Gas turbines and Their Different Uses

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Abstract. The structure of the gas turbine and how it is used in a closed cycle will be explained in this paper; the principles of the universal gas turbine will be specified by means of a specific piece of machinery, the Titan 130; there are a number of ways to improve the thermal efficiency of the gas turbine, and in this paper three specific solutions will be proposed. Due to the immense significance of the gas turbine for mankind, two significant applications of the gas turbine will be elucidated, namely the combined cycle and microgeneration technology. Furthermore, the performance of the gas turbine in the compressor, combustion chamber, and turbine will be demonstrated through equations, and the significant factors in the combined cycle will be exemplified. Finally, the concept of the microturbine will be described, as well as the changes it will undergo in the future and the problems it is facing now.

Keywords: Gas turbines; Efficiency analysis; combined cycle; Power generation.

1. Introduction

Gas turbines are widely used in various fields, especially in power generation. The current technology is perfect, but there is still room for development in the economy. It is expected that by 2032, the economic growth of gas turbines used in aviation will account for the economic growth of gas turbines [1]. The gas turbine has many characteristics, such as a low impact on the environment, a high degree of maneuverability, and a high power per unit area. Due to its cooling and coating technology, its melting point is higher than that of the structure. Despite its considerable complexity, the gas turbine plays a significant role in the global arena, resulting in an increasing number of nations committing additional resources to scholars in the corresponding fields for the advancement of gas turbine general-purpose technology. Because it is a constantly evolving machine, investment in advanced technology cannot be interrupted in order to keep its level of research at a comparable level.

Gas turbine research technology reflects a country's comprehensive industrial level. The gas turbine is a high-tech product that involves design thermodynamics, materials science, fluid mechanics, and other disciplines. In the future, China will invest more money into research into gas turbines. At present, the advancement of domestic scientific research is remarkably smooth. Despite the requirement for novel materials, novel technologies, and other complexities, the localization of gas turbine auxiliary systems has exceeded 95%. Furthermore, the foundation of the concept of manufacturing is evident, enabling the technology to adapt to China's production capacity [2]. Additionally, the unwavering pursuit of scientific research has enabled the resolution of fundamental technical issues.

At the power generation level, the desired power of a gas turbine is 70% or greater, and 50% within a single cycle. Despite ample efforts from the research sector, neither of the desired efficiency levels has been achieved yet. The most efficient approach to achieving the objective is to enhance the combustion temperature. However, this approach has its limitations, including an increase in the emission of nitrogen oxides (NOx), a crucial factor in meeting the demands of the gas turbine industry. To achieve both of these goals, we need additional scientific materials, but the risks are extremely high.

Each country is now attempting to innovate in terms of materials and coatings, combustion profiles, mixing and circulation systems, and so on. In addition to hydrogen burners, which will be discussed in greater detail later, we can reduce NOx emissions by lowering the combustion temperature to less than 1,500 degrees Celsius and allowing the fuel and air to mix earlier. Nonetheless, this approach results in the fluctuation of the flame's position, rendering it challenging to pinpoint its location in conditions of elevated temperature and pressure. Furthermore, even if the flame's position is pinpointed precisely, it is inevitable that additional nitrogen oxides will be generated. Hence, it is imperative to investigate novel combustion techniques to address the aforementioned issues. These combustion modes ought to permit the adjustment of the combustion duration, thereby reducing the stagnation time of nitrogen oxides and reducing the rate of their production.

However, in general, gas turbines are still essential to mankind, and it can be said that gas turbines are involved in all aspects of our lives, and the world has never stopped developing them. However, many people are still unaware of it, for such a flexible machine with a broad future background. If it is not widely understood, it will have a significant impact on the efficiency of work. Ultimately, a comprehensive explanation will be provided on the structure of the gas turbine within the combined cycle, as well as the significant factors and the significance of small gas turbines in power generation.

2. Stationary Gas turbine

2.1. Structure of stationary gas turbine

A gas turbine is composed of many parts, and at the same time it has a tight structure. Each part has its own different function. For instance, in the compressor, the task of compression will be completed. Different gas turbines also have different cycles, of which the open cycle is the most common.

In a closed loop, Helium can be utilized as a suitable substitute for air. When the system is compressed from outside, the gas is heated by external combustion [3]. Furthermore, in such a cycle, the gas turbine in its generalized form can function as a steam turbine. The turbine utilizes water and steam as its work material. The pressure is increased by means of pumps, which undergo pressurization and heating processes. Finally, the heat is emitted by the condenser, completing its thermal cycle. A combined gas turbine and internal combustion engine power plant is a turbocharger, which is widely used in internal combustion engines. This type of power unit typically operates under high-pressure and robust conditions in all states, with the exception of expansion, exhibiting an intermittent carry-over.

2.2. Principle of stationary gas turbine

The gas turbine has good efficiency and thermoelectric ratio. Its main way of working is to rotate, while using high temperatures to convert chemical energy into energy for mechanical motion. It works by compressing outside air with a pressurizer. There exists a diverse range of pressurizers, however, micro or small gas turbines consistently employ centrifugal pressurizers, which typically possess a minimal power output of approximately 1.5 MW [4]. Another type of axial flow compressor is often used in medium and large gas turbines, where the compression of the gas is accomplished through multiple layers of compressor blades.

Take the Titan130 to analyze how it works [4]. First, the gas is compressed by the 13-stage vanes to about fourteen times the atmospheric pressure, then the air velocity is reduced by the axial flow deflector, thus again increasing the air pressure, and this time the gas is sent to the combustion chamber. At this time, the combustion chamber is also equipped with other fuels through the nozzle. When the high-pressure gas is combined with them, it will be fully combusted in this process and produce high temperature, high-pressure flue gas. During this period, the flue gas undergoes thermal expansion and is subsequently deflected by the deflector plate. Upon contact with the first stage blades, the turbine blades are pushed, resulting in the rotation of the main shaft. After completing the process, the gas is not directly discharged from the outlet or re-processed by the heat exchanger to be utilized. Instead, it is contacted with the second and third heat exchangers in turn to do the work.

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2.3. Methods to improve the efficiency of stationary gas turbine

There are many ways to make it more efficient. The first way is to raise the temperature of the gas. In order to attain this objective, it is imperative to initiate the development of materials that are suited to the temperature. Blade materials are subject to numerous undesirable influences that can affect the service life of the unit. The application of protective coatings or the development of alternative materials, such as ceramic blades, is the most effective approach to mitigate the adverse effects of corrosion at elevated temperatures. Furthermore, enhancing cooling technology and utilizing it in combustion chambers and turbine blades [5] is also a highly effective approach to achieve this goal. Another effective way to increase efficiency in the thermal cycle is by increasing the temperature of the gas and increasing the ratio of pressures. This approach has the potential to enhance single-stage pressure ratios and attain transgenic levels. Additionally, the overall pressure ratio can be elevated, thereby significantly expanding the compressor's operating range.

The final approach entails optimizing the utilization of the generated waste heat. The residual heat generated by the gas and fuel in the combustion chamber can be captured, and this heat is captured through the utilization of a return heater, which is currently being developed to be lightweight and efficacious. It is also possible to use a gas-steam combined cycle, in which the steam can be heated by exhaust gases, effectively increasing the total efficiency [5].

3. The use of stationary gas turbines

3.1. Pressurized Fluidized Bed Combustion Combined Cycle (PFBC)

3.1.1. Combined cycle model

There are three essential machines for the combined cycle, which I will describe in more detail next: the compressor, the combustion chamber, and the turbine.

The combined gas-steam cycle consists of a gas top cycle and a steam bottom cycle [5]. The top cycle consists of three parts: compressor, combustion chamber and gas turbine. The cyclic flow of this subject is shown Figure 1 [6].

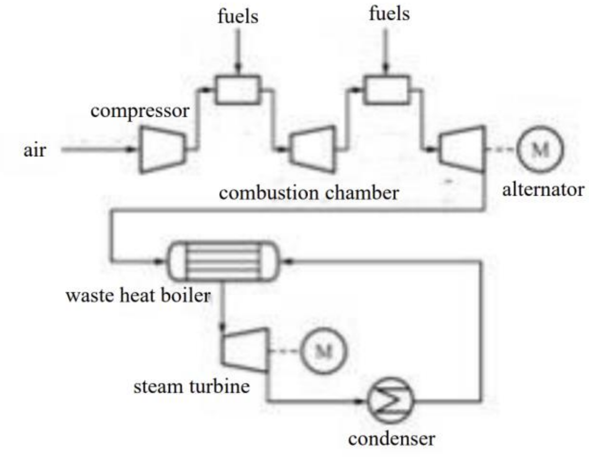

Fig 1. Reheat gas turbine combined cycle system sketch.

In a compressor, the gas is compressed in stages, and the process at each stage may be expressed as follows:

$$s_2 - s_1 = \left[\frac{(1-\tau_p)}{\tau_p}\right] \times R \times \ln\left(\frac{P_2}{P_1}\right) \tag{1}$$

In this equation, s represents the value of entropy, p represents the value of pressure, subscript 1 represents before compression, subscript 2 represents after compression, and τ_p represents the efficiency of the compression [7].

In a combustion chamber, the energy equalization equation is:

$$\dot{m}_{air}h_{air} + \dot{m}_{fuel}h_{fuel} + \dot{m}_{fuel}H_{fuel}\tau_{cmb} + e_{loss} = \dot{m}_{fuel}h_{gas} \quad (2)$$

In this equation, $\dot{m}_{air}, \dot{m}_{fuel}, \dot{m}_{fuel}$ represent the flow rate into the combustion chamber, and from the subscript you can also know what corresponds; h_{air}, h_{fuel} represent the ratio of enthalpy of air to gas; H_{fuel} represents the calorific value of the fuel at the lower level, τ_{cmb} represents whether or not the combustion is complete or not, with the higher one indicating the more complete, and e_{loss} represents the energy lost in the system

Assuming that the subject matter of our investigation is a continuum turbine, the cooling model can be divided into three distinct components, namely the first stage nozzle, the turbine for cooling, and the turbine for non-cooling. Furthermore, through the continuum expansion, we can further segment it into seven and twenty-three distinct components, without distinguishing between moving and static blades, provided that the first stage nozzle is not present.

Before the absence of the thermal barrier, the heat transfer from the gas to the cooling mass had a total of three stages, which became four with the addition of the layer. FiThe vertical coordinates represent temperatures, while the different subscripts represent different scalars. In general conditions, as the thickness of the thermal barrier layer is only one tenth of the thickness of the blade wall (which is approximately two to three millimeters thick), the coating's thermal resistance value is significantly higher than that of the blade wall.

3.1.2. Important factors in the Combined cycle

There exist numerous factors that influence combustion efficiency, and in this article, we shall discuss two significant ones, namely the temperature of the combustion chamber outlet and the pressure of reheating.

The vertical coordinate is used to represent the total cooling percentage of air, and the horizontal coordinate represents the pressure ratio in the cycle. Each of the four curves represents the output temperature of the combustion chamber at different temperatures. It is evident from the graph that as the temperature increases, the value of the vertical coordinate also increases in tandem. At temperatures exceeding 1983k, the proportion of cool air surpasses 30 percent, and the heat loss resulting from the mixing of such gas with gas is even greater.

In Figure 2, the parameter regulated is the pressure in the combustion chamber, and the horizontal coordinates denote the distribution of the high-pressure turbine to the low-pressure turbine. Based on the analysis of the image, it can be discerned that there exists a peak in the expansion ratio that maximizes the efficiency when it is unaffected by external factors. This peak is approximately 2.22 expansion ratio, at which point the efficiency of the combined cycle can surpass 60% [6]. However, if the expansion ratio is higher than this peak, the efficiency decreases as the expansion ratio increases, and the efficiency of the combined cycle can surpass 60% when the expansion ratio exceeds 60%

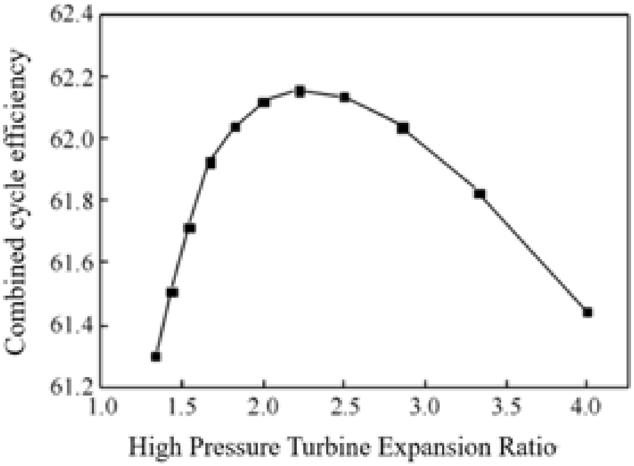

Fig 2. Combined cycle efficiency as a function of high-pressure turbine expansion ratio.

3.2. Power generation

3.2.1 Micro Gas Turbine

If the gas turbine is used for power generation, its power generation efficiency will be greatly increased compared with other machines, and it can adapt to different working conditions. A single microgenerator can have a power of up to 300 kilowatts, and it generates electricity by making the impeller machine flow out. Currently, technology has been broken through, and it is possible to connect the battery and the power generation to form a new device, and its efficiency is more than 60%. The impact on the environment is also minimal.

The compressor of a gas engine mixes external gases into the combustion chamber with the gases coming out of the nozzles. The two gases have different properties, which results in a mixture with high temperatures and low pressure of heat. While the nozzle is driven by the gas turbine, the rotor is driven by the expander, and the two rotate concurrently at high speeds, resulting in high-temperature mechanical energy that generates electricity. When the process is complete, the remaining heat will be recovered and utilized, improving overall efficiency [8].

Micro gas machines have numerous other advantages, such as long service life, high flexibility, and low environmental pollution, making them one of the popular machines today. At present, because of climate-induced stress changes, more and more countries are jumping on the bandwagon of researching renewable energy. Turbines are also gradually transitioning from the utilization of natural gas to hydrogen.

The utilization of hydrogen remains a challenge as the low calorific value of natural gas surpasses that of hydrogen, necessitating a larger fuel flow. Despite the rapid flame speed of hydrogen, safety is not fully guaranteed, and the operation remains challenging [9]. Additionally, the emission of nitrogen oxides is another aspect that requires attention. Lastly, due to the disparity in the workpiece, the flow rate will be accelerated to a certain extent. Therefore, it is imperative to address the degree of alignment of the turbine with the workpiece.

4. Conclusion

Despite the present difficulties encountered in incorporating novel materials into gas turbines, it may be necessary to employ novel technology to address these obstacles. Nonetheless, it is certain that with the advancement of technology, the issues we are currently encountering will be resolved. The gas turbine will become more popular in the future. It will retain the original excellent structure, but at the same time it will be based on the original structure to expand new areas and apply to more industries.

In the near future, the fuel for gas turbines will gradually transition from natural gas to hydrogen. Due to their low NOx emissions, gas turbines will gradually improve their efficiency while simultaneously reducing their environmental impact. The modification will encompass not only a modification in fuel and physical structure, but also in its compatibility with renewable energy sources and its capacity to operate autonomously and sustainably.

It is imperative that every relevant department conducts an analysis of the present development objectives and considers the future trends of high digitalization and intelligence, combustion chambers, mechanical management, automated operation and maintenance, and other crucial areas of research, in order to foster the development of gas turbines that are more in tune with the requirements of today and tomorrow.

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