GAS TURBINE ENGINES

1. **What do you know about gas turbines?**
2. **What purposes are gas turbines used for?**
3. **Where do gas turbines find their applications?**

1. **Read Text 1A without a dictionary.**

TEXT1A. FUNDAMENTALS OF GAS TURBINE ENGINES

2. **New words and word combinations to be memorized.**

Extract (v) - извлекать
internal combustion engine (n) – двигатель внутреннего сгорания
drive (v) – приводить в действие
jet thrust (n) – реактивная тяга
blade (n) – лопасть
bearing (n) – подшипник
ignite (v) – зажигать
check valve(n) –обратный клапан
drawback (n) – недостаток
efficiency- к.п.д.

The gas turbine is an internal combustion engine that uses air as the working fluid. The engine extracts chemical energy from fuel and converts it to mechanical energy using the gaseous energy of the working fluid (air) to drive the engine and propeller, which, in turn, propel the airplane.

The Gas Turbines. General Overview

The problem of converting the energy into mechanical work by means of a gas turbine has occupied inventors and engine designers for many years. However, only during the last few decades gas turbines have become practical in various applications.

The turbine is a major component, common to the gas turbine – propeller engine and to the thermal jet engine. It should be noted, that gas turbine – propeller engines are designed to deliver auxiliary jet thrust from the exhaust gases in addition to the propeller thrust, the proportions being 80% propeller thrust and 20% auxiliary jet thrust.

In many respects, the turbine for these two types of engines is similar to the conventional steam turbine. The usual turbine consists of four fundamental parts:

1. The rotor, which carries the blades or buckets;
2. The stator consisting of cylinder and casing, which are often combined and turns within the rotor;
3. The nozzles, which are generally fixed to the inside of the cylinder;
4. The frame or base for supporting both the stator and the rotor, the latter being carried in bearings.

The basic requirements for the turbine are the same for either type of engine. They are:

1. Light weight;
2. Small frontal area;
3. High efficiency;
4. Ability to operate for long periods at high temperature;
5. Reliability.

Depending upon the method of combustion gas turbines may be subdivided into two groups: explosion turbines and continuous-combustion turbines.

In an explosion turbine, fuel is injected into compressed air admitted to a closed chamber and the air-fuel mixture ignites by a spark. The pressure rise opens a check valve and the gases flow through the nozzle and strike the blades of the turbine wheel. The drawbacks of this cycle are low thermodynamic and hydraulic efficiency of the turbine, relatively low overall efficiency and the fact, that the gas turbine is not self-starting. Yet, the advantages are simplicity, lightweight and the use of pulverized coal instead of liquid or gaseous fuel.

Gas turbines may be applied in stationary power plants, aircraft propulsion, marine propulsion and locomotives.

3. **Answer the following questions:**

1) What is a gas turbine?
2) What kind of energy does it extract from fuel?
3) Why does the engine convert this kind of energy into mechanical energy?
4) What problem has occupied the engine designers for many years?
5) Why is the gas turbine considered to be the propeller engine?
6) What similarity is there between two types of engines?
7) What parts does the usual turbine consist of?
8) What two groups are the gas turbines subdivided into?
9) What are the drawbacks and advantages of these two cycles?
10) Where may gas turbines be applied?

4. **Discuss the design and application of a gas turbine in pairs.**
5. **Read Text 1B using a dictionary.**

TEXT1B. THE GAS TURBINE CYCLE

The basic principle of the airplane turbine engine is identical to any and all engines that extract energy from chemical fuel. The basic 4 steps for any internal combustion engine are:

1. Intake of air (and possibly fuel). 2. Compression of the air (and possibly fuel). 3. Combustion, where fuel is injected (if it was not drawn in with the intake air) and burned to convert the stored energy. 4. Expansion and exhaust, where the converted energy is put to use.

In the case of a piston engine, such as the engine in a car or reciprocating airplane engine, the intake, compression, combustion, and exhaust steps occur in the same place (cylinder head) at different times as the piston goes up and down.

In the turbine engine, however, these same four steps occur at the same time but in different places. As a result of this fundamental difference, the turbine has engine sections called:

1. The inlet section 2. The compressor section 3. The combustion section (the combustor) 4. The turbine (and exhaust) section.

The turbine section of the gas turbine engine has the task of producing usable output shaft power to drive the propeller. In addition, it must also provide power to drive the compressor and all engine accessories. It does this by expanding the high temperature, pressure, and velocity gas and converting the gaseous energy to mechanical energy in the form of shaft power.

A large mass of air must be supplied to the turbine in order to produce the necessary power. This mass of air is supplied by the compressor, which draws the air into the engine and squeezes it to provide high-pressure air to the turbine. The compressor does this by converting mechanical energy from the turbine to gaseous energy in the form of pressure and temperature.

If the compressor and the turbine were 100% efficient, the compressor would supply all the air needed by the turbine. At the same time, the turbine would supply the necessary power to drive the compressor. In this case, a perpetual motion machine would exist. However, frictional losses and mechanical system inefficiencies do not allow a perpetual motion machine to operate. Additional energy must be added to the air to accommodate for these losses. Power output is also desired from the engine (beyond simply driving the compressor); thus, even more energy must be added to the air to produce this excess power. Energy addition to the system is accomplished in the combustor. Chemical energy from fuel as it is burned is converted to gaseous energy in the form of high temperatures and high velocity as the air passes through the combustor. The gaseous energy is converted back to mechanical energy in the turbine, providing power to drive the compressor and the output shaft.

6. **Describe the gas turbine cycle?**

TEXT1C. SOME BASIC PRINCIPLES

As air passes through a gas turbine engine, aerodynamic and energy requirements demand changes in the air’s velocity and pressure. During compression, a rise in the air pressure is required, but not an increase in its velocity. After compression and combustion have heated the air, an increase in the velocity of gases is necessary in order for the turbine rotors to develop power. The size and shape of the ducts through which the air flows affect these various changes. Where a conversion from velocity to pressure is required, the passages are divergent. Conversely, if a conversion from pressure to velocity is needed, a convergent duct is used.

Before further discussion, an explanation of convergent ducts, divergent ducts, and the behavior of air within these ducts should be made. An understanding of the difference between static pressure (Ps), impact pressure, (Pi), and total pressure (Pt) is also needed.

The difference between static, impact, and total pressures is as follows. Static pressure is the force per unit area exerted on the walls of a container by a stationary fluid. An example is the air pressure within a car tire. Impact pressure, on the other hand, is the force per unit area exerted by fluids in motion. Impact pressure is a function of the velocity of the fluid. An example of impact pressure is the pressure exerted on one's hand held outside a moving car’s window. Total pressure is the sum of static and impact pressures.

Figure 2-1 illustrates the methods used to measure pressures. Part (a) illustrates the measurement of static pressure. Static pressure will not take into account the velocity of the air. Part (b) illustrates the measurement of total pressure, which accounts for both static pressure and the pressure due to the moving fluid (impact pressure). In order to obtain impact pressure, the value of the static pressure is subtracted from the value of total pressure.

Figure 2-2 shows the principle of divergent ducts, where energy is neither being added or taken away, but where the gaseous energy is being converted from velocity to pressure and temperature. There is a velocity decrease as air flows from a small inlet to a larger outlet. As velocity decreases, impact pressure (Pi) also decreases. Since no energy is added or subtracted from the system, total pressure (Pt) for the air remains constant and static pressure (Ps) increases. One way of viewing this is that the impact pressure is converted to static pressure; thus, a static pressure rise is seen as air flows through a divergent duct and is compressed. A temperature rise is also noticed since compression is a heating process.

The convergent duct operates exactly in reverse of the divergent duct. Figure 2-3 shows the principle of convergent ducts, where energy is neither being added or taken away, but where the gaseous energy is being converted from pressure and temperature to velocity. There is a velocity increase as air flows from a large inlet to a smaller outlet. As velocity increases, impact pressure also increases. Since no energy is added or subtracted from the system, total pressure remains constant and static pressure decreases. One way of viewing this is that the static pressure is converted to impact pressure; thus, a static pressure decrease is seen as air flows through a convergent duct and goes through expansion. A temperature drop is associated with any expansion process.

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NOTE: Even though the static and impact pressures are changing as fluids flow through either convergent or divergent ducts, the total pressure does not change. This is true if fluid friction is neglected and energy is not added or taken away from the fluid flow. In actuality, there will be a slight decrease in total pressure because of fluid frictional losses.

TEXT1D. PERFORMANCE AND EFFICIENCY

The type of operation for which the engine is designed dictates the performance requirement of a gas turbine engine. The performance requirement is mainly determined by the amount of shaft horsepower (s.h.p.) the engine develops for a given set of conditions. The majority of aircraft gas turbine engines are rated at standard day conditions of 59° F and 29.92 inches Hg. This provides a baseline to which gas turbine engines of all types can be compared.

The need for high efficiency in the engine becomes more important as fuels become more costly. Engine efficiency is primarily defined by the specific fuel consumption (s.f.c.) of the engine at a given set of conditions.

Many factors affect both the efficiency and the performance of the engine. The mass flow rate of air through the engine will dictate engine performance. Any restrictions acting against the smooth flow of air through the engine will limit the engine's performance. The pressure ratio of the compressor, the engine operating temperatures (turbine inlet temperature), and the individual component efficiencies will also influence both the performance and the efficiency of the overall engine. All these factors are considered during the design of the engine. An optimum pressure ratio, turbine inlet temperature, and air mass flow rate are selected to obtain the required performance in the most efficient manner. In addition, individual engine components are designed to minimize flow losses to maximize component efficiencies.

TEXT 2A. ENGINE SECTIONS

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.

The inlet duct assembly is usually designed and produced as a separate system rather than as part of the design and production of the engine.

Compressor

The compressor is responsible for providing the turbine with all the air it needs in an efficient manner. In addition, it must supply this air at high static pressures. The example of a large turboprop axial flow compressor will be used. The compressor is assumed to contain fourteen stages of rotor blades and stator vanes. The overall pressure ratio (pressure at the back of the compressor compared to pressure at the front of the compressor) is approximately 9.5:1. At 100% (>13,000) RPM, the engine compresses approximately 433 cubic feet of air per second. At standard day air conditions, this equals approximately 33 pounds of air per second. The compressor also raises the temperature of the air by about 550° F as the air is compressed and moved rearward. The power required to drive a compressor of this size at maximum rated power is approximately 7000 horsepower.

In an axial flow compressor, each stage incrementally boosts the pressure from the previous stage. A single stage of compression consists of a set of rotor blades attached to a rotating disk, followed by stator vanes attached to a stationary ring. The flow area between the compressor blades is slightly divergent. Flow area between compressor vanes is also divergent, but more so than for the blades.

In general terms, the compressor rotor blades convert mechanical energy into gaseous energy. This energy conversion greatly increases total pressure (Pt). Most of the increase is in the form of velocity (Pi), with a small increase in static pressure (Ps) due to the divergence of the blade flow paths.

The stator vanes slow the air by means of their divergent duct shape, converting 'the accelerated velocity (Pi) to higher static pressure (Ps). The vanes are positioned at an angle such that the exiting air is directed into the rotor blades of the next stage at the most efficient angle. This process is repeated fourteen times as the air flows from the first stage through the fourteenth stage. Figure 2-4 shows one stage of the compressor and a graph of the pressure characteristics as the air flows through the stage.

In addition to the fourteen stages of blades and vanes, the compressor also incorporates the inlet guide vanes and the outlet guide vanes. These vanes, located at the inlet and the outlet of the compressor, are neither divergent nor convergent. The inlet guide vanes direct air to the first stage compressor blades at the "best" angle. The outlet guide vanes "straighten" the air to provide the combustor with the proper airflow direction.

The efficiency of a compressor is primarily determined by the smoothness of the airflow. During design, every effort is made to keep the air flowing smoothly through the compressor to minimize airflow losses due to friction and turbulence. This task is a difficult one, since the air is forced to flow into ever-higher pressure zones.

Air has the natural tendency to flow toward low-pressure zones. If air were allowed to flow "backward" into the lower pressure zones, the efficiency of the compressor would decrease tremendously as the energy used to increase the pressure of the air was wasted. To prevent this from occurring, seals are incorporated at the base of each row of vanes to prevent air leakage. In addition, the tip clearances of the rotating blades are also kept at a minimum by the use of coating on the inner surface of the compressor case.

All components used in the flow path of the compressor are shaped in the form of airfoils to maintain the smoothest airflow possible. Just as is the case for the wings of an airplane, the angle at which the air flows across the airfoils is critical to performance. The blades and vanes of the compressor are positioned at the optimum angles to achieve the most efficient airflow at the compressor's maximum rated speed.

Any deviation from the maximum rated speed changes the characteristics of the airflow within the compressor. The blades and vanes are no longer positioned at their optimum angles. Many engines use bleed valves to unload the force of excess air in the compressor when it operates at less than optimum speed. The example engine incorporates four bleed valves at each of the fifth and tenth compressor stages. They are open until 13,000 RPM (~94% maximum) is reached, and allow some of the compressed air to flow out to the atmosphere. This results in higher air velocities over the blade and vane airfoils, improving the airfoil angles. The potential for airfoil stalling is reduced, and compressor acceleration can be accomplished without surge.

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.

In addition to critical aerodynamic functions, the diffuser also provides:

- engine structural support, including engine mounting to the nacelle,

-support for the rear compressor bearings and seals

-bleed air ports, which provide pressurized air for:

- airframe "customer" requirements (air conditioning, etc.)
- engine inlet anti-icing
- control of acceleration bleed air valves
- pressure and scavenge oil passages for the rear compressor and front turbine bearings
- mounting for the fuel nozzles

Combustor

Once the air flows through the diffuser, it enters the combustion section, also called the combustor. The combustion section has the difficult task of controlling the burning of large amounts of fuel and air. It must release the heat in a manner that the air is expanded and accelerated to give a smooth and stable stream of uniformly-heated gas at all starting and operating conditions. This task must be accomplished with minimum pressure loss and maximum heat release. In addition, the combustion liners must position and control the fire to prevent flame contact with any metal parts.

The engine in this example uses a can-annular combustion section. Six combustion liners (cans) are positioned within an annulus created by inner and outer combustion cases. Combustion takes place in the forward end or primary zone of the cans. Primary air (amounting to about one fourth of the total engine’s total airflow) is used to support the combustion process. The remaining air, referred to as secondary or dilution air, is admitted into the liners in a controlled manner. The secondary air controls the flame pattern, cools the liner walls, dilutes the temperature of the core gasses, and provides mass. This cooling air is critical, as the flame temperature is above 1930□ C (3500'F), which is higher than the metals in the engine can endure. It is important that the fuel nozzles and combustion liners control the burning and mixing of fuel and air under all conditions to avoid excess temperatures reaching the turbine or combustion cases. Maximum combustion section outlet temperature (turbine inlet temperature) in this engine is about 1070□ C (>1950□ F).

The rear third of the combustion liners is the transition section. The transition section has a very convergent duct shape, which begins accelerating the gas stream and reducing the static pressure in preparation for entrance to the turbine section.

All gas turbine combustors perform the same function: the increase the temperature of the high-pressure gas. The gas turbine combustor uses very little of its air (10%) in the combustion process. The rest of the air is used for cooling and mixing. New combustors are also circulating steam for cooling purposes. The air from the compressor must be diffused before it enters the combustor. The velocity of the air leaving the compressor is about 400/600 ft. /sec (122-183 m/sec) and the velocity in the combustor must be maintained below 50 ft. /sec (15.2 m/sec). Even at these low velocities, care must be taken to avoid the flame to be carried on downstream.

The combustor is a direct-fired air heater in which fuel is burned almost stoichiometrically with one-third or less of the compressor discharge air. Combustion products are then mixed with the remaining air to arrive at a suitable turbine inlet temperature. Despite the many design differences in combustors all gas turbine combustion chambers have three features: (1) a recirculation zone, (2) a burning zone (with a recirculation zone, which extends to the dilution zone), and (3) a dilution zone. The air entering a combustor is divided so that the flow is distributed between three major regions: (1) Primary Zone, (2) Dilution Zone, and (3) Annular space between the liner and casing.

The combustion in a combustor takes place in the Primary Zone. Combustion of natural gas is a chemical reaction that occurs between carbon, or hydrogen, and oxygen. Heat is given off as the reaction takes place. The products of combustion are carbon dioxide and water. The reaction is Stoichometric, which means that the proportions of the reactants are such that there are exactly enough oxidizer molecules to bring about a complete reaction to stable molecule forms in the products. The air enters the combustor in a straight through flow, or reverse flow. Most aero-engines have straight through flow type combustors. Most of the large frame type units have reverse- flow. The function of the recirculation zone is to evaporate, partly burn, and prepare the fuel for rapid combustion within the remainder of the burning zone.

Ideally, at the end the burning phase, all fuel should be burnt so that the function of the dilution zone is solely to mix the hot gas with the dilution air. The mixture leaving the chamber should have a temperature and velocity distribution acceptable to guide vanes and turbine. Generally, the addition of dilution air is so abrupt that if combustion is not complete at the end the burning zone, chilling occurs, which prevents completion. However, there is evidence with some chambers, that if the burning zone is run over-rich, some combustion does occur within the dilution region.

Combustor inlet temperature depends on engine pressure ratio, load, engine type, and, whether or not the turbine is regenerative or non-regenerative, especially at the low-pressure ratios. The new industrial turbine pressure ratio's are between 17:1 and 35:1, which means that the combustor inlet temperature ranges from 850 degrees F (454 degrees C) to 1200 degrees F (649 degrees C). The new aircraft engines have pressure ratios, which are in excess of 40:1.

Combustor performance is measured by efficiency, the pressure decrease encountered in the combustor, and the evenness of the outlet temperature profile. Combustion efficiency is a measure of combustion completeness. Combustion completeness affects fuel consumption directly, since the heating value of any unburned fuel is not used to increase the turbine inlet temperature.

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.

Each stage of the turbine consists of a row of stationary vanes followed by a row of rotating blades. This is the reverse of the order in the compressor. In the compressor, energy is added to the gas by the rotor blades, then converted to static pressure by the stator vanes. In the turbine, the stator vanes increase gas velocity, and then the rotor blades extract energy.

The vanes and blades are airfoils that provide for a smooth flow of the gases. As the airstream enters the turbine section from the combustion section, it is accelerated through the first stage stator vanes. The stator vanes (also called nozzles) form convergent ducts that convert the gaseous heat and pressure energy into higher velocity gas flow (Pi). In addition to accelerating the gas, the vanes "turn" the flow to direct it into the rotor blades at the optimum angle.

As the mass of the high velocity gas flows across the turbine blades, the gaseous energy is converted to mechanical energy. Velocity, temperature, and pressure of the gas are sacrificed in order to rotate the turbine to generate shaft power. Figure 2-5 represents one stage of the turbine and the characteristics of the gases as it flows through the stage.

The efficiency of the turbine is determined by how well it extracts mechanical energy from the hot, high-velocity gasses. Since air flows from a high-pressure zone to a low pressure zone, this task is accomplished fairly easily. The use of properly positioned airfoils allows a smooth flow and expansion of gases through the blades and vanes of the turbine.

All the air must flow across the airfoils to achieve maximum efficiency in the turbine. In order to ensure this, seals are used at the base of the vanes to minimize gas flow around the vanes instead of through the intended gas path. In addition, the first three stages of the turbine blades have tip shrouds to minimize gas flow around the blade tips.

Exhaust

After the gas has passed through the turbine, it is discharged through the exhaust. Though most of the gaseous energy is converted into 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 as jet thrust - the principle of equal and opposite reaction means that the force of the exhausted air drives the airplane forward.

TEXT 2B. EFFECTS OF TURBINE PRESSURE, TEMPERATURE AND VELOCITY

The materials used in the turbine section of the engine limit the maximum temperature at which a gas turbine engine can operate. The first metal the hot gases from the combustion section strike is the turbine inlet. The temperature of the gas stream is carefully monitored to ensure that overtemperature does not occur.

Sample Engine Pressure, Temperature, and Velocity ?

Compromises are made in turbine design to achieve the optimum balance of power, efficiency, cost, engine life, and other factors. As an example, our sample engine can operate at a higher turbine inlet temperature than previous models due to improved materials and design. The higher temperature allows for increased power and improved efficiency while adding higher cost for the direct cooling of the first turbine stage airfoils and other components.

EFFECTS OF ATMOSPHERIC CONDITIONS

The performance of the gas turbine engine is dependent on the mass of air entering the engine. At a constant speed, the compressor pumps a constant volume of air into the engine with no regard for air mass or density. If the density of the air decreases, the same volume of air will contain less mass, so less power is produced. If air density increases, power output also increases as the air mass flow increases for the same volume of air.

Atmospheric conditions affect the performance of the engine since the density of the air will be different under different conditions. On a cold day, the air density is high, so the mass of the air entering the compressor is increased. As a result, higher horsepower is produced. In contrast, on a hot day, or at high altitude, air density is decreased, resulting in a decrease of output shaft power.

TEXT 2C. COMPRESSOR STALL/SURGE

Background information

Compressor stall or surge is not peculiar to any one particular brand or type of engine. It may occur on any turbine engine if conditions are right. Stall has been encountered on two-stage or turbo-supercharged piston engines, so there is no need to look upon stall as some mysterious product of gas turbine engines.

Any number of mechanical defects, such as bad spark plugs, lean carburetion, poor timing, or sticking valves, can result in reciprocating engines backfiring. Similarly, for gas turbine engines, maintenance or flight conditions can influence the compressor stall or surge appreciably. The condition and operation of the bleed valve and fuel system components are of vital importance in maintaining surge-free operation.

Why are engines at risk of surge? As engines are designed to meet demands for higher power or lower specific fuel consumption, the engines must accommodate:

 Increased mass airflow. Increased pressure (compression) ratio. Increased maximum allowable turbine inlet and outlet temperatures. Improved efficiency of the compressor and turbine sections.

Quick engine starts and rapid accelerations are also desirable. To provide higher power with low specific fuel consumption and acceptable starting and acceleration characteristics, it is necessary to operate as close to the surge region as possible.

To prevent compressor stall or surge, fuel flow must be properly metered during the start and acceleration cycle of any gas turbine engine. To accomplish this, the example engine incorporates 5th and 10th stage acceleration bleed valves.

In general, there are fewer surge problems on centrifugal compressors than on axial flow compressors. There are several reasons for the difference; the primary reason is that centrifugal flow compressors operate at somewhat lower pressure ratios than axial flow compressors.

Explanation of stall/surge

A surge from a turbine engine is the result of instability of the engine's operating cycle. As discussed earlier, the operating cycle of the turbine engine consists of intake, compression, combustion, and exhaust, which occur simultaneously in different places in the engine. The part of the cycle susceptible to instability is the compression phase. Compressor surge may be caused by engine deterioration, it may be the result of ingestion of birds or ice, or it may be the final sound from a “severe engine damage” type of failure.

In a turbine engine, compression is accomplished aerodynamically as the air passes through the stages of the compressor, rather than by confinement, as is the case in a piston engine. The air flowing over the compressor airfoils can stall just as the air over the wing of an airplane can. When this airfoil stall occurs, the passage of air through the compressor becomes unstable and the compressor can no longer compress the incoming air. The high-pressure air behind the stall further back in the engine escapes forward through the compressor and out the inlet.

This escape is sudden, rapid and often quite audible as a loud bang. Engine surge can be accompanied by visible flames forward out the inlet and rearward out the tailpipe. Instruments may show high EGT and EPR or rotor speed changes; but, in many stalls, the event is over so quickly that the instruments do not have time to respond.

Once the air from within the engine escapes, the reason (reasons) for the instability may self-correct and the compression process may re-establish itself. A single surge and recovery will occur quite rapidly, usually within fractions of a second. Depending on the reason for the cause of the compressor instability, an engine might experience:

1. A single self-recovering surge
2. Multiple surges prior to self-recovery
3. Multiple surges requiring pilot action in order to recover
4. A non-recoverable surge.

For complete, detailed procedures, flight crews must follow the appropriate checklists and emergency procedures detailed in their specific Airplane Flight Manual. In general, however, during a single self-recovering surge, the cockpit engine indications may fluctuate slightly and briefly. The flight crew may not notice the fluctuation. (Some of the more recent engines may even have fuel-flow logic that helps the engine self-recover from a surge without crew intervention. The stall may go completely unnoticed, or it may be annunciated to the crew – for information only – via EICAS messages.) Alternatively, the engine may surge two or three times before full selfrecovery. When this happens, there is likely to be cockpit engine instrumentation shifts of sufficient magnitude and duration to be noticed by the flight crew. If the engine does not recover automatically from the surge, it may surge continually until the pilot takes action to stop the process. The desired pilot action is to retard the power lever until the engine recovers. The flight crew should then SLOWLY re-advance the power lever. Occasionally, an engine may surge only once but still not self-recover.

The actual cause for the compressor surge is often complex and may or may not result from severe engine damage. Rarely does a single compressor surge CAUSE severe engine damage, but sustained surging will eventually over-heat the turbine, as too much fuel is being provided for the volume of air that is reaching the combustor. Compressor blades may also be damaged and fail as a result of repeated violent surges; this will rapidly result in an engine which cannot run at any power setting.

TEXT 2D. HOW GAS TURBINE POWER PLANTS WORK

The combustion (gas) turbine being installed in many of today's natural-gas-fueled plants are complex machines, but they basically, involve three main sections:

- The compressor, which draws air into the engine, pressurizes it, and feeds it to the combustion chamber at speeds of hundreds of miles per hour.
- The combustion system typically made up of a ring of fuel injectors that inject a steady stream of fuel into combustion chambers, where it mixes with the air. The mixture is burned at a temperatures of more than 2000 degrees F. The combustion produces a high temperature, high pressure gas stream that enters and expands through the turbine section.
- The turbine is an intricate array of alternate stationary and rotating aero foil-section blades. As hot combustion gas expands through the turbine, it spins the rotating blades. The rotating blades perform a dual function: they drive the compressor to draw more pressurized air into the combustion section, and they spin a generator to produce electricity.

Land based gas turbines are of two types: (1) heavy frame engines and (2) aero derivative engines. Heavy frame engines are characterized by lower pressure ratios (typically below 20) and tend to be physically large. Pressure ratio is the ratio of the compressor discharge pressure and the inlet air pressure. Aero derivative engines are derived from jet engines, as the name implies, and operate at very high compression ratios (typically in excess of 30). Aero derivative engines tend to be very compact and are useful where small power outputs are needed. As large frame turbines have higher power outputs, they can produce larger amount of emissions, and must be designed to achieve low emissions of pollutants, such as NOx.

One key to a turbine's fuel-to-power efficiency is the temperature at which it operates. Higher temperatures generally mean higher efficiencies, which in turn, can lead to operation that is more economical. Gas flowing through a typical power plant turbine can be as hot as 2300 degrees F, but some of the critical metals in the turbine can withstand temperatures only as hot as 1500 to 1700 degrees F. Therefore, air from the compressor might be used for cooling key turbine components, reducing ultimate thermal efficiency.

One of the major achievements of advanced technology engineering turbine programs was to break through previous limitations on turbine temperatures, using a combination of innovative cooling technologies and advanced materials. The advanced turbines that emerged from research programs were able to boost turbine inlet temperatures to as high as 2600 degrees F – nearly 300 degrees hotter than in previous generations' turbines, and achieve efficiencies as high as 60 percent.

Another way to boost efficiency is to install a recuperator or heat recovery steam generator (HRSG) to recover energy from the turbine's exhaust. A recuperator captures waste heat in the turbine exhaust system to preheat the compressor discharge air before it enters the combustion chamber. A HRSG generates steam by capturing heat from the turbine exhaust. These boilers are also known as heat recovery steam generators. High-pressure steam from these boilers can be used to generate additional electric power with steam turbines, a configuration called a combined cycle.

A simple cycle gas turbine can achieve energy conversion efficiencies ranging between 20 and 35 percent. With the higher temperatures, future hydrogen and syngas fired gas turbine combined cycle plants are likely to achieve of 60 percent and more. When waste heat is captured from these systems for heating or industrial purposes, the overall energy cycle efficiency could approach 80 percent.

TEXT 3A. Air-start system

An air-start system is a power source used to provide the initial rotation to start large diesel and gas turbine engines.

Compared to a gasoline (petrol) engine, diesel engines have very high compression ratios to provide for reliable and complete ignition of the fuel without spark plugs. An electric starter powerful enough to turn a large diesel engine would itself be so large as to be impractical, thus the need for an alternative system/ When starting the engine, compressed air is admitted to whichever cylinder has a piston just over top dead center, forcing it downwards. As the engine starts to turn, the air-start valve on the next cylinder in line opens to continue rotation. As this goes on, fuel is injected into the cylinders, the engine is then under way and the air is cut off.

To further complicate matters, a large engine is usually “blown over” first with zero fuel settings and the indicator cocks open, to prove that the engine is clear of any water build up and that everything is free to turn. After a successful blow ahead and a blow astern, the indicator cocks are closed on all the cylinders, and then the engine can be started on fuel. Significant complexity is added to the engine by using an air-start system, as the cylinder head must have extra valve systems. This added complexity and cost limits the use of air-starters to very large and expensive reciprocating engines.

Another method of air-starting an internal combustion engine by using compressed air or gas to drive a fluid motor in place of an electric motor. They can be used to start engines from 5 to 320 liters in size and if more starting power is necessary two or more motors can be used. Starters of this type are used in place of electric motors because of their lighter weight and higher reliability. They can also outlast an electric starter by a factor of three and are easier to rebuild.

An air-starter on a turbine engine would typically consist of a radial flow turbine, or axial flow turbine, which is connected to the High Pressure compressor spool through the accessory gearbox, plus the associated piping and valves. Compressed air is provided to the system by bleed air from the aircraft's auxiliary power unit or from an air compressor mounted on ground support equipment.

Compared to electric starters, air-starters have a higher power-to-weight ratio. Electric starters and their wiring can become excessively hot if it takes longer than expected to start the engine, while air-starters can run as long as their air supply lasts. Turbine starters are much simpler and are a natural fit for turbine engines, and thus are used extensively on large turbofan engines exploited on commercial and military aircraft.

TEXT 3B. Turbocharger

A turbocharger, a turbo, is a gas compressor used for forced-induction of an internal combustion engine. Like a supercharger, the purpose of a turbocharger is to increase the mass of air entering the engine to create more power. However, a turbocharger differs in that a turbine driven by the engine's own exhaust gases powers the compressor. The word turbo is derived from the Latin word 'turba', which in turn originates from the Greek word that indicates 'bustle, turmoil, disorder or tumult'.

The Working principle

A turbocharger is a small radial fan pump driven by the energy of the exhaust gases of an engine. A turbocharger consists of a turbine and a compressor on a shared shaft. The turbine section of a turbocharger is a heat engine in itself. It converts the heat energy from the exhaust to power, which then drives the compressor, compressing ambient air and delivering it to the air intake manifold of the engine at high pressure, resulting in a greater mass of air entering each cylinder. In some instances, compressed air is rooted through an intercooler before introduction to the intake manifold. Since a turbocharger is a heat machine, and converts otherwise wasted exhaust heat to power, it compresses the inlet air to the engine more efficiently than a supercharger.

The objective of a turbocharger is the same as that of a supercharger: to improve upon the size-to-output efficiency of an engine by finding a solution to one of its cardinal constraints. A naturally aspirated automobile engine uses only the downwards stroke of a piston in order to create an area of low pressure so that to draw air into the cylinder through the intake valves. As the atmospheric pressure is no more than 1 bar (approximately 14.7 psi), there ultimately will be a limit to pressure difference across the intake valves and, thus the amount of airflow entering the combustion chamber. This ability to fill the cylinder with air is referred to as its volumetric efficiency. Since the turbocharger increases the pressure at the point, where air enters the cylinder, a greater mass of air (oxygen) will be forced in as the inlet manifold pressure increases. The additional oxygen makes it possible to add more fuel, increasing the power and torque output of the engine.

Because the pressure in the cylinder must not go too high to avoid detonation and physical damage, the intake pressure ought to be monitored by controlling the rotational speed of the turbocharger. The control function is performed by a waste gate, which routes some of the exhaust flow away from the exhaust turbine. This controls the shaft speed and regulates air pressure in the intake manifold.

The application of a compressor to increase pressure at the point of the cylinder air intake is often referred to as forced induction. Centrifugal superchargers compress air in the same fashion as a turbocharger. However, the energy to spin the supercharger is taken from the rotating output energy of the engine’s crankshaft as opposed to normally exhausted gas from the engine. Superchargers use output energy from an engine to achieve a net gain, which must be provided from some of the engine’s total output. Turbochargers, on the other hand, convert some of the piston engine’s exhaust into useful work. This energy would otherwise be wasted out of the exhaust. This means that a turbocharger provides a more efficient use of the heat energy obtained from the fuel than a supercharger.

The Components

The turbocharger has four main components. The turbine (predominantly a radial turbine) and impeller; compressor wheels, each contained within their own folded conical housing on the opposite sides of the third component, the center housing; the hub rotating the assembly (CHRA).

The housings fitted around the compressor impellor and the turbine, collect and direct the gas flow through the wheels as they spin. Their size and shape can determine some of the performance characteristics of the overall turbocharger. Oftentimes, the same basic turbocharger assembly will be available from the manufacturer with multiple housing choices for the turbine itself, and sometimes for the compressor cover as well. This fact allows for the designer of the engine system to tailor the compromises between performances, response and efficiency to applications or preferences. Twin-scroll designs have two valve-operated exhaust gas inlets, a smaller sharper angled one for quick response and a larger less angled one for peak performance.

The turbine and impeller wheel dimensions also determine the amount of air or exhaust that can be flowed through the system, and the relative efficiency at which they operate. Generally, the larger the turbine wheel and compressor wheel, the bigger the flow capacity. Measurements and shapes can vary, as well as the curvature and number of blades on the wheels. Turbochargers of various geometry are further developments of these ideas.

The center hub rotating assembly (CHRA) houses the shaft, which connects the compressor impeller and turbine. I also must contain a bearing system to suspend the shaft, allowing it to rotate at a very high speed with minimal friction. For instance, in automotive applications the CHRA typically uses a thrust bearing or a ball bearing lubricated by a constant supply of pressurized engine oil. The CHRA may also be considered “water cooled” by having an entry and exit point for the engine coolant to be cycled. Water cooled models allow the engine coolant to be used in order to keep the lubricating oil cooler, and avoiding possible oil coking from the extreme heat found in the turbine. The development of airfoil bearings has removed the risk.

TEXT 3C. Turbine Expander Section

There are two types of turbines used in gas turbines. These consist of the axial-flow type and the radial-inflow type. The axial-flow turbine is used in more than 95% of all applications.

The two types of turbines - axial-flow and radial-inflow turbines – can be divided further into impulse or reaction type units. Impulse turbines take their entire enthalpy drop through nozzles, while the reaction turbine takes a partial drop through both the nozzles and the impeller blades.

Radial-Inflow Turbine

The radial-inflow turbine, or inward-flow radial turbine, has been in use for many years. Basically, a centrifugal compressor with reversed flow and opposite rotation, the inward-flow radial turbine is used smaller loads and over a smaller operational range than axial turbine.

Radial-inflow turbines are only now beginning to be used because little was known about them heretofore. Axial turbines have enjoyed tremendous interest due to their low frontal area, making them suited to the aircraft industry. However, the axial machine is much longer than the radial machine, making it unsuited to certain applications. Radial turbines are used in turbochargers and in some types of expanders.

The inward-flow radial turbine has many components similar to a centrifugal compressor. There are two types of inward-flow radial turbines: the cantilever and the mixed-flow. The cantilever type is similar to an axial-flow turbine, but it has radial blading. However, the cantilever turbine is not popular because of design and production difficulties.

Mixed-flow turbine. This type is almost identical to a centrifugal compressor - except its components have different functions. The scroll is used to distribute the gas uniformly around the periphery of the turbine.

The nozzles, used to accelerate the flow toward the impeller tip, are usually straight vanes with no airfoil design. The vortex is a vaneless space and allows an equalization of the pressures. The flow enters the rotor radially at the tip with no appreciable axial velocity and exits the rotor through the exducer axially with little radial velocity.

These turbines are used because of lower production costs, in part because the nozzle blading does not require any camber or airfoil design.

Axial-Flow Turbines

The axial-flow turbine, like its counterpart the axial-flow compressor, has flow, which enters and leaves in the axial direction. There are two types of axial turbines: impulse type and reaction type. The impulse turbine has its entire enthalpy drop in the nozzle; therefore it has a very high velocity entering the rotor. The reaction turbine divides the enthalpy drop in the nozzle and the rotor.

Most axial-flow turbines consist of more than one stage: the front stages are usually impulse (zero reaction) and the later stages have about 50% reaction. The impulse stages produce about twice the output of a comparable 50% reaction stage, while the efficiency of an impulse stage is less than that of a 50% reaction stage.

TEXT3 D. Comparative Study on Modelling of Gas Turbines in Combined Cycle Power Plants

Gas turbines are important for electric power generation specially the Combined Cycle Power Plants (CCPP). For this electric power generation, the dynamics of the gas turbines become increasingly more important. In order to study such dynamics, accurate models of gas turbines are needed. Recently, several gas turbine models have been proposed with different degree of complexity and success. The purpose of this work is concerned with understanding, modelling, and analysing the behaviour of the gas turbinebased plants to investigate the power system problems. This purpose is achieved by a complementary and comparative study of different dynamic models response that published in different literature for Combined Cycle Power Plants (CCPP). Among these models, there are three models were completely simulated using Matlab/Simulink. It is easy to conclude that the obtained results via these simulations in this study are highly matched with the results presented in the related scientific articles. The study illustrates the effectiveness and accuracy of frequency dependant model as well as the detailed model of gas turbines in CCPP.

I. INTRODUCTION

THE gas turbine is a main part of the current power plant, which produces a great amount of energy for its size and weight. The gas turbine has established growing service in the past 40 years in the power industry both among utilities and merchant plants as well as the petrochemical industry, and utilities throughout the world. The last 20 years has seen a noticeable growth in Gas Turbine Technology. The growth is developed by the enhancement of materials technology, new coatings and new cooling schemes. This, with the conjunction of increase in compressor pressure ratio, has increased the gas turbine thermal efficiency from about 15 to over 45 percent, which is suitable for power plants. In the past, large coal and nuclear power plants dominated the electric power generation. However, natural gas-fired turbines now dominate the field of

Power generation because of their black start capabilities, higher efficiencies, lower capital costs, shorter installation times, better emission characteristics, and abundance of natural gas supplies. The construction cost of gas turbine power plants is roughly half that of comparable conventional fossil fuel steam power plants, which were the primary power plants until the early 1980s. More than half of all power plants to be installed in the foreseeable future are forecast to be gas turbine or combined gas-steam turbine types. Current low prices for crude oil make fuels such as diesel, kerosene, and clean gaseous fuels such as natural gas the most desirable for gas turbines. However, these fuels will become much more expensive and will eventually run out. So, provisions must therefore be made to burn alternative fuels. Now, gas turbines are used in a wide range of applications. The two major application areas of gas turbine engines are: Aircraft propulsion. Electric power generation. For electric power generation, common uses include stationary power generation plants (electric utilities) and mobile power generation engines (ships and aircraft). The term ‘‘Combined Cycle Power Plant (CCPP)” describes the combination of gas turbine generator(s) (Brayton cycle) with turbine exhaust waste heat boiler(s) and steam turbine generator(s) (Rankine cycle) for the production of electric power. During the last decades there has been continuous development of combined cycle power plants due to their increased efficiency and their low emissions, as well as reduced natural gas prices. However, in a large-scale blackout occurred in Malaysia in August 1996, CCPP and gas turbine plants sequentially tripped out. The cause of this chain trip was thought to be a system frequency drop. Also, there were the blackout events in Italy, Denmark/southern Sweden and the USA/Canada, which resulted in major economic losses. Also strong crises in electric demand appeared in Egypt in summer of 2010, which made more focus on CCPP. Therefore, A mathematical model of a CCPP is needed, including relevant control and protective functions. In this study, a simple model for CCPP will be developed in the Simulink environment of MatLAB. This to help in obtaining accurate models, which are highly needed. In the last decades, several gas turbine models have been proposed with different degree of complexity and success. It should be known that the complete gas turbine model consists of the turbine thermodynamics, the fuel system, and the control loops, as illustrated in Figure (1). Some models implement all of them together such as [1, 2], whereas the other models implement a separate block for the turbine dynamics such as [3, 13]. This article is focusing on the comparative study for various gas turbines characteristics (thermodynamics) only. These characteristics are published in different literature. The fuel system and control loops will be discussed later in another research results. Furthermore, this study is considered a complementary study for different gas turbines models as well.

Effect of Compression Ratio on Performance of Combined Cycle Gas Turbine

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Abstract It is known the performance of a gas turbine (GT) has strong dependence of climate conditions. A suitable solution to minimize this negative effect is to raise inlet turbine temperature and reduce temperature of inlet air to GT compressor. Combined cycles gas turbines (CCGT) are a lot used to acquire a high-efficiency power plant. Increases the peak compression ratio has been proposed to improve the combined-cycle gas-turbine performance. The code of the performance model for CCGT power plant was developed utilizing the MATLAB software. The simulating results show that the overall efficiency increases with the increase of the peak compression ratio. The total power output increases with the increase of the peak compression ratio. The peak overall efficiency occurs at the higher compression ratio with low ambient

temperature and higher turbine inlet temperature. The overall thermal efficiencies for CCGT are higher compared to gas-turbine plants.

1. Introduction.

   The gas and steam turbines are the greatest means to generate mechanical power. Both gas and steam turbines have been successfully working in large scale to generate the electricity, whereas gas turbine ensures superior thermal efficiency as compared to steam turbine. Different means have been employed by a lot of researchers to get better thermal efficiency of the turbines, particularly the gas turbine. One of the means is to increase the gas-turbine inlet temperatures and decrease the compressor inlet air temperatures, this mean increase the peak cycle temperature ratio. As a consequence of cycle peak temperature ratio, higher exhaust gases temperature results, which means increase the energy loss at the stack[1-2]. Many researchers focus on improve the modeling of CCGT power plant system utilizing the Brayton Cycle gas turbine and Rankine Cycle steam turbine with air (gases) and water (steam) as working fluids achieve efficient, reliable, and economic power generation as shown in Figure 1. Current commercially available generation CCGT power plants achieve total thermal efficiency typically in the 50- 60% Lower Heating Value range[3-4]. Further development of simple cycle gas turbine, metal surface cooling technology, and high temperature bleed materials show promise for near term generation power for CCGT power plants capable

of reaching more than 60% plant thermal efficiency. Additional the development in gas-turbine technology, as well as increases in steam-turbine cycle temperature and pressure, HRSG stage design enhancement, is expected to achieve further combined-cycle gas-turbine power plants efficiency improvement[5-6]. The combination of the gas-turbine Brayton Cycle and the steam turbine power plant Rankine Cycle complement each other to form efficient CCGT power plants. The Brayton Cycle has high source temperature and rejects heat at a temperature that is conveniently used as the energy source for the Rankine Cycle plant. The most commonly used working fluid for combined-cycle gas-turbine power plants are air and steam[7]. Kaushika et al.[5]. Studied optimum performance of a CCGT power plant; the CCGT power plant has been modelled and simulated. The behaviour of the gas turbine was studied at part load. Results of a sensitivity analysis of the effect of atmospheric temperature on the gas-turbine performance are presented. The best combination of process parameters of steam leaving the steam generator that will give optimum performance of the CCGT power plant were determined at part load operation. Results for the optimum values of thermal efficiency and power output together with values of the decision variables are presented[8]. Khaliq and Kaushik[9] created the simulator of the combined-cycle co-generation power plant. The simulator is built by the mathematical model, which is a model for power plant modelling. The simulator is divided into two parts, the first is a simulation of fluid flow in the power plant, and the other part is a simulation of the control system of the plant[10, 11].

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Supplimentary Texts

TEXT1. Effect of Compression Ratio on Performance of Combined Cycle Gas Turbine

In the present work, a parametric thermodynamic analysis of a combined-cycle gas turbine is undertaken. The effect of operating parameters, including peak pressure ratio, gas-turbine peak temperature ratio, isentropic compressor and efficiency and air fuel ratio, on the overall plant performance is investigated.

It is known the performance of a gas turbine (GT) has strong dependence of climate conditions. A suitable solution to minimize this negative effect is to raise inlet turbine temperature and reduce temperature of inlet air to GT compressor. Combined cycles gas turbines (CCGT) are a lot used to acquire a high-efficiency power plant. Increases the peak compression ratio has been proposed to improve the combined-cycle gas-turbine performance. The code of the performance model for CCGT power plant was developed utilizing the MATLAB software. The simulating results show that the overall efficiency increases with the increase of the peak compression ratio. The total power output increases with the increase of the peak compression ratio. The peak overall efficiency occurs at the higher compression ratio with low ambient temperature and higher turbine inlet temperature. The overall thermal efficiencies for CCGT are higher compared to gas-turbine plants.

Keywords Combined Cycle, Compression Ratio, Gas Turbine, Power, Thermal Efficiency

Introduction.

The gas and steam turbines are the greatest means to generate mechanical power. Both gas and steam turbines have been successfully working in large scale to generate the electricity, whereas gas turbine ensures superior thermal efficiency as compared to steam turbine. Different means have been employed by a lot of researchers to get better thermal efficiency of the turbines, particularly the gas turbine. One of the means is to increase the gas-turbine inlet temperatures and decrease the compressor inlet air temperatures, this mean increase the peak cycle temperature ratio. As a consequence of cycle peak temperature ratio, higher exhaust gases temperature results, which means increase the energy loss at the stack[1-2]. Many researchers focus on improve the modeling of CCGT power plant system utilizing the Brayton Cycle gas turbine and Rankine Cycle steam turbine with air (gases) and water (steam) as working fluids achieve efficient, reliable, and economic power generation as shown in Figure 1. Current commercially available generation CCGT power plants achieve total thermal efficiency typically in the 50- 60% Lower Heating Value range[3-4]. Further development of simple cycle gas turbine, metal surface cooling technology, and high temperature bleed materials show promise for near term generation power for CCGT power plants capable of reaching more than 60% plant thermal efficiency. Additional the development in gas-turbine technology, as well as increases in steam-turbine cycle temperature and pressure, HRSG stage design enhancement, is expected to achieve further combined-cycle gas-turbine power plants efficiency improvement[5-6]. The combination of the gas-turbine Brayton Cycle and the steam turbine power plant Rankine Cycle complement each other to form efficient CCGT power plants. The Brayton Cycle has high source temperature and rejects heat at a temperature that is conveniently used as the energy source for the Rankine Cycle plant. The most commonly used working fluid for combined-cycle gas-turbine power plants are air and steam[7]. Kaushika et al.[5]. Studied optimum performance of a CCGT power plant; the CCGT power plant has been modelled and simulated. The behaviour of the gas turbine was studied at part load. Results of a sensitivity analysis of the effect of atmospheric temperature on the gas-turbine performance are presented. The best combination of process parameters of steam leaving the steam generator that will give optimum performance of the CCGT power plant were determined at part load operation. Results for the optimum values of thermal efficiency and power output together with values of the decision variables are presented[8]. Khaliq and Kaushik[9] created the simulator of the combined-cycle co-generation power plant. The simulator is built by the mathematical model, which is a model for power plant modelling. The simulator is divided into two parts, the first is a simulation of fluid flow in the power plant, and the other part is a simulation of the control system of the plant[10, 11].

TEXT 2. Modeling of Combined Cycle Gas Turbine.

A combined cycle gas turbine power plants having Brayton cycle based topping cycle and Rankine cycle based bottoming cycle has been considered for the present study and analysis. Gas turbine power plants consist of four components, compressor, combustion chamber, turbine and generator. Air is drawn in by the compressor and delivered to the combustion chamber. Liquid or gaseous fuel is commonly used to increase the temperature of compressed air through a combustion process. Hot gases leaving the combustion chamber expands in the turbine which produces work and finally discharges to the atmosphere (state 1, 2, 3 in Figure 2)[12,13]. The waste exhaust gas temperature from gas turbine decreases as it flows into the heat recovery steam generator (HRSG), which consists of superheater, evaporator and economizer. Then the HRSG supplies a steam for the steam turbine in producing electricity. In the latter, the waste condensate from the steam turbine will be flowed into a condenser, where cooling water transfers waste heat to the cooling tower. In the final stage, feed water is the output from a condenser, which is suctioned by the feed water pump and sent to the heat recovery steam generator [5, 14].