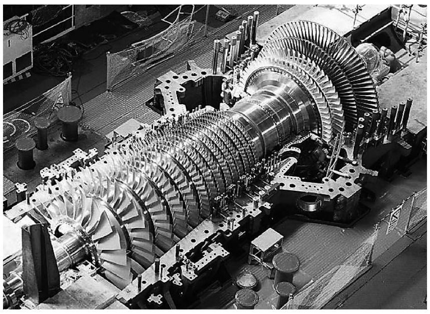

Large Frame Gas Turbines, The Leading Technology of Power Generation Industries

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In developing large-capacity gas turbines for use in power generation as the main machines in combined cycle power plants, MHI has made every effort to increase thermal efficiency. Since the 1980s when the commercial operation of power generation plants with a combustion temperature of 1100 deg.C began, the combustion temperatures have been increasing at a rate of approximately 20 deg.C per year. The maximum combustion temperature currently reaches about 1500 deg.C. However, temperature increases beyond that temperature come up against a number of technical problems including reducing NOx emissions and the need to increase the strength of materials and, accordingly, the gradient of temperature rise tends to decrease. On the other hand, the period of high growth in which a specified increase in demand for power could be expected has come to an end for gas turbines, which have been increasing in capacity with a rise in temperature, and now it is a time in which new products must be created that are capable of coping with dramatically varying social and economic conditions. In addition, global environmental problems are becoming greater, and from the viewpoint of the utilization of limited fossil fuels and reducing the amount of CO_2 emissions, it is indispensable to develop more highly efficient power generation plants. This paper takes a brief look at future directions in the development of large-capacity gas turbines.

1. Introduction

Since their adoption as the main power generating machines of Japanese thermal power plants at the beginning of the 1980s, large commercial gas turbines operating on natural gas as a main fuel have contributed significantly to an increase in thermal efficiency and reducing contamination by exhaust emissions. The maximum turbine inlet temperature (combustor outlet temperature) at present is 1500 deg.C, and the overall thermal efficiency has reached almost 60% on a lower calorific value basis (LHV). The past twenty years were an era in which the efficiency of combined power generating plants had been increased through increases in the temperature and efficiency of gas turbines.

Since the amount of air required for a lean-premixed combustion at 1500 deg.C nears the amount of air that is usable for combustion, any increases in efficiency by further rises in temperature tends to be slowed down at present due to an increase in the amount of cooling air necessary to maintain safe operation, even if the most advanced material with high thermal strength are used.

In this paper, the future direction in the large-capacity gas turbines is described from the four viewpoints of an increase in cycle maximum temperature, diversification of fuels, intermediate capacity peak power generation, and challenges to new cycles.

2. Increase in maximum cycle temperature

According to the second law of thermodynamics, when the maximum temperature of a thermal cycle is raised, the efficiency of recovery energy conversion is increased. It is an ideal combination in which the power of high temperature heat energy at 1100 deg.C or higher is recovered by the gas turbine, while the power from low temperature heat energy at 600 deg.C or less is recovered by the steam turbine. By using what are commonly referred to as heat cascades in the combination of two temperature ranges, thermal efficiency can be increased more in combined cycles than in simple cycles.

2.1 Steam cooling technology

Mitsubishi Heavy Industries, Ltd. (MHI) has developed a variety of advanced technologies aimed at increasing peak temperatures of cycle. One of these technologies consists of cooling the high temperature parts of a gas turbine by using steam cycle. As shown in **Fig. 1**, the gas temperature at the outlet of a combustor (inlet of 1st vane) and the temperature on the downstream side of the outlet can be increased by adopting this system for cooling the combustor.

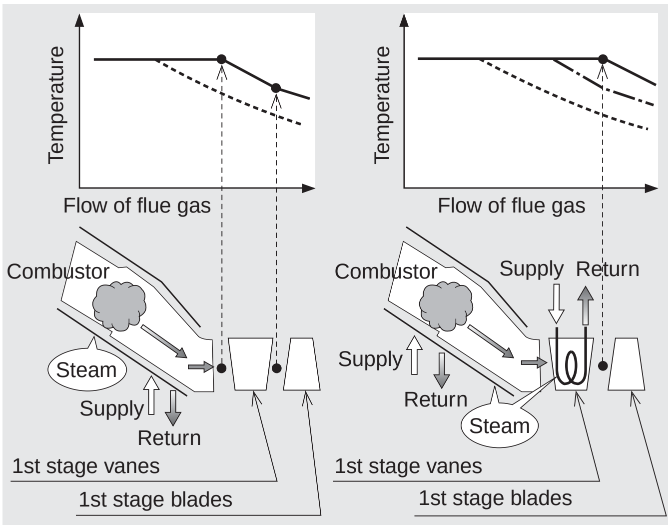

Fig. 1 Steam cooled combustor system

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In addition, by cooling steam at the 1st vane, the inlet gas temperature of the 1st blade can be further increased for recovering power. By using the cooling effect of steam having a large specific heat, the mixing of cooling air into the main gas flow can be reduced and the maximum cycle temperature can be increased through the use of conventional materials.

As shown in **Fig. 2**, since 1997 eighteen G-series gas turbines started operation in the verification power plant of MHI Takasago Machinery Works in which cooling steam is adopted in the combustor. Since then, these turbines have been commercially operated in the world. Their cumulative operating time currently exceeds 190 000 hours. Their operation has continued satisfactorily with high reliability through an improved design that makes use of MHI's extensive experience in the verification power generation facility.

Through the adoption of steam cooling, the tip clearance of the turbine blades can be controlled by the active use of the steam heat transfer, as shown in **Fig. 3**. In this technology, the tip clearance is increased at the time of start up of the gas turbine by allowing steam to flow into the turbine blade ring cooling passage leading to the combustor to heat the turbine casing. The tip clearance is minimized by cooling the casing at the time of rated load operation. This technology has been adopted in the G-series gas turbines.

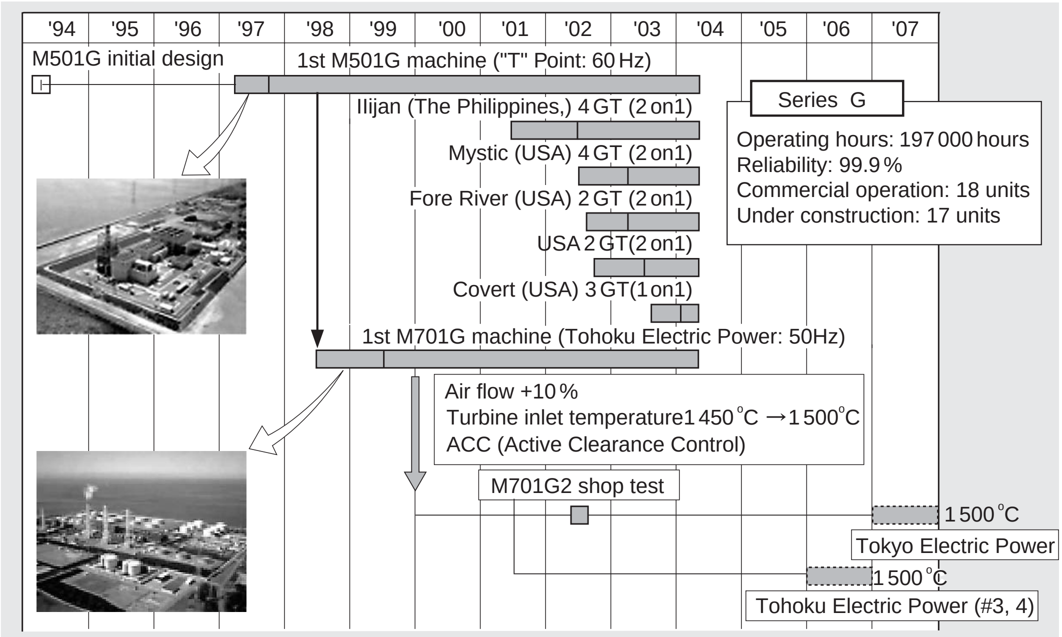

Fig. 2 Operating experience of G-series gas turbines

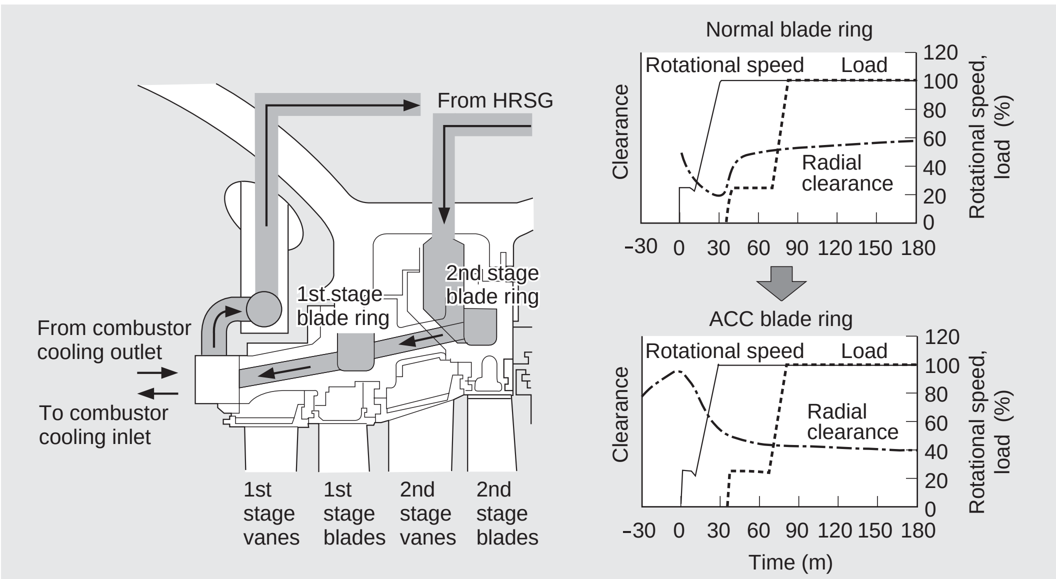

Fig. 3 Blade tip active clearance control (ACC)

2.2 Challenge to technology for further increasing temperature

As shown in **Fig. 4**, MHI is working to develop systems capable of combustion temperatures of 1 700 deg.C and a combined cycle thermal efficiency of 62 to 65% (LHV) as the next standard values. To achieve this goal, technological breakthroughs based on new concepts that differ from simply extending conventional technologies are required in the form of new materials, cooling technologies, aerodynamic technologies, and low NOx combustion technologies. MHI is now making every effort achieve this goal.

3. Diversification of fuels

Fuels commonly used in gas turbines are shown in **Fig. 5**. Gas turbine fuels other than natural gas used in the past include excess refinery gas and gas from ironworks blast furnaces. In the future, the use of excess gas is expected to expand for the effective use of various energies. Approximately 40% of coal imported into Japan including that used for manufacturing coke is consumed in ironworks. The amount of CO_2 generated per heating value of coal is about 1.5 times that of natural gas, and an increase in energy efficiency in ironworks would contribute significantly to reducing CO_2 exhaust.

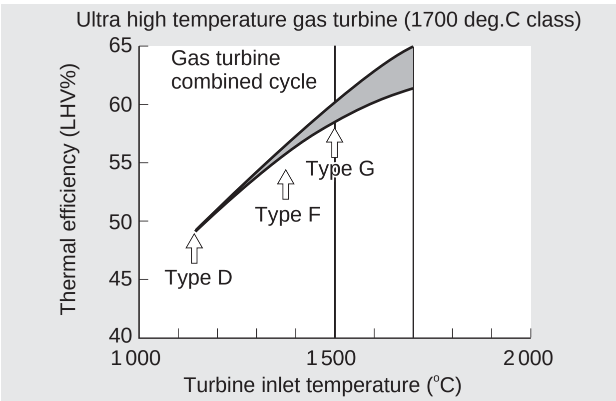

Fig. 4 Technical challenges to higher combustion temperature

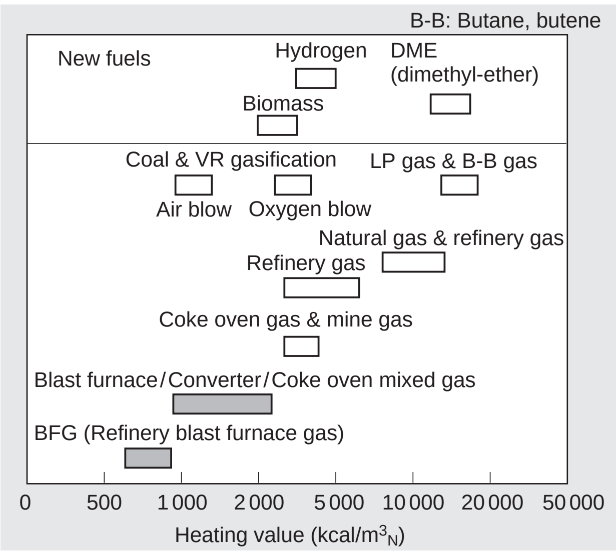

Fig. 5 Diversification of gas turbines fuels

MHI has put into practical use furnace gas-fired combined plants with combustion temperatures ranging from 1 100 to 1 250 deg.C. As shown in **Fig. 6**, MHI has also put into practical use the world's largest 1 300 deg.C class furnace gas-fired combined plant, which began commercial operation in July 2004. Until now, the amount of CO_2 exhaust from the plant could be reduced by approximately 25% compared with the conventional boiler firing plant. Overseas, the consumption of energy per unit iron manufactured in the ironworks of China is said to be approximately 150% that consumed in ironworks in Japan. Since energy-savings in the ironworks of China is important to protecting the global environment, MHI is actively making efforts towards this end.

In addition, work on a coal gasification combined plant which is currently under development as a national project will be started this fall and its operation is scheduled to begin in 2007.

In the future, from the viewpoint of energy security in Japan and reducing CO_2 emissions, demand by society for the effective use of limited fossil fuels is expected to increase more and more, and demand for highly efficient power generation using various alternative fuels is expected to increase. In addition to conventional fuels, there are fuel gases that are generated from natural waste such as biomass gas, and low pollution liquid fuels such as DME (dimethyl ether) as well as GTL (Gas-to-Liquid) that is artificially manufactured from natural fossil fuels. These fuels are expected to be used in the future. MHI has also been active in performing combustion tests of DME in the national project to verify the practicality of such fuels.

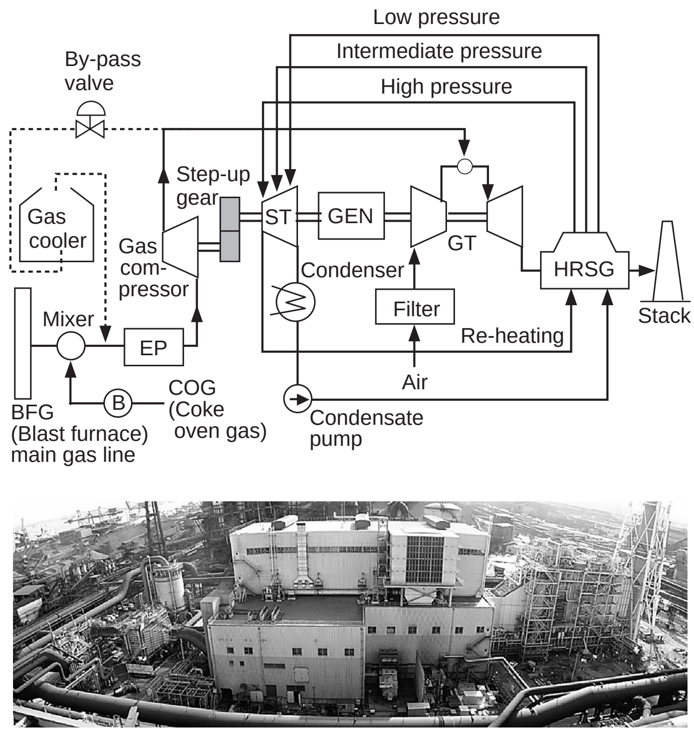

Fig. 6 Blast furnace gas-fired combined cycle

4. Middle range capacity peak power generation

The capacity of single large gas turbines has increased due to increases in combustion temperature. At present, MHI's maximum capacity reaches 330 MW for the M701G2 turbine, while single-shaft combined power generation now reaches 500 MW. On the other hand, there must be sufficient demand for 500 MW turbine power generation plants in order for such plant to continue to be commercially viable in the long term.

Though a variety of large new power sources had been planned during the era when demand for power increased due to sustained economic growth, in the present rapidly varying situation in which economic growth has slowed and various social circumstances affect the peak demand for power, a middle range capacity thermal power station capable of being constructed in a shorter period than a large capacity machine is needed.

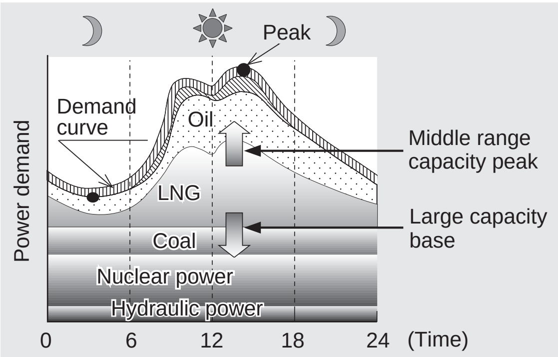

Fig. 7 Power demand during a day

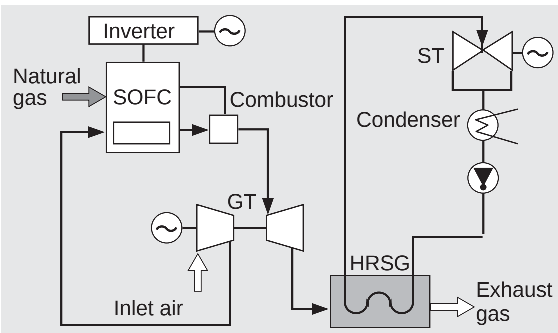

Fig. 8 SOFC + GT combined system

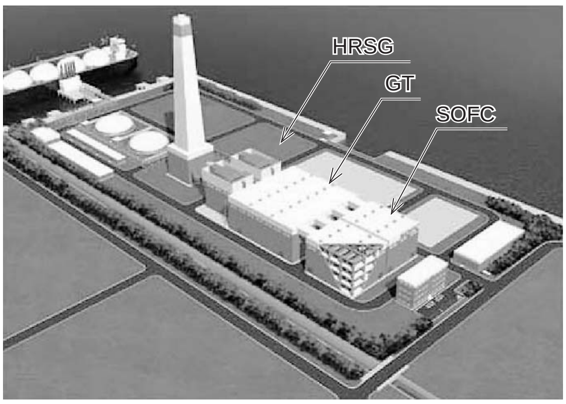

Fig. 9 Layout of SOFC + GT combined plant

In addition, as shown in **Fig. 7**, differences in the demand for power between day and night tend to increase more and more with the propagation of air conditioners mainly in advanced countries. As a result, the expectations of gas turbine combined plants, which play important role in controllable thermal power plants, are becoming greater. From these points of view, intermediate capacity, high efficiency power generation plants with rather low utilization factor of approximately 40% will be in demand in the future. It is expected that future combined gas turbines will diverged into base load operating systems that place emphasis on efficiency and middle range capacity machines with high efficiency, minimized initial costs, and high operating maneuverability.

5. Challenge to new cycles

As mentioned earlier, although an increase in combustion temperature leads to a rise in overall thermal efficiency, the completely effective use of heat energy with a maximum combustion temperature of approximately 2 000 to 2 500 deg.C which can be achieved by fossil fuels involves many technological problems that must be solved, even if advanced gas turbine technologies are developed further.

To solve this problem, MHI has been examining the prospects of combining present gas turbines with other cycles with the aim of realizing further increases in thermal efficiency, in addition to rises in the combustion temperature of gas turbines. The combination of gas turbines with fuel batteries as shown in **Fig. 8** uses the fuel remaining after fuel is chemically converted into electricity in a gas turbine combined cycle to increase overall thermal efficiency. **Figure 9** shows a birds-eye view of a 300 MW class combined plant.

In addition, as shown in **Fig. 10**, examinations were carried on a national level into a CO_2 closed cycle in which air is not used as a dilution medium for combustion and flue gas is re-circulated and NOx is not emitted as exhaust.

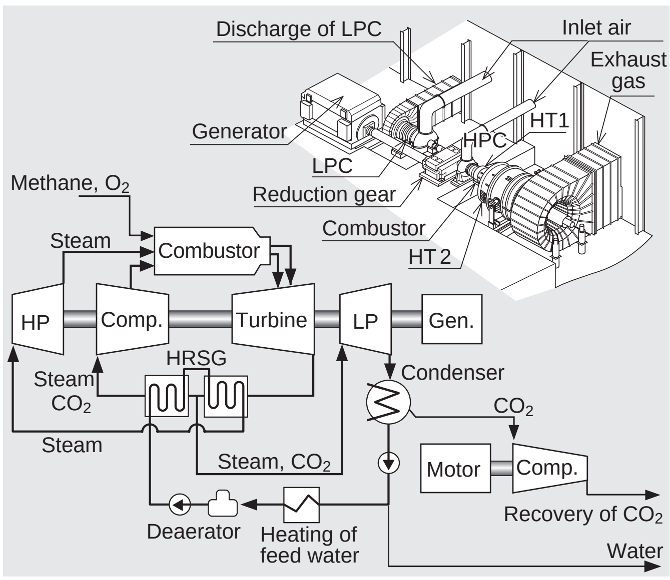

Fig. 10 CO_2 closed cycle

To improve efficiency and environmental protection, new thermal cycles were actively studied, and the multiplication and complexity of cycles were advanced. It is expected that gas turbines that efficiently convert thermal energy of 1 100 deg.C or higher into electric power will to lead more advanced technologies that will serve as core technologies in thermal power generation plants in the future.

6. Conclusion

In this paper, the two points concerning the diversification of fuels and intermediate capacity peak power generation were cited as near future trends, while the two points concerning further increases in the combustion temperature of gas turbines and challenges to new cycles were cited as mid- and long-term trends.

As can be seen in **Fig. 11**, in recovering energy obtained from fossil fuels, it is important to efficiently convert the thermal energy of the fossil fuels with a maximum combustion temperature of 2 000 to 2 500 deg.C to electric power through cascades achieved by combining cycles.

The means for accomplishing this goal include the following efforts: (1) to increase the maximum temperature of the present 1 500 deg.C gas turbines, (2) to achieve a new cycle to recover thermal energy at the 2 000 deg.C level by other methods, and (3) to develop a combined cycle to recover thermal energy without combustion (like fuel battery system).

In the future, MHI will make every effort to realize commercialization of these approaches and systems. In any event, gas turbines are very effective machines for efficiently converting temperature levels from 1 100 to 1 500 deg.C on a large scale, and it can safely be said that, in the examination of various cycles, gas turbines will play an important role as an effective means of converting combustion energy in the future.

The cost of power generation plants is expected to increase as cycles multiply in number and increase in complexity. On the other hand, problems concerning the global environment are becoming ever more serious, and an increase in thermal efficiency will become an important challenge as fossil fuel resources are used up. It can be expected that, if a scheme for compensating additional costs can be established through new business opportunities such as CO_2 ECO Right, problems associated with increased costs due to the increased complexity of cycles can be solved and the advancement of power generation plants can be accelerated.

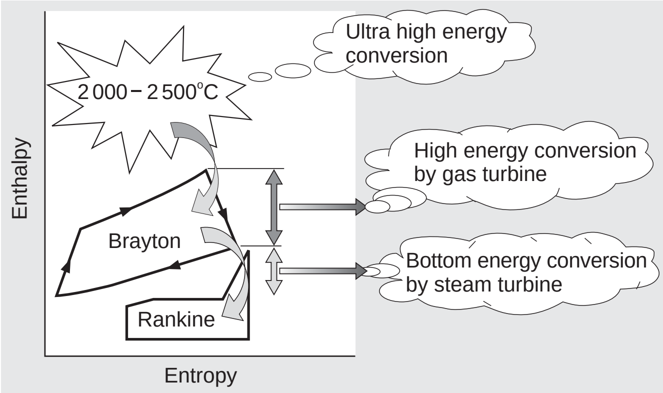

Fig. 11 Use of heat cascades

To meet the needs of society in the future, MHI will continuously strive to develop gas turbines as main machines for leading the large-capacity power generation plant market by developing new materials, improving the elemental efficiencies of compressors and turbines, and by lowering contamination and pollution.

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