A REVIEW ON RECENT DEVELOPMENT OF GAS TURBINE

Gohel Ketankumar Nathalal,
Lecturer in Mechanical Engineering
Mechanical Department
Government Polytechnic, Porbandar, India.

Abstract: The gas turbine is the most versatile item of turbo machinery now days. Today, when we talk about the most widely used power generation, we think about the gas turbine technologies because these are the most widely used power generation technologies now a days. Gas turbine could play a key role in future power generation addressing issues of producing clean, efficient and fuel flexible electric power. In this paper author presents a brief description of Advanced Materials used for different components, advances in blade cooling technology, technologies for reducing NOx emissions as well as increasing thermal efficiency and improving combustion stability and New Combustion Technologies for 1700℃ Class Ultra High Temperature of Gas Turbine.

***Index Terms* – Gas turbine, Blade cooling, Thermal Efficiency, combustion Technology.**

1. INTRODUCTION

A turbine is any kind of spinning device that uses the action of a fluid to produce work. Typical fluids are: air, wind, water, steam and helium. Windmills and hydroelectric dams have used turbine action for decades to turn the core of an electrical generator to produce power for both industrial and residential consumption. Simpler turbines are much older, with the first known appearance dating to the time of ancient Greece.

In the history of energy conversion, however, the gas turbine is relatively new. The first practical gas turbine used to generate electricity ran at Neuchatel, Switzerland in 1939, and was developed by the Brown Boveri Company. The first gas turbine powered airplane flight also took place in 1939 in Germany, using the gas turbine developed by Hans P. von Ohain. In England, the 1930s' invention and development of the aircraft gas turbine by Frank Whittle resulted in a similar British flight in 1941.

The name "gas turbine" is somewhat misleading, because to many it implies a turbine engine that uses gas as its fuel. Actually a gas turbine has a compressor to draw in and compress gas (most usually air); a combustor (or burner) to add fuel to heat the compressed air, and a turbine to extract power from the hot air flow. The gas turbine is an internal combustion (IC) engine employing a continuous combustion process. This differs from the intermittent combustion occurring in Diesel and automotive IC engines.

Because the 1939 origin of the gas turbine lies simultaneously in the electric power field and in aviation, there have been a profusion of "other names" for the gas turbine. For electrical power generation and marine applications it is generally called a gas turbine, also a combustion turbine (CT), a turbo shaft engine, and sometimes a gas turbine engine. For aviation applications it is usually called a jet engine, and various other names depending on the particular engine configuration or application, such as: jet turbine engine; turbojet; turbofan; fanjet; and turboprop or prop jet (if it is used to drive a propeller). The compressor combustor-turbine part of the gas turbine is commonly termed the gas generator. [1]

1.1 THE BRAYTON CYCLE

To start with, it is advisable to know a short background of the gas turbine theoretical cycle, which is called "The Brayton Cycle". The Brayton cycle was first proposed by George Brayton for use in the reciprocating oil-burning engine that he developed around 1870. Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating machinery. The ideal cycle that the working fluid undergoes in this closed loop is the Brayton cycle, which is made up of four internally reversible processes as shown in Fig 1.1.

1-2 Isentropic compression (in a compressor)
2-3 Constant-pressure heat addition
3-4 Isentropic expansion (in a turbine)
4-1 Constant-pressure heat rejection

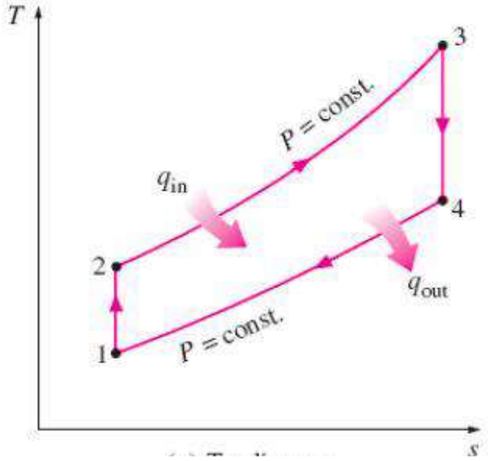

Figure 1.1 T-s diagram of an ideal Brayton cycle

The Brayton cycle is the cycle which the engineers and researchers make it the reference for them to compare and try to reach. In reality, the gas turbine does not work as the ideal Brayton cycle. It works under many effects, such that both the compression process (1-2) with fluid friction and the expansion process (3-4) with fluid friction results in an increase in entropy. The T-s diagram for the real or non-ideal Brayton cycle will become as shown below in Fig 1.2.

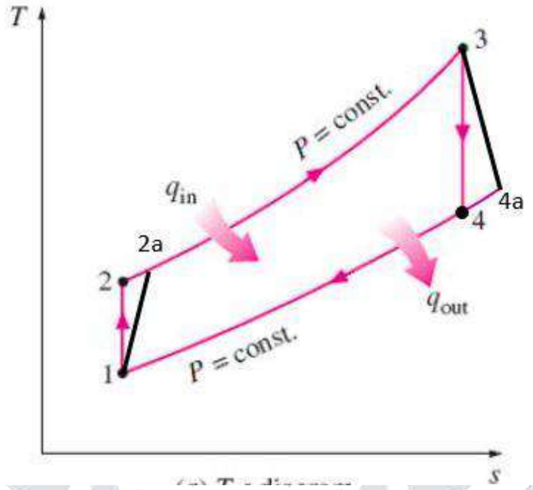

Figure 1.2 T-s diagram of ideal and non-ideal Brayton cycle (a indicates actual process)

1.2 THE GAS TURBINE CYCLE

The basic operation of the gas turbine is shown schematically in Fig. 1.3. It is starting by gas flows through a compressor at point 1 that brings it to higher pressure. Energy is then added by spraying fuel into the gas and igniting it so the combustion generates a high-temperature flow at point 2. This high-temperature high-pressure gas enters a turbine to point 3, where it expands through point 4, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. A typical gas turbine is shown in Fig.1.4.

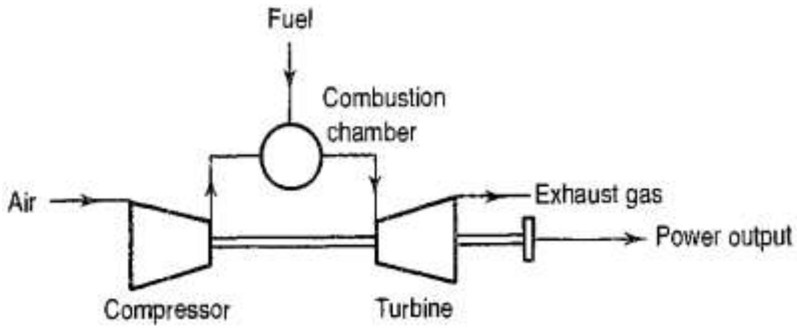

Figure 1.3 Schematic of a simple gas turbine cycle

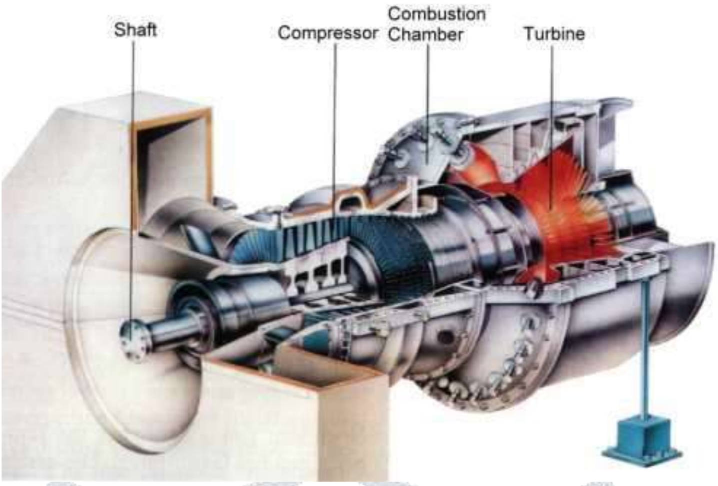

Figure 1.4 Gas turbine internal components

2. ADVANCED MATERIALS USED FOR DIFFERENT COMPONENTS OF GAS TURBINE

Shailendra Kumar Bohidar, Ravi Dewangan, Prof.Kalpit Kaurase [2] focused on the Study of various materials for their applicability for different components of gas turbine for increasing the performance, reliability and emissions in gas turbines. They present a critical review of the existing literature of gas turbine materials.

Design of Turbo machinery is complex and efficiency is directly related to material performance, material selection is of prime importance. Temperature limitations are the most crucial limiting factors to gas turbine efficiencies. The problems at various components are of different magnitudes. As a result, the materials selection for individual components is based on varying criteria in gas turbines. Also materials and alloys for high temperatures application are very costly. They will focus light on above issues and each plays an important role within the Gas Turbine Material literature and ultimately influences on planning and development practices.

2.1 Material used in Gas Turbine Blades

Turbine Blades are subjected to significant rotational and gas bending stresses at extremely high temperature, as well as severe thermo mechanical loading cycles as a consequence of normal start-up and shutdown operation and unexpected trips. The most difficult and challenging point is the one located at the turbine inlet, because, there are several difficulties associated to it like, Extreme temperature (14000C-15000C),high pressure, high rotational speed,vibration,small circulation area and so on. These effects produced in the blades are shown on the table2.1.

Table 2.1 Severity of the different surface-related problems for gas turbine applications

(Effects)→ (Applications)↓	**Oxidation**	**Hot corrosion**	**Interdiffusion**	**Thermal Fatigue**
Aircraft	Severe	Moderate	Severe	Severe
Land-based Power Generator	Moderate	Severe	Moderate	Light
Marine Engines	Moderate	Severe	Light	Moderate

In order to overcome those barriers, gas turbine blades are made using advanced materials and modern alloys (super alloys) that contains up to ten significant alloying elements, but its microstructure is very simple; consisted of rectangular blocks of stone stacked in a regular array with narrow bands of cement to hold them together. This material(cement) has been changed because in the past, intermetallic form of titanium was used in it, but now a days, it has been replaced by titanium[2].The change gave improved high temperature strength and also improved oxidation resistance.

2.2 Material used in Turbine Wheels:

The main functions of a turbine disc are to locate the rotor blades within the hot gas path and to transmit the power generated to the drive shaft. To avoid excessive wear, vibration and poor efficiency this must be achieved with great accuracy, whilst withstanding the thermal, vibrational and centrifugal stresses imposed during operation, as well as

Axial loadings arising from the blade set. Creep and low cycle fatigue resistance are the principal properties controlling turbine disc life and to meet the operational parameters requires high integrity advanced materials having a balance of key properties:

Various alloys used for turbine wheel with their short description are as follows:

- **Alloy 718 Nickel-Based Alloy**: This alloy has been used for wheels in aircraft turbines for more than 20 years. Alloys 718 contains a high concentrations of alloying elements and is therefore difficult to produce very large ingot sizes needed for the large frame type turbine wheel and spacer forgings.
- **Alloy 706 Nickel-based Alloy:** It offers a very significant increase in stress rupture and tensile yield strength compared to the other wheel alloys. This alloy is similar to Alloy 718, but contains somewhat lower concentrations of alloying elements, and is therefore easier to produce in the very large ingots sizes needed for the large frame type gas turbines.
- **Cr-Mo-V Alloy:** Turbine wheels and spacers having single shaft heavy duty gas turbines are made of Cr-1%, Mo-1.25%, and V-0.25% steel. This alloy is used in the quenched and tempered condition to enhance bore toughness. Stress rupture strength of the periphery is controlled by providing extra stock at the periphery to produce a slower cooling rate during quenching.
- **12Cr Alloys:** This family of alloys has a combination of properties that makes it especially valuable for turbine wheels. These properties include good ductility at high strength levels, uniform properties throughout thick sections and favorable strength at temperatures up to about 9000F (4820C) . Alloy M-152 is a 2-3% nickel containing member of the 12Cr family of alloys. It features outstanding fracture toughness in addition to the properties common to other 12Cr alloys. Alloys M-152 is intermediate in rupture strength, between Cr-Mo-Vo and A286 alloy and has higher tensile strength than either one.
- **A286 Alloy:** A286 is an austenitic iron base alloy that has been used for years in aircraft engine applications. Its use for industrial gas turbines started about 1965 era, when technological advances made the production of sound ingots sufficient in size to produce these wheels possible.

2.3 Coating Materials used in Gas Turbine:

The main requirements of a coating are to protect blades against oxidation, corrosion and cracking problems. Coatings are there to prevent the base metal from attack. Other benefits of coatings include thermal fatigue from cyclic operation, surface smoothness and erosion in compressor coatings and heat flux loading when one is considering thermal barriers.

The main types of protective coatings used for gas turbine components can be defined as follows:

- **Diffusion Coatings:** Formed by the surface enrichment of an alloy with aluminum (aluminides), chromium (chromised) or silicon (siliconised). In some systems combinations of these elements are possible i.e. chrome-aluminised or silicon-aluminised.
- **Overlay Coatings:** Formed by applying a layer to the component surface. This type forms the bulk of the coatings used in gas turbine engines. They are applied by a variety of methods including thermal and slurry spraying, physical vapour deposition and welding. Examples include: Simple paints, corrosion resistant coatings such as MCrAlY (where M is the base metal, normally Ni or Co or a combination of the two; Cr is chromium, Al is aluminium and Y is yttrium). Thermal barrier coating based on a ceramic topcoat, usually partially stabilized cubic Zirconia, attached to the metal substrate by means of an oxidation resistant bond coat (typically a MCrAlY or a diffusion aluminide coating)).

They concluded that the Current trends such as increasing severity of process gasses and increasing material cost make it fairly clear that material advancement will become much more prevalent in the turbo machinery industry in the future.

3. ADVANCES IN GAS TURBINE BLADE COOLING TECHNOLOGY

R.S.Amano [3] summarizes the most advanced cooling technologies that are currently used in USA and EUROPE for the power generation systems as well as aerospace projects. Author presents a background of the gas turbine blade cooling technologies along with numerical methodologies and physical models that are most commonly used in the computations of blade flows in gas turbine blades. In addition some advancement in the cooling technologies is also discussed.

Cooling technology, as applied to gas turbine components is composed of five main elements, (1) internal convective cooling, (2) external surface film cooling, (3) materials selection, (4) thermal-mechanical design, and (5) selection and/or conditioning of the coolant fluid. Cooled turbine components are merely highly specialized and complex heat exchangers that release the cold side fluid in a controlled fashion to maximize work extraction. The enhancement of internal convective flow surfaces for the augmentation of heat transfer was initially improved some 25 to 30 years ago through the introduction of rib-roughness or tabulators, and also pin-banks or pin-fins.

Figure 3.1 shows an example schematic of a blade cooling circuit that utilizes many tabulated passages, a pin bank in the trailing edge, and impingement in the leading edge (coolant is released via film holes, tip holes, and trailing edge). These surface enhancement methods continue to play a large role in today’s turbine cooling designs. Film cooling is the practice of bleeding internal cooling flows onto the exterior skin of the components to provide a heat flux reducing cooling layer, as shown by the many holes placed over the airfoil in Figure 3.1. Film cooling is intimately tied to the internal cooling technique used in that the local internal flow details will influence the flow characteristics of the film jets injected on the surface.

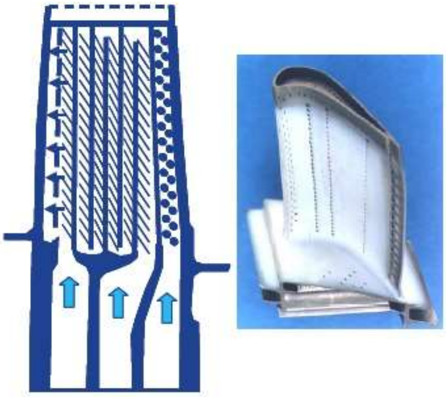

Figure 3.1 Example cooled turbine blade and cooling circuit.

At last author had concluded that there are no simple solutions for better thermal technologies. It is hoped that his summary will aid in focusing attention in the critical areas of heat transfer and thermal management for gas turbine hot sections required to make significant new gains in overall efficiency, operability, and durability.

4. KEY TECHNOLOGIES FOR 1700°C CLASS ULTRA HIGH TEMPERATURE GAS TURBINE

Koichiishizaka, Keijioro Saitoh, Eisakuito, Masanori Yuri, Junichiro Masada [4] describes part of the high-efficiency gas turbine technology demonstration project (the development of ultra-high efficiency 1700°C-class gas turbines) which is under implementation as a project subsidized by New Energy and Industrial Technology Development Organization (NEDO) and they were developing technologies to be applied to the actual equipment toward the development and demonstration of key technologies required for actual use.

4.1 Development of boundary layer controlled high-performance compressor

To improve the cycle efficiency by increasing the turbine inlet temperature, the compressor is required to have a larger pressure ratio than the current one. To achieve an increase in the pressure ratio with the number of stages and an axial length equivalent to those of the conventional compressor, a higher aerodynamic loading needs to be applied to the compressor blade rows, which may cause a reduction of the efficiency, surge margin and stability at gas turbine start up.

Therefore, a highly accurate numerical flow simulation method with the actual geometry being modeled in detail was developed, and they had been studying the clarification of the mechanism to increase the growth of the boundary layer associated with the increase in pressure ratio, as well as an improved design for controlling the boundary layer.

Figure 4.1 shows the verification results of the compressor instability (surge) point under the low-cycle condition, using test equipment that is a scale model of the front 8 stages of the compressor. It demonstrated that through a change of the blade shape, the target flow rate was satisfied as expected.

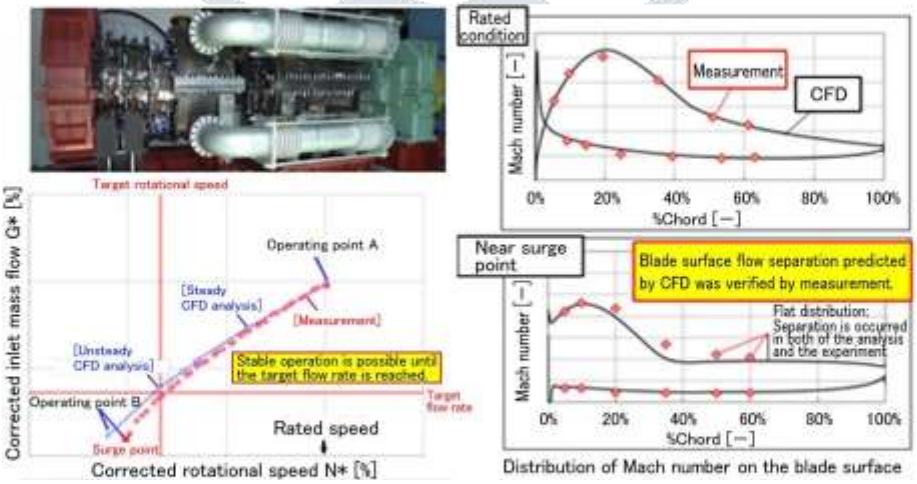

Figure 4.1 Verification of 8-stage compressor surge test and simulation

4.2 Development of high-performance cooling system

A turbine blade leading edge has a cooling structure called a showerhead film hole, and a relatively large amount of cooling airflow is used. Therefore, it is expected that there is room for the reduction of airflow. By measuring the local cooling efficiency at this point, a more appropriate cooling system can be adopted depending on the cooling structure, resulting in the reduction of the cooling airflow and the improvement of performance.

As such, using a test rig that simulates the combustor and a single-stage stationary blade of an actual gas turbine (Figure 4.2), they obtained the efficiency distribution of the film around the stationary blade leading edge (Figure 4.3).

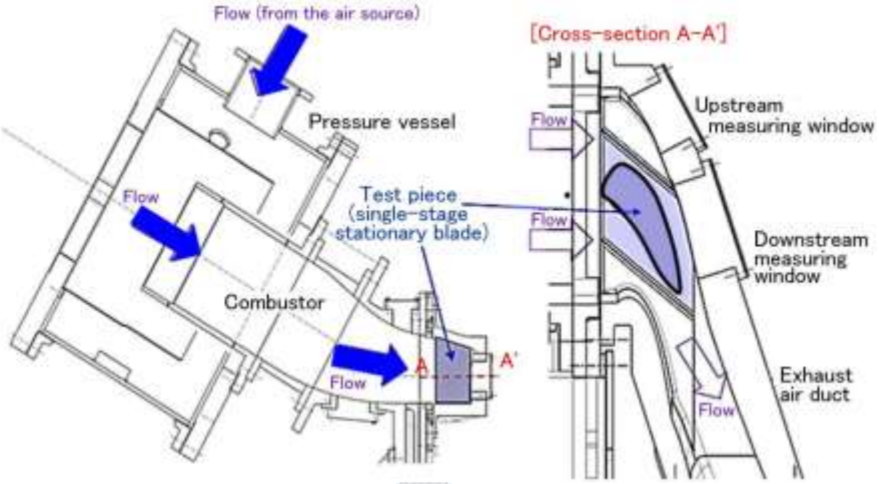

Figure 4.2 Schematic diagram of the device

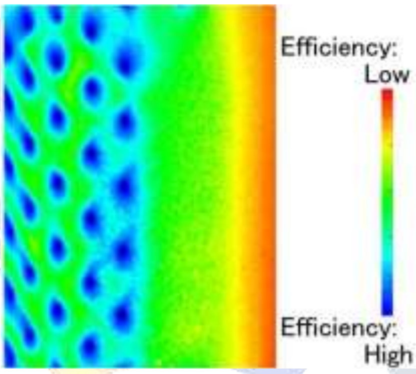

Figure 4.3 Test results (Film efficiency distribution)

4.3 Development of advanced thermal barrier coating

Toward the development of 1700°C-class gas turbines, we have consistently conducted material development, the optimization of thermal spraying process parameters, the development of a program for application to actual blades, and verification with an actual unit, and have also developed an advanced thermal barrier coating (hereinafter referred to as TBC) and implemented a further improvement in performance.

For that they conducted a computational study of candidate materials with low-thermal conductivity and superior high-temperature stability and tried to manufacture the sintered bodies with the compositions of the candidate materials and evaluated them.

As a result, materials with low-thermal conductivity and superior high-temperature stability were extracted as shown in figure 4.4.

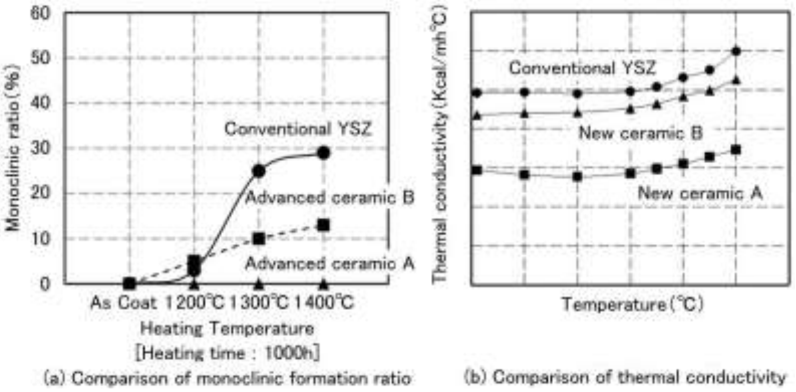

Figure 4.4 Measurement results of high-temperature stability and thermal conductivity of the topcoat materials (sintered bodies)

5. High-efficiency Gas Turbine Development applying 1600°C class "J" Technology

Satoshi Hada, Kazumasa Takata, Yosifumi Ivasaki, Masonori Yuri, Junichiro Masada [5] have developed the M501J capable of achieving the world's first turbine inlet temperature of 1,600°C and even a thermal efficiency in gas turbine combined cycle (GTCC) of 61.5% or more, using developments attained in the national "1,700°C-Class Ultrahigh-Temperature Gas Turbine Component Technology Development" project.

5.1 Development of M501J gas turbine

The M501J has made a turbine inlet temperature of 1,600°C achievable not only through the compilation of all component technologies already demonstrated in the F Series with a turbine inlet temperature of a 1,400°C class, as well as the G and H Series in the same 1,500°C class, all having abundant operational achievements, but also through the application of the most advanced 1,700°C-class technology developments attained in the national project. The higher turbine inlet temperature achieved and the state-of-the-art element technologies adopted bring much higher GTCC power-generating gross thermal efficiency than that of existing equipment. Moreover, if the conventional coal-fired thermal power plant is replaced with a natural gas firing J-series combined cycle counterpart, CO2 emissions can be reduced by about 60 percent. Figure 5.1 shows the technological characteristics of the M501J.

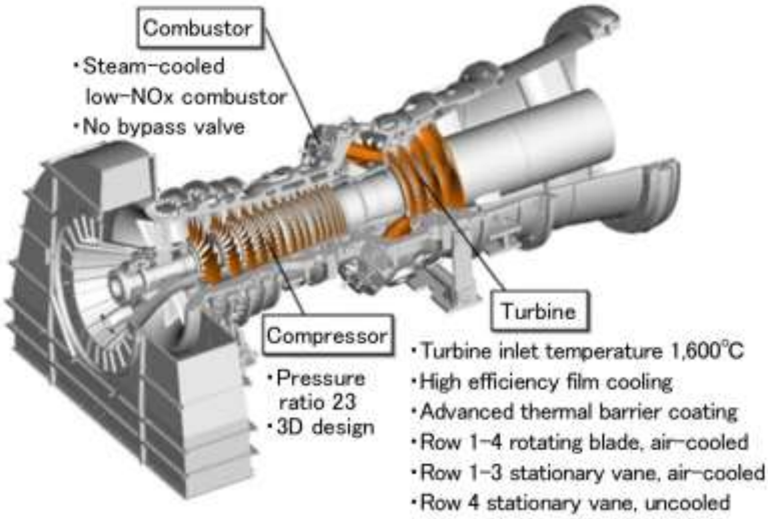

Figure 5.1 Characteristics of M501J gas turbine

5.2 Verification at in-house demonstration plant "T point"

In the development of the M501J, each component was verified at the basic design stage and test results were reflected in detailed design for final verification using actual power generation for the demonstration and subsequent production of commercial units.

In the analysis of the M501J's development design and verification results as well, these design tools are used effectively and the results of utilization are also reflected in the development of the high-efficiency gas turbines introduced in this paper, thus greatly contributing to the improvement of performance and reliability. . Figure 5.2 and. Figure 5.3 shows the analytical results of the compressor's all-stage CFD, indicating such results have a good grasp of what actual equipment is like.

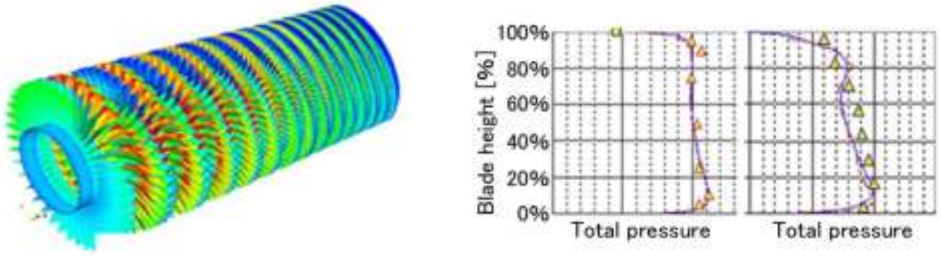

Figure 5.2 Actual compressor's all-stage CFD analysis and total pressure distribution
(Left: 5-stage stationary vane inlet, right: diffuser inlet)

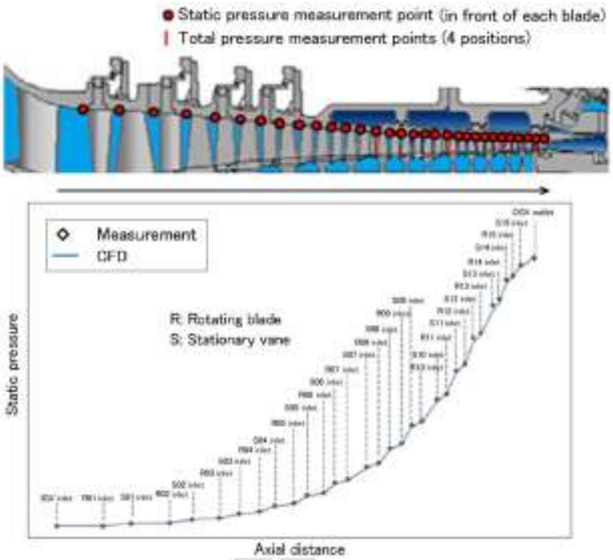

Figure 5.3 Actual compressor's all-stage casing surface pressure distribution (measurements vs. CFD)

6. NEW COMBUSTION TECHNOLOGIES IN MODERN GAS TURBINES

M. Khosravy el_Hossaini [6] gives review of technologies for reducing NOx emissions as well as increasing thermal efficiency and improving combustion stability has been reported.

Next-generation gas turbines will operate at higher pressure ratios and hotter turbine inlet temperatures conditions that will tend to increase nitrogen oxide emissions. To conform to future air quality requirements, lower-emitting combustion technology will be required. Author reviewed in this section a number of new combustion systems have been introduced where some of them could be found in the market, and the others are under development.

6.1. Trapped vortex combustion (TVC)

The trapped vortex combustion concept has been under investigation since the early 1990's. The trapped vortex combustor (TVC) may be considered as a promising technology for both pollutant emissions and pressure drop reduction. TVC is based on mixing hot combustion products and reactants at a high rate by a cavity stabilization concept as shown in figure 6.1.

Flame stability is achieved through the use of recirculation zones to provide a continuous ignition source which facilitates the mixing of hot combustion products with the incoming fuel and air mixture. Turbulence occurring in a TVC combustion chamber is "trapped" within a cavity where reactants are injected and efficiently mixed. Since part of the combustion occurs within the recirculation zone, a "typically" flameless regime can be achieved, while a trapped turbulent vortex may provide significant pressure drop reduction. Besides this, TVC is having the capability of operating as a staged combustor if the fuel is injected into both the cavities and the main airflow.

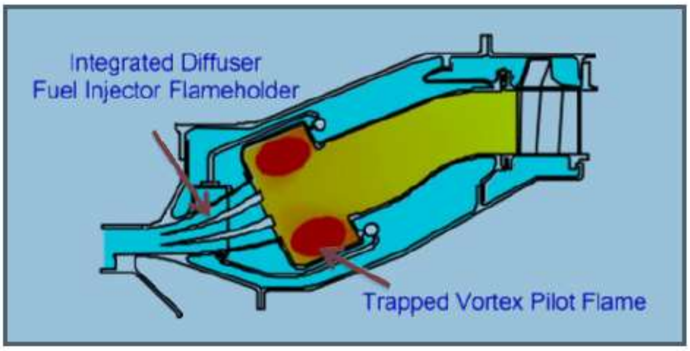

Figure 6.1 Trapped vortex combustor schematic.

An experiment in NASA with water injected TVC demonstrated a reduction in NOx by a factor three in a natural gas fueled and up to two in a liquid JP-8 fueled over a range in water/ fuel and fuel/air ratios.

6.2. Rich burn, quick- mix, lean burn (RQL)

The concept of RQL was proposed in 1980 as a significant effort for reducing NOx emission. Lean direct injection (LDI) and rich-burn/quick-quench/lean-burn (RQL) are two of the prominent low-emissions concepts for gas turbines.

LDI operates the primary combustion region lean, hence, adequate flame stabilization has to be ensured; RQL is rich in the primary zone with a transition to lean combustion by rapid mixing with secondary air downstream. Hence, both concepts avoid stoichiometric combustion as much as possible, but flame stabilization and combustion in the main heat release region are entirely different. Relative to aviation engines, the need for reliability and safety has led to a focus on LDI of liquid fuels

[7]. However, RQL combustor technology is of growing interest for stationary gas turbines due to the attributes of more effectively processing of fuels with complex composition.

It is known that the primary zone of a gas turbine combustor operates most effectively with rich mixture ratios so, a "rich-burn" condition in the primary zone enhances the stability of the combustion reaction by producing and sustaining a high concentration of energetic hydrogen and hydrocarbon radical species. Secondly, rich burn conditions minimize the production of nitrogen oxides due to the relative low temperatures and low population of oxygen containing intermediate species. Critical factors of a RQL that need to be considered are careful tailoring of rich and lean equivalence ratios and very fast cooling rates. So the combustion regime shifts rapidly from rich to lean without going through the high NOx route as shown in figure 6.2.

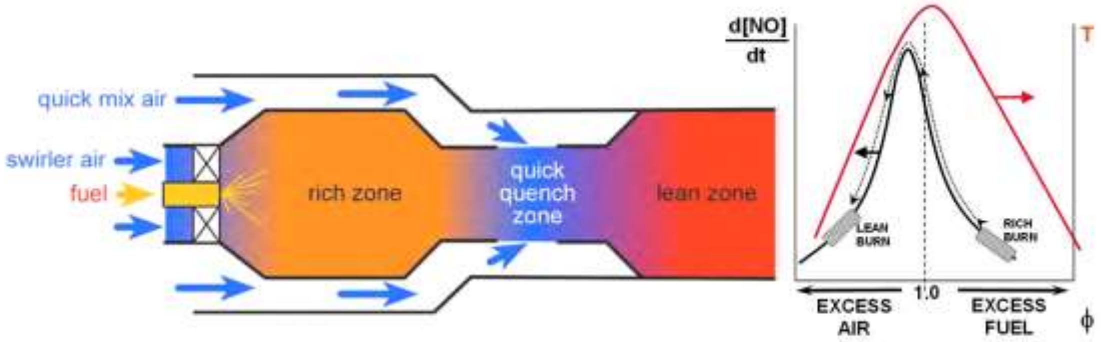

Figure 6.2 Rich-Burn, Quick-Mix, Lean-Burn combustor.

The drawback of this technology is increased hardware and complexity of the system.

6.3. Staged air combustion

The COSTAIR4 combustion concept uses continuously staged air and internal recirculation within the combustion chamber to obtain a stable combustion with low NOX and CO emissions. Research work on staged combustors started in the early 1970s under of the Energy Efficient Engine (E3) Program in the USA [8] and now widely used in industrial engines burning gaseous fuels, in both axial and radial configurations.

The principle of staged air combustion is illustrated in Figure 6.3. It consists of a coaxial tube; the combustion air flows through the inner tube and the fuel through the outer cylinder ring. The combustion air is continually distributed throughout the combustion chamber by an air distributor with numerous openings on its contour, and fuel enters by several jets arranged around the air distributor.

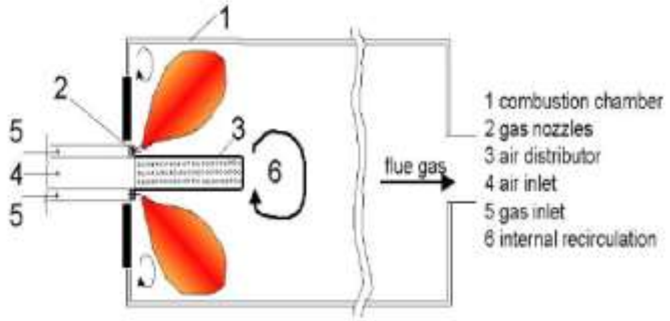

Figure 6.3 staged air combustion

6. CONCLUSION

This summary will aid in focusing attention in the critical areas of heat transfer and thermal management for gas turbine hot sections required to make significant new gains in overall efficiency, operability, and durability.

REFERENCES

[1] Gas Turbine by Yousef Almarzooq Pages 3-7.

[2] Shailendra Kumar Bohidar, Ravi Dewangan, Prof.Kalpit Kaurase International Journal of scientific research and management (IJSRM) ||Volume||1||Issue||7 ||Pages|| 366-370||2013||

[3] R. S. Amano, Advances in gas turbine blade cooling technology, Pages 1-4.

[4] Koichiishizaka, Keijioro Saitoh, Eisakuito, Masanori Yuri, Junichiro Masada, Mitsubishi Heavy Industries Technical Review Vol. 54 No. 3 (September 2017),pages 23-24,28-29.

[5] Satoshi Hada,Kazumasa Takata,Yosifumi Ivasaki,Masonori Yuri,Junichiro Masada Mitsubishi Heavy Industries Technical Review Vol. 52 No. 2 (June 2015),Pages pages 2-6.

[6] M. Khosravy el_Hossaini, Review of the New Combustion Technologies in Modern Gas Turbines, pages 151-156

[7] Dunn-Rankin D (2008) Lean Combustion: Technology and Control, Academic Press, USA.

[8] Wulff A and Hourmouziadis J (1997) Technology Review of Aeroengine Pollutant Emissions. Aerospace Science and Technology. 1: 557-572.