentrically arranged within the circular turbine casing which is substantially designed to withstand the steam pressure.[4]

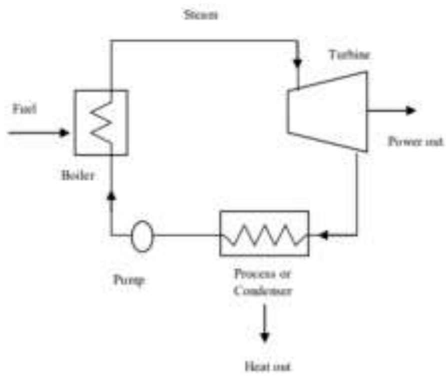

Figure 3: *Simple Boiler/Steam Turbine System*[3]

An ideal steam turbine is considered to be an isentropic process, or constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine. No steam turbine is truly "isentropic", however, with typical isentropic efficiencies ranging from 20%-90% based on the application of the turbine. The interior of a turbine comprises several sets of blades, or "buckets" as they are more commonly referred to. One set of stationary blades is connected to the casing and one set of rotating blades is connected to the shaft. The sets intermesh with certain minimum clearances, with the size and configuration of sets varying to efficiently exploit the expansion of steam at each stage.[1]

Steam turbine power plants are based on the Rankine cycle investigated by a Scotch Engineer and Scientist William Rankine (1820 -1872). Rankine cycle for Steam turbine power plant with ideal turbines and pumps and superheated and saturated steam as a working fluid respectively as shown below. A conventional power plant steam for such a consideration is also shown:

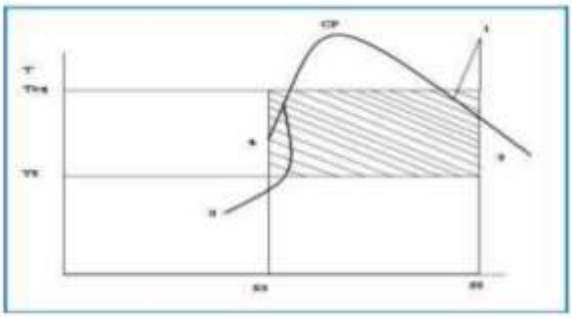

Figure 4: *Ideal Rankine cycle for superheated steam on T-S axes.*[4]

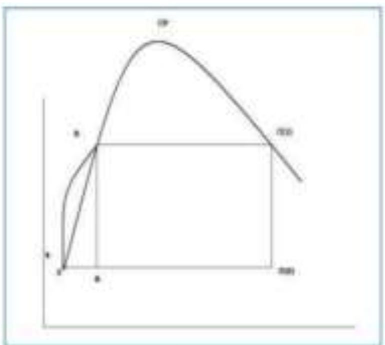

Figure 5: *Ideal Rankine cycle for saturated steam on T-S axes*[4]

The steam turbine is fed with steam under temperature t1, pressure p1, and enthalpy h1. Expanding within the turbine, steam produces work Wt and goes into the condenser under conditions p2 and h2. Hence its rejects heat Qr to cooling water and the resulted condensate with enthalpy h3<<h2, but with the same t3=t2 and pressure p3=p2 comes to the pump. At the expense of the pump work Wp , the feed water pressure and enthalpy rise to values p4 and h4 with which feed water enters the steam generators where it is heated and evaporated due to the heat added Qa.[4]

Ideal Rankine cycle with superheated steam as a working fluid consists of the following processes:

1-2 Adiabatic reversible expansion in the turbine

2-3 Isothermal (under constant temperature) and isobaric (under constant pressure) Heat rejection within the condenser.

3-4 Adiabatic reversible compression to the saturated liquid to the steam generator Pressure by the pump.

4-B-C-1 Isobaric heat addition in the steam generator

4-B: Heating feed water in economizer

B-C: Heating in boiler

C-1: Heating in super heater[4]

For saturated – steam cycle the steam expansion process in the turbine begins from C, and with complete condensation in 3 with subsequent compression by the pump. Thermal efficiency of ideal Rankine cycle for superheated –steam turbine power plant can be defined as:

$$n_{th} = \frac{d\,W_{net}}{Q_a} = \frac{(W_t - W_p)}{Q_a} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$$

$$= \{(h_1 - h_2) / (h_1 - h_4)\} \quad x \quad \{1 - (h_4 - h_3) / (h_1 - h_2)\}$$

$$= n_{th} \ x \ (1 - W_p/Q_a)$$

Here n_{th} is the gross thermal efficiency that is without regard to the expense of energy with in the cycle. If pump working is neglected, then the efficiency,

$n_{th} = (h_1 - h_2) / (h_1 - h_4)$

Steam reheat

In the cycle with steam reheat instead of through adiabatic steam expansion from initial steam pressure p1 to end pressure p2, steam expands within the HP turbine part to the intermediate pressure (point5) and then is heated isothermally to steam reheat temperature (point 6) and then expands within IP-LP part to same end pressure p2 as shown below. In this case, for ideal cycle the thermal efficiency is approximately given by[4]:

$$n_{th} = \frac{(h_1 - h_5) + (h_6 - h_2)}{(h_1 - h_4) + (h_6 - h_5)}$$

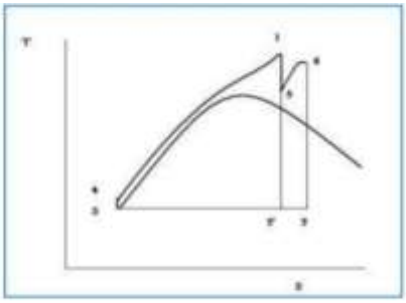

Figure 6: *Ideal Rankine cycles for steam reheat*[4]

In the steam turbine, the steam is expanded to a lower pressure providing shaft power to drive a generator or run a mechanical process. There are two distinct designs for steam turbines – impulse and reaction turbines. The difference between these two designs is shown in fig.6.

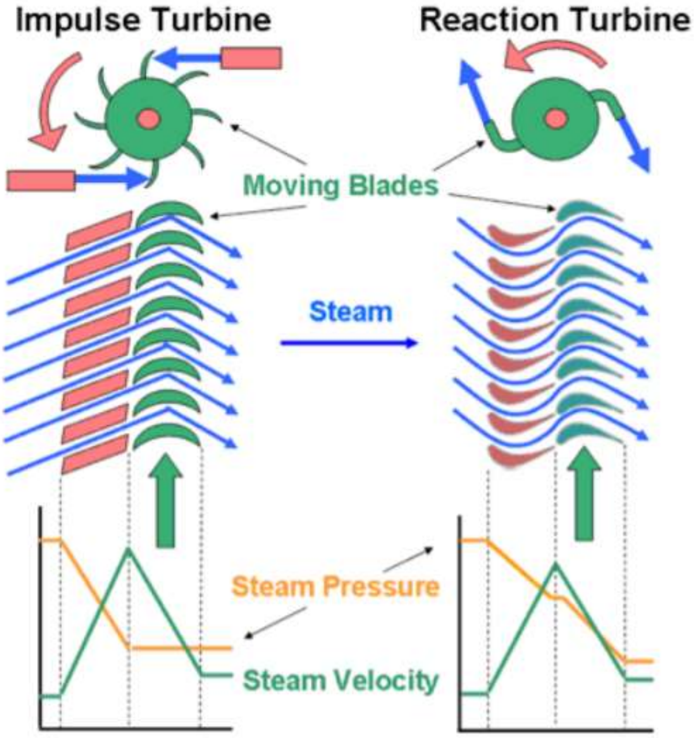

Figure 7: *Schematic diagram outlining the difference between an impulse and a reaction turbine*

On ***impulse turbines***, the steam jets are directed at the turbine's bucket shaped rotor blades where the pressure exerted by the jets causes the rotor to rotate and the velocity of the steam to reduce as it imparts its kinetic energy to the blades. The next series of fixed blades reverses the direction of the steam before it passes to the second row of moving blades. [3]

In ***Reaction turbines***, the rotor blades of the reaction turbine are shaped more like airfoils, arranged such that the cross section of the chambers formed between the fixed blades diminishes from the inlet side towards the exhaust side of the blades. The chambers between the rotor blades essentially form nozzles so that as the steam progresses through the chambers its velocity increases while at the Catalog of CHP Technologies 4–4 Steam Turbines same time its pressure decreases, just as in the nozzles formed by the fixed blades.[3]

Turbines in power generation – generating electricity with steam

- **Solar**
  Harnessing solar energy to create steam through a central receiver, parabolic trough or linear Fresnel reflectors.
- **Geothermal**
  Using the heat from the earth. Energy is accessed by drilling water or steam wells in a process similar to drilling for oil.
- **Biomass, Biogas and Biofuel**
  Generating steam with crops, manure, waste or biofuels.
- **Nuclear**
  Using a nuclear reactor as the heat source.
- **Coal**
  Burning thermal coal. Combined with CCS, it allows generating carbon-free electricity. [14]

1.3.VARIOUS PARTS OF STEAM TURBINE

a. **Nozzle:** The nozzle expands steam of comparatively low velocity and high static pressure within considerable increase in velocity. The nozzle is so positioned as to direct the flow of steam into the rotor passage.

b. **Diffuser:**

   • It is a mechanical device that is designed to control the characteristics of steam at the entrance to a thermodynamic open system. Diffusers are used to slow the steam's velocity and to enhance its mixing into the surrounding steam. In contrast, a nozzle is often intended to increase the discharge velocity and to direct the flow in one particular direction.

   • Flow through nozzles and diffusers may or may not be assumed to be adiabatic. Frictional effects may sometimes be important, but usually they are neglected. However, the external work transfer is always assumed to be zero. It is also assumed that changes in thermal energy are significantly greater than changes in potential energy and therefore the latter can usually be neglected for the purpose of analysis.

c. **Blades Or Buckets:** The blades or buckets form the rotor flow passage and serves to change the direction and hence the momentum of the steam received in the stationary nozzles.

d. **Guide Or Guide blades:** Often a turbine is arranged with a series of rotor flow passages. Intervening between the blades comprising the rotor passages are rows of stationary guide blades. The purpose of this guide is to reverse the direction of steam leaving the preceding moving blade row so that general direction of steam leaving the preceding moving blade rows is similar. If guide blades were not provided, opposing force would be exerted on the rotor which would largely negate each other.

e. **Casing Shell Or Cylinder:** The turbine enclosure is generally called the casing although the other two names are in common use. The nozzle and guide are fixedon casing, which in addition to confining the steam serves as support for the bearings. Sometimes the word cylinder is restricted as a cylindrical form attached to inside of the casing to which the guides are fixed.

f. **Shaft, Rotor, Spindle:** These terms are applied to the rotating assembly which carries the blades.

g. **Disc Or Wheel:** The moving blades are attached to the disc which in turn is keyed to the shaft.
h. **Diaphragm:** The diaphragm which is fixed to the cylinder or casing contains the nozzle and serves to confine the steam flow to nozzle passage.
i. **Packing:** Packing in the form of carbon rings minimizes the leaking in the annular space between the diaphragm and shaft.
j. **Thrust Bearings:** Usually a combination of Kingsbury and collar types absorbs the axial forces.
k. **Exhaust Hood:** The exhaust hood is the portion of the casing which collects and delivers the exhaust steam to exhaust pipe or condenser.
l. **Steam Chest:** The steam chest is the supply chamber from which steam is admitted to the nozzles.
m. **Governor:** The governing system may be designated to control steam flow so as to maintain constant speed with load fluctuations to maintain constant pressure with variation of demand for processed steam or both.
n. **Throttle Or Stop Valves:** The throttle and stop valves are located in the steam supply line to the turbine. The stop valve is hydraulically operated quick opening and shutting valves designed to be either fully opened or shut. On small turbines the stop valves may be manually operated but in any case is intended for emergency use or when fully shut down. The throttle valve is used in smaller turbines in addition to stop valve as a means of regulating steam flow during the starting or stopping the operation.[4]

1.4. CLASSIFICATION OF STEAM TURBINES

Steam turbines may be classified into different categories depending on their construction, the process by which heat drop is achieved, the initial and final conditions of steam used and their industrial usage as follows:

a. According to the Number of pressure stages:

Single – stage turbines with one or more velocity stages usually of small power capacities, mostly used for driving centrifugal compressors, blowers and other similar machinery. Multistage impulse and Reaction turbines, made in a wide range of power capacities varying from small to large. [4]

b. According to the direction of steam flow:

Axial turbines, in which the steam flows in a direction parallel to the axis of the turbine. Radial turbines, in which the steam flows in a direction perpendicular to the axis of the turbine. One or more low pressure stages in such turbines are made axial. [4]

c. According to the Number of cylinders:

- Single cylinder turbines
- Multi cylinder (2, 3 and 4 cylinders) turbines, which can have single shaft, i.e. rotors mounted of the same shaft, or multiaxial, having separate rotor shaft and have their cylinders placed parallel to each other. [4]

d. According to the method of governing:

- Turbines with nozzle governing.
- Turbines with bypass governing in which steam besides being fed to the first stage is also directly led to one, two or even three intermediate stages of the turbine. [4]

e. According to the Principle of Action of Steam:

- Impulse turbines.

- Axial Reaction turbines.
- Radial reaction turbines without any stationary guide blades.
- Radial reaction turbines having stationary guide blades.[4]

f. ***According to the Heat Drop Process:***

- Condensing turbines with exhaust steam let into condenser with Regenerators, Condensing turbines with one or two intermediate stage extractions at specific pressures for industrial and heating purposes.
- Back pressure turbines, the exhaust steam from which is utilized for industrial and heating purposes.
- Back – pressure turbines with steam extraction from intermediate stages at specific pressures.
- Low – pressure (Exhaust pressure) turbines in which the exhaust steam from reciprocating steam engines, power hammers, presses, etc is utilized for power generation.
- Mixed – pressure with two or three pressure extractions with supply of exhaust steam to its intermediate stages. [4]

g. ***According to the Steam Conditions at inlet:***

- Low – pressure turbines using at pressures 1.2 to 2 ata.
- Medium – pressure turbines using steam at pressure up to 4.0 ata.
- High – pressure turbines using steam at above40 ata.
- Very high pressure turbines using steam up to 40 ata and higher pressure and temperature. [4]

h. ***According to their Usage in industry:***

- Stationary turbines with constant speed of rotation primarily used for driving alternators.
- Stationary turbines with variable speeds meant for driving turbo blowers, air circulators, pumps etc.
- Non stationary turbines with variable speeds employed in steamers, ships, railway (turbo) locomotives etc.[3]

1.5. STEAM TURBINE ATTRIBUTES

- **Size range**: Steam turbines are available in sizes from under 100 kW to over 250 MW. In the multi-megawatt size range, industrial and utility steam turbine designations merge, with the same turbine (high pressure section) able to serve both industrial and small utility applications.
- **Custom design:** Steam turbines can be designed to match CHP design pressure and temperature requirements. The steam turbine can be designed to maximize electric efficiency while providing the desired thermal output.
- **Thermal output:** Steam turbines are capable of operating over a very broad range of steam pressures. Utility steam turbines operate with inlet steam pressures up to 3500 psig and exhaust at vacuum conditions as low as 2 psia. Steam turbines can be custom designed to deliver the thermal requirements of the CHP application through use of backpressure or extraction steam at appropriate pressures and temperatures.
- **Fuel flexibility:** Steam turbines offer a wide range of fuel flexibility using a variety of fuel sources in the associated boiler or other heat source, including coal, oil, natural gas, wood and waste products, in addition to waste exhaust heat recaptured in a heat recovery steam generator.

- **Reliability and life:** Steam turbine equipment life is extremely long. There are steam turbines that have been in service for over 50 years. When properly operated and maintained (including proper control of boiler water chemistry and ensuring dry steam), steam turbines are extremely reliable with overhaul intervals measured in years. Larger turbines require controlled thermal transients as the massive casing heats up slowly and differential expansion of the parts must be minimized. Smaller turbines generally do not have start-up restrictions.[3]

CHAPTER 2

2.GAS TURBINES

Gas turbine transforms the chemical energy in the fuel, for example, natural gas or the similar fuel into mechanical energy.The mechanical energy generated by the turbine exit shaft is then transferred through a gearbox to the generator's shaft.[8]

2.1.TIMELINE OF DEVELOPMENT

Early Gas Turbine History

1791 First patent for a gas turbine (John Barber, United Kingdom)

1904 Unsuccessful gas turbine project by Franz Stolze in Berlin (first axial compressor)

1906 GT by Armengaud Lemale in France (centrifugal compressor, no useful power)

1910 First GT featuring intermittent combustion (Holzwarth, 150 kW, constant volume combustion)

1923 First exhaust-gas turbocharger to increase the power of diesel engines

1939 Hans von Ohian and Max Hahn of Germany develop and patent their own design [10]

1939 World's first gas turbine for power generation (Brown Boveri Company), Neuchâtel, Switzerland (velox burner, aerodynamics by Stodola)[5]

Figure 8:*The man behind the early steam and gas turbine, Prof. Aurel Stodola (1859-1942)[5]*

1939 The world's first industrial gas turbine in Neuchâtel, Switzerland, in 1939, and commercial operation of the first gas turbine in the U.S. used to generate electric power—a 3.5-MW General Electric (GE) unit at the Belle Isle Station in Oklahoma City in 1949.[11]

1939 Brown-Bovery installs the first marine gas turbine in the french ship Athos.[6]

Figure 9*:First Marine Gas Turbine (6 June 1939)*[6]

1939 In August, the company Ernst Heinkel Aircraft flies the first gas turbine jet plane, the HE178.[10]

1941 Sir Frank Whittle designs the first successful turbojet, the Gloster Meteor[10]

1942 Dr. Franz Anselm develops the axial-flow turbojet, Junkers Jumo 004, used in the Messerschmitt Me 262, the world's first operational jet fighter.[10]

1948 First turbojet breaks sound barrier.[10]

1949 First use of turbojet for commercial service.[10]

1949 America's First Power Generating Gas Turbine[10]

1955 First use of reheat to increase thrust of turbojet.[10]

1995 Siemens is the first manufacturer of large electricity producing gas engines to incorporate single crystal turbine blade technology into their production models, allowing higher operating temperatures and greater efficiency.[12]

2011 Mitsubishi Heavy Industries tests the first 60% efficiency gas turbine (the M501J) in Takasago, Hyogo.[12]

2.2.PRINCIPLE OF OPERATION

In an ideal gas turbine, gases undergo four thermodynamic processes: an isentropic compression, an isobaric (constant pressure) combustion, an isentropic expansion and heat rejection. Together, these make up the Brayton cycle. [8]

Gas turbines are also Brayton engines, with three components: a gas compressor, a burner (or combustion chamber), and an expansion turbine.

Ideal Brayton cycle:

1. isentropic process – ambient air is drawn into the compressor, where it is pressurized.
2. isobaric process – the compressed air then runs through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.
3. isentropic process – the heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.
4. isobaric process – heat rejection (in the atmosphere).[7]

Actual Brayton cycle:

1. adiabatic process – compression
2. isobaric process – heat addition
3. adiabatic process – expansion
4. isobaric process – heat rejection[7]

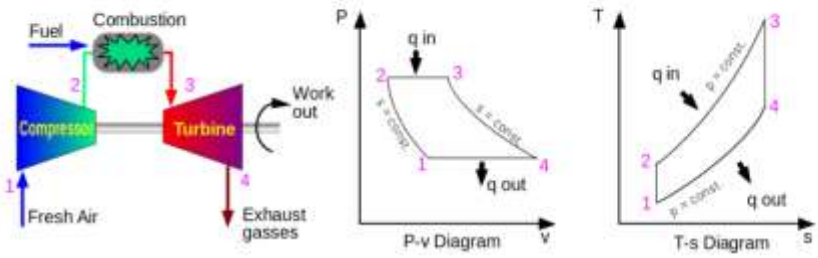

Figure 10: *Brayton cycle diagrams*[7]

The efficiency of the ideal Brayton cycle is $\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}$, where γ is the heat capacity ratio.[7]

In a real gas turbine, mechanical energy is changed irreversibly (due to internal friction and turbulence) into pressure and thermal energy when the gas is compressed (in either a centrifugal or axial compressor). Heat is added in the combustion chamber and the specific volume of the gas increases, accompanied by a slight loss in pressure. During expansion through the stator and rotor passages in the turbine, irreversible energy transformation once again occurs. Fresh air is taken in, in place of the heat rejection.[8]

Most likely you know about "Fire Triangle" or "Combustion Triangle" which illustrates the necessary ingredients of fire or combustion, i.e. "Fuel", "Air", and "Heat"(Figure 11).To transform the chemical energy of the fuel gas into mechanical energy, the fuel should be burnt in the "Combustion Chamber" of a Gas turbine, so I need air and heat added to the fuel.[8]

Figure 11: *Fire Triangle* [8]

The compressor draws in the air at the hub of the impeller and accelerates it radially by centrifugal force through the impeller. It leaves the impeller at a high velocity and a low pressure and flows through the diffuser (figure 12, view A). The diffuser converts the high-velocity, LP air to lowvelocity, HP air. The compressor manifold diverts the flow of air from the diffuser (an integral part of the manifold) into the combustion chambers.[13]

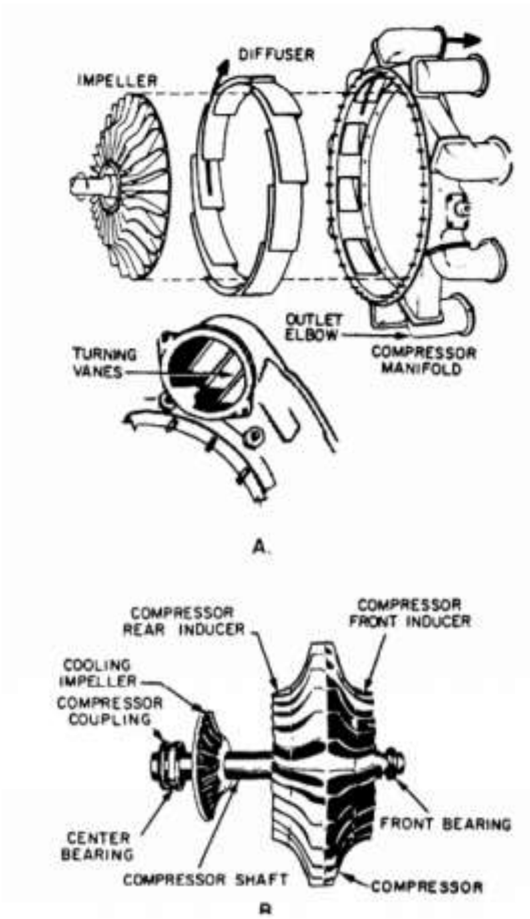

Figure 12: *Centrifugal compressors. A. Single entry. B. Dual entry.[9]*

The purpose of gas-turbine power plants is to produce mechanical power from the expansion of hot gas in a turbine. In these notes we will focus on stationary plants for electric power generation, however, gas turbines are also used as jet engines in aircraft propulsion. The simplest plant is the open turbine gas cycle used to produce electrical power as shown in figure 13. [9]

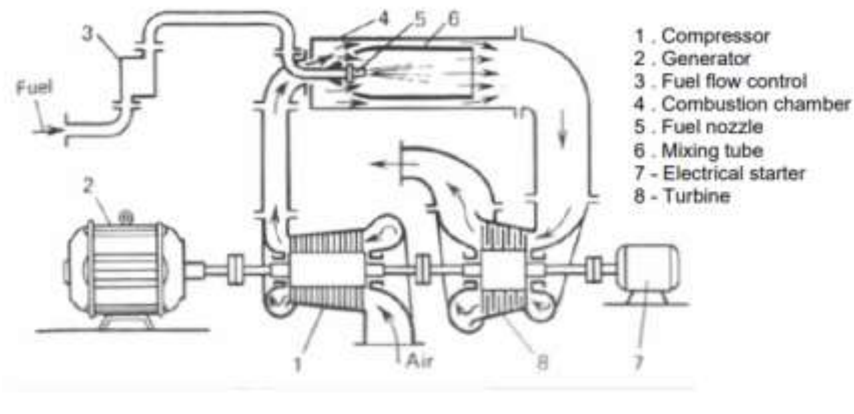

Figure 13:*Open turbine gas cycle*

The net power available on the shaft is transformed into electrical power by the generator while the electrical starter is an electrical engine which is only used when the plant is turned on. The schematic picture of the previous plant, non including electrical starter and generator, is shown in figure 14.[9]

G_b(fuel mass flow rate)

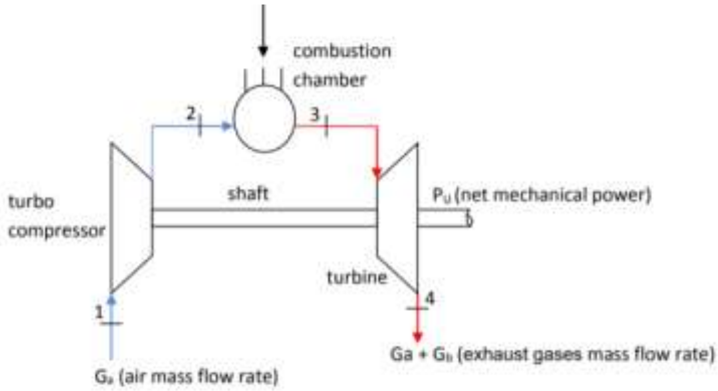

Figure 14: *Open turbine gas cycle*[9]

- Air at room pressure and temperature is compressed to a high pressure in the turbo compressor
- Fuel is added in the combustion chamber where combustion takes place resulting in high-temperature combusted gases
- The hot gases expand in the turbine back to the atmospheric pressure producing mechanical power.[9]

The cycle is said to be open because fresh air enters the compressor continuously and exhaust is expelled, but thermodynamically it is as if the operating fluid returns to its initial state. Part of the mechanical power generated by the turbine is used to drive the compressor.[9]

An alternative plant is the so called closed turbine gas cycle, schematically shown in figure 15.

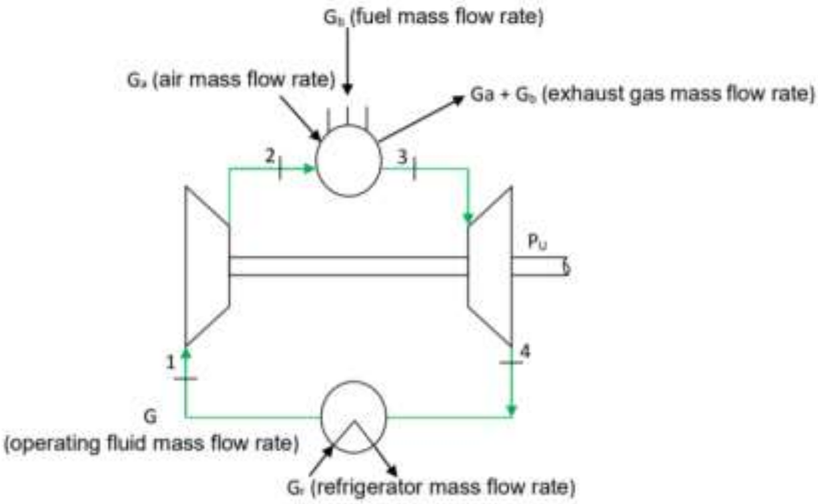

Figure 15: *Closed turbine gas cycle*[9]

In this case the operating fluid does not undergo any chemical transformations (because it is not involved in combustion processes) but only thermodynamic transformations. Combustion takes place between air and fuel in the combustion chamber, which is also a heat exchanger. Both plants have advantages and disadvantages. In the first case it is not necessary to cool down the operating fluid (this requires a huge amount of refrigerator PU Ga (air mass flow rate) Gb (fuel mass flow rate) Ga + Gb (exhaust gas mass flow rate) 1 2 3 4 Gr (refrigerator mass flow rate) G (operating fluid mass flow rate) Prof. A. Valentini - Gas Turbine Power Plants 9 mass flow rates) and so this plant can be adopted on sites with low water availability. One of the advantages of the closed turbine gas cycle is that the turbine stays clean because the combustion products do not pass through it. Another advantage is that it is possible to use gases with $k > kair$ ($kair$ = 1.4), which increases the efficiency of the cycle.[9]

2.3.VARIOUS PARTS OF GAS TURBINE

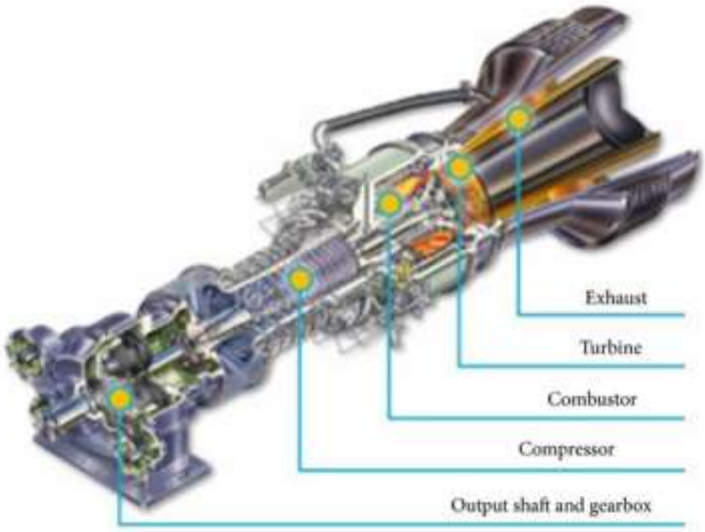

Figure 16: *Parts of gas turbine*

a. Compressor

Air compressor is in fact another gas turbine part that is used in a gas turbine power plant . The air filter is connected to the inlet on the compressor, the place the air is filtered from dust. The rotating blades attached to the shaft force the air between stationary blocks, which raises air pressure and at the compressor outlet, high-pressure air is available.[14]

b. Combustion chamber

Combustion chambers are of some tubular heat resistant structures and fuel is usually injected into it from the circumference and at different cross-sectional locations.The temperatures at different locations of the combustion chamber are thoroughly monitored by means of proper sensors like thermocouples.[8]

c. Turbine

Turbine This example engine has a four-stage turbine. The turbine converts the gaseous energy of the air/burned fuel mixture out of the combustor into mechanical energy to drive the compressor, driven accessories, and, through a reduction gear, the propeller. The turbine converts gaseous energy into mechanical energy by expanding the hot, high-pressure gases to a lower temperature and pressure.[15]

d. Exhaust

After the gas has passed through the turbine, it is discharged through the exhaust. Though most of the gaseous energy is converted to mechanical energy by the turbine, a significant amount of power remains in the exhaust gas. This gas energy is accelerated through the convergent duct shape of the exhaust to make it more useful 10 as jet thrust - the principle of equal and opposite reaction means that the force of the exhausted air drives the airplane forward.[15]

e. Inlet

The air inlet duct must provide clean and unrestricted airflow to the engine. Clean and undisturbed inlet airflow extends engine life by preventing erosion, corrosion, and foreign object damage (FOD). Consideration of atmospheric conditions such as dust, salt, industrial pollution, foreign objects (birds, nuts and bolts), and temperature (icing conditions) must be made when designing the inlet system. Fairings should be installed between the engine air inlet housing and the inlet duct to ensure minimum airflow losses to the engine at all airflow conditions.[15]

f. Diffuser

Air leaves the compressor through exit guide vanes, which convert the radial component of the air flow out of the compressor to straight-line flow. The air then enters the diffuser section of the engine, which is a very divergent duct. The primary function of the diffuser structure is aerodynamic. The divergent duct shape converts most of the air's velocity (Pi) into static pressure (PS). As a result, the highest static pressure and lowest velocity in the entire engine is at the point of diffuser discharge and combustor inlet. Other aerodynamic design considerations that are important in the diffuser section arise from the need for a short flow path, uniform flow distribution, and low drag loss.[15]

2.4. GAS TURBINE ATTRIBUTES

- **Size range** Simple cycle turbines are available in sizes from 30 kW (known as microturbines) up to 300 MW (there are a few products that exceed 300 MW).
- **Thermal output** Gas turbines produce high temperature exhaust, and thermal energy can be recovered from this exhaust to produce steam, hot water, or chilled water (with an absorption chiller). The exhaust can also be used directly for industrial process drying or heating.
- **Part-load operation** The electrical generation efficiency of gas turbines declines significantly as the load is decreased. Therefore, gas turbines provide the best economic performance in base load applications where the system operates at, or near, full load.
- **Fuel** Gas turbines can be operated with a wide range of gas and liquid fuels. For CHP, natural gas is the most common fuel.
- **Reliability** Gas turbines are a mature technology with high reliability.
- **Other** Gas turbines have relatively low emissions and require no cooling. Gas turbines are widely used in CHP applications and have relatively low installed costs[3]