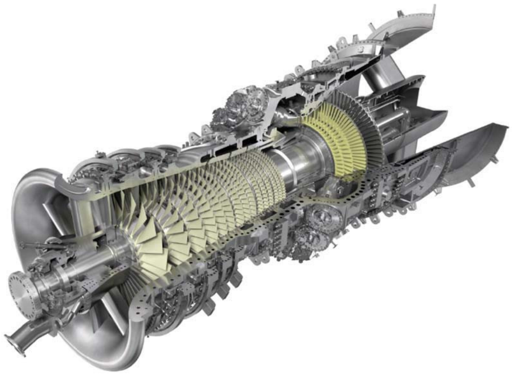
Operating Results of J-series Gas Turbine and Development of JAC



MASANORI YURI[*1] JUNICHIRO MASADA[*2]
SATOSHI HADA[*3] SUSUMU WAKAZONO[*4]

Mitsubishi Hitachi Power Systems, Ltd. (MHPS) has continued to contribute to the preservation of the global environment and the stable supply of energy through constant gas turbine development based on our abundant operating results, research and verification of state of the art technology. In recent years, using development results from the "1700°C Class Ultrahigh-Temperature Gas Turbine Component Technology Development" national project that we have participated in since 2004, MHPS has successfully developed the highly-efficient M501J, which achieved the world's first turbine inlet temperature of 1600°C, and started verifying operations using the verification facility in the MHPS Takasago Works in 2011. Thereafter, the M501J has been delivered all over the world, and has accumulated operating results. In addition, to further improve the efficiency of the gas turbine combined cycle power generation (GTCC) and enhance the operability, we replaced the steam-cooled system for the cooling of the combustor and developed a new enhanced air-cooled system. This paper presents the development and operational situation of the state-of-the-art, high-efficiency gas turbine of MHPS and the development of the next-generation 1650°C class JAC (J Air Cooled) gas turbine using an enhanced air-cooled system as the core technology based on the technology adopted for the M501J.

1. Introduction

For higher GTCC efficiency, a higher temperature of the gas turbine has played an important role, and MHPS developed the M701D, a 1150°C class, large-capacity gas turbine, in the 1980s. This was followed by the M501F, which had a turbine inlet temperature of 1350°C, and the M501G, which employs a steam-cooled combustor and has a turbine inlet temperature of 1500°C (**Figure 1**). Through these developments, we have demonstrated high plant thermal efficiency and reliability, as well as low emission. From 2004, we participated in the national project "1700°C class Ultrahigh-Temperature Gas Turbine Component Technology Development" to take on research and development of the latest technology necessary for higher temperature/efficiency and used the results of the development to develop the M501J, which achieved the world's first turbine inlet temperature of 1600°C. Verification operation of the M501J GTCC started in 2011 at the demonstrator (T-point) in the MHPS Takasago Works and operating results have steadily accumulated.

The J-series gas turbine adopts the steam-cooled system for cooling the combustor, but if an air-cooled system can be used while maintaining the high turbine inlet temperature, further improvement in the efficiency and operability of GTCC can be expected. Therefore, MHPS worked on the development of next-generation GTCC that realizes air cooling of high-temperature gas turbines, and devised the enhanced air-cooled system that is a core technology thereof. In the spring of 2015 we completed the verification test of the entire system at the gas turbine combined

*1 Deputy General Manager, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.
*2 Senior General Manager, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.
*3 Manager, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.
*4 Chief Staff Manager, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.

cycle power plant verification facility in the MHPS Takasago Works and since then we have been performing long-term operation. This paper presents the development and operational situation of MHPS's state-of-the-art high-efficiency gas turbine and the development of the next-generation 1650°C class JAC (J Air Cooled) gas turbine using the enhanced air-cooled system as its core technology.

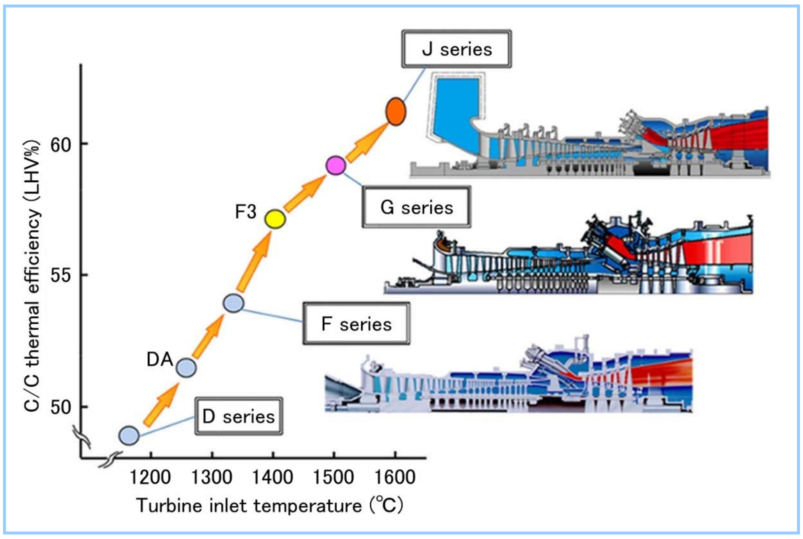


Figure 1 History of development of large gas turbine models

2. Development and results of M501J gas turbine

The M501J was able to achieve a turbine inlet temperature of 1600°C based on the component technologies already demonstrated by the abundantly-proven F-series gas turbine and G-/H-series gas turbines, with turbine inlet temperature classes of 1400°C and 1500°C, respectively, and the application of the development of the most advanced 1700°C class technology resulting from a national project. Due to the increase of the turbine inlet temperature and the adoption of the latest component technology, the GTCC power generation end thermal efficiency has greatly increased in comparison with existing equipment. CO_2 emissions can be reduced by about 60% when a conventional coal-fired thermal power plant is replaced with a natural gas-fired J-series gas turbine combined cycle power plant. **Figure 2** shows the technical features of the M501J.

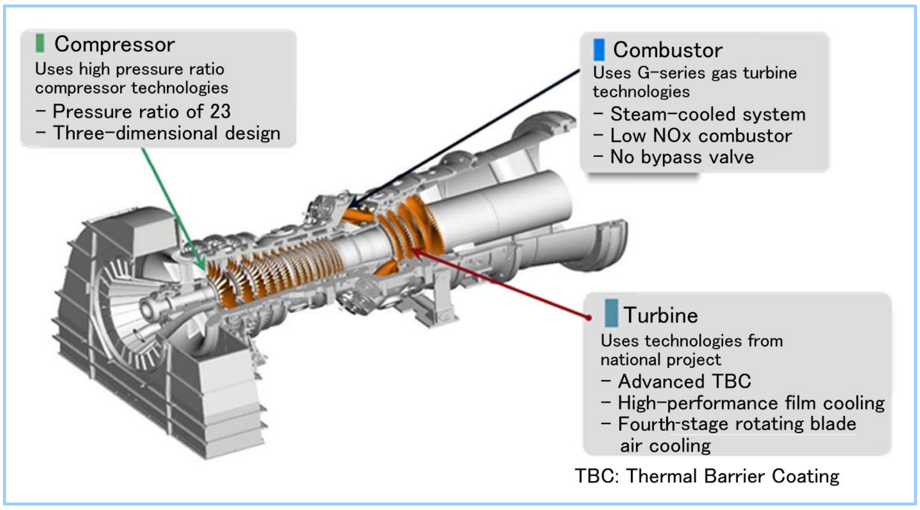


Figure 2 Technological characteristics of M501J gas turbine

The development of the M501J gas turbine was carried out by conducting verification tests of each element at the basic design stage, reflecting the results in the detailed design, and finally verifying the actual operation of the entire gas turbine in the verification power generation facility. **Figure 3** shows the appearance of the gas turbine combined cycle power plant demonstrator (T-point) in the MHPS Takasago Works. We carried out 2,300 special measurements on the first model of the M501J and verified that the performance, mechanical characteristics, and combustion characteristics satisfied the target values, before the shipping of the commercial product. We have received orders for 45 J-series gas turbines from domestic and overseas customers, and are shipping them as they become available. Up to now, 23 units have been put into commercial operation, and the total operational time of more than 400,000 hours has been reached. (**Figure 4**)

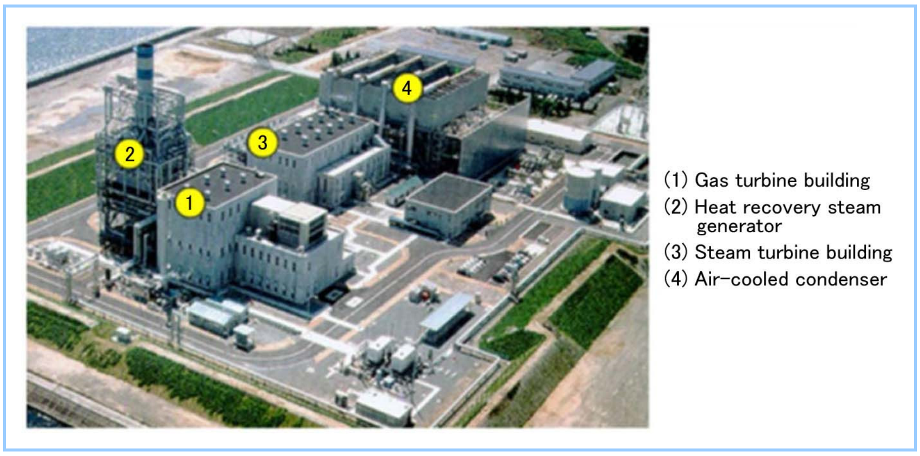


Figure 3 Gas turbine combined cycle power generation plant demonstrator (T-point) in the MHPS Takasago Works

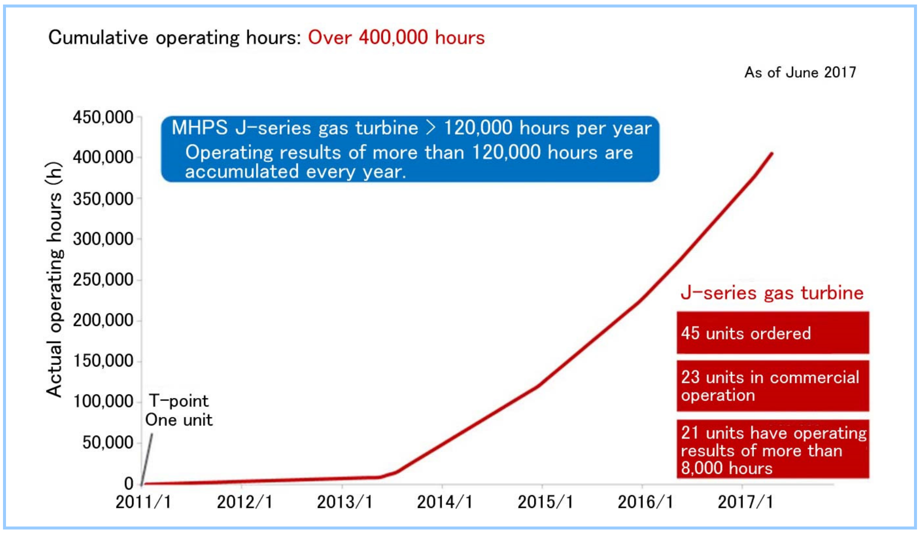


Figure 4 Operating results of M501J gas turbine (including 50 Hz units)

3. Core technology of next-generation gas turbine

The J-series gas turbine adopts the steam-cooled system for cooling the combustor, but if an air-cooled system can be used while maintaining the high turbine inlet temperature, further improvement in the efficiency and operability of GTCC can be expected. Therefore, MHPS worked on the development of next-generation GTCC that realizes air cooling of high-temperature gas turbines, and devised the enhanced air-cooled system that is a core technology thereof. By adopting this enhanced air-cooled system, air cooling of gas turbines even with a turbine inlet temperature of 1650°C can be realized, achieving high combined power generation efficiency and improving the operability of the entire plant. In the spring of 2015, we completed the actual equipment verification test of the entire system at T-point. This section presents an overview of the air-cooled system.

3.1 Overview of enhanced air-cooled system

In the enhanced air-cooled system, air extracted from the compressor outlet (combustor casing) is cooled by the enhanced cooling air cooler, pressurized by the enhanced cooling air compressor, used for cooling the combustor, and then returned to the casing. **Figure 5** shows a schematic diagram of the enhanced air-cooled system.

The characteristics of the enhanced air-cooled system are described below.

(1) The efficiency of the system can be improved by recovering the waste heat of the enhanced cooling air cooler on the bottoming cycle side.

(2) Cooling performance equal to or higher than that of existing steam-cooled system can be achieved by optimizing the combustor cooling structure.

(3) The startup time of the entire GTCC can be shortened in comparison with the steam-cooled system.

It is important for the efficiency improvement of next-generation GTCC with an enhanced air-cooled system to develop a combustor that can perform efficient cooling with a small amount of cooling air, reduce the waste heat from the enhanced cooling air cooler, improve the recovery efficiency, and reduce the power of the enhanced cooling air compressor.

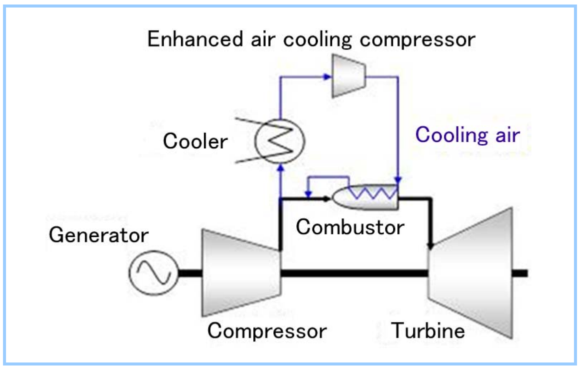


Figure 5 Schematic diagram of enhanced air-cooled system

3.2 Enhanced air-cooled combustor

The cooling structure of the enhanced air-cooled combustor adopts an MT-FIN structure utilizing convective heat transfer similar to the steam-cooled system adopted by the J-series gas turbines. The upstream side of the combustor is cooled by air in the combustor chamber and the downstream side is cooled by enhanced cooling air through the enhanced cooling air compressor. The amount of cooling air passing through the enhanced cooling air compressor is minimized by limiting the cooling range using the enhanced cooling air only on the downstream side. Furthermore, the cooling direction on the downstream side is designed to perform cooling efficiently while securing the cooling capacity at the outlet by supplying the cooling air from the combustion liner outlet where the heat load is high. On the upstream side, an acoustic liner is installed to suppress combustion dynamics and the structure is designed so that the air that convectively cooled the combustion liner through the MT-FIN is purged through the acoustic liner holes. **Figure 6** shows a schematic of the cooling structure of the combustion liner. Prior to the verification of the entire enhanced air-cooled system to be described later, it was confirmed by the high-pressure combustion test facility that there was no problem in cooling performance and combustibility of this enhanced air-cooled combustor.

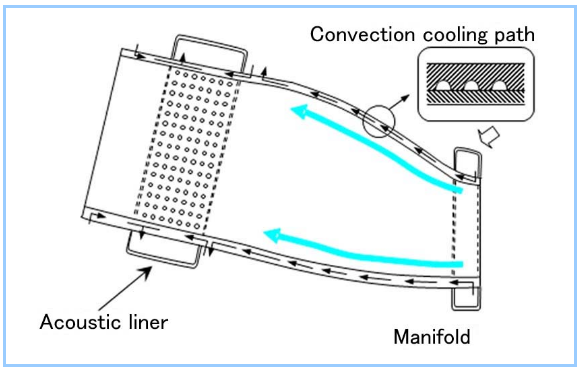


Figure 6 Cooling structure of combustion liner of enhanced air-cooled combustor

3.3 Enhanced air-cooled system actual equipment verification

Figure 7 shows the overall view of the facility and the system overview of the enhanced air-cooled system verification executed at T-point. In the enhanced air-cooled system, the waste heat of the enhanced cooling air cooler is recovered in the bottoming cycle, but a radiator type cooler was added as an enhanced cooling air cooler because the verification at T-point used the existing bottoming system.

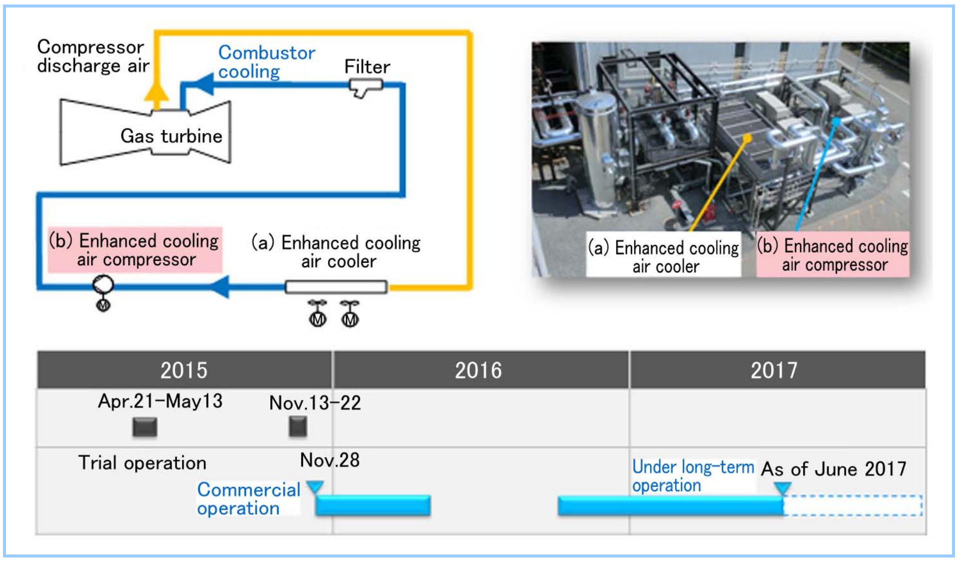


Figure 7 Enhanced air-cooled system verification equipment and system of T-point

In the spring of 2015, we verified the operability of the enhanced air-cooled system, that is, the responsiveness to transient changes such as start/stop, load change, and load rejection, using this demonstrator (T-point), and confirmed that there was no problem. The enhanced cooling air compressor operating point behavior during the gas turbine trip test was also tested and it was confirmed that the enhanced cooling air compressor could be stopped safely without entering the surging state at a trip from the 100% load of the gas turbine.

In addition, the metal temperature of the enhanced air-cooled combustor was measured and the cooling performance of the actual equipment was verified. **Figure 8** shows the behavior of the combustor metal temperature when the amount of cooling air was changed. Although the metal temperature rose as the amount of cooling air decreased, it was lower than the design tolerance even if the amount was smaller than the initial planned amount of cooling air, and there was no problem in the cooling performance. In addition, the combustion dynamics characteristics and exhaust gas emissions were not problematic and it was confirmed that stable operation is possible.

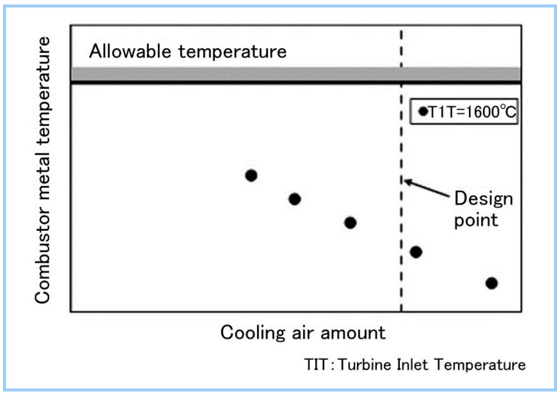


Figure 8 Metal temperature of enhanced air-cooled combustor

Based on this enhanced air-cooled system, we also verified the system that enables clearance control during load operation. This system includes two supply systems: one supply method that supplies cooling air to the combustor directly by bypassing the turbine blade ring and the other method that supplies cooling air to the combustor after ventilating the turbine blade ring to maximize the performance by reducing the turbine clearance during load operation, and these two systems can be switched using the switching valve (three-way valve) even during load operation. The former makes it possible to cope with a large load changing operation by opening the clearance (Flexible Mode). On the other hand, the latter makes it possible to reduce the clearance during load operation and maximize the performance (Performance Mode). **Figure 9** shows the clearance behavior when the three-way valve is switched during load operation. Using this system, it is expected that the operability can be improved more than before while maximizing the performance.

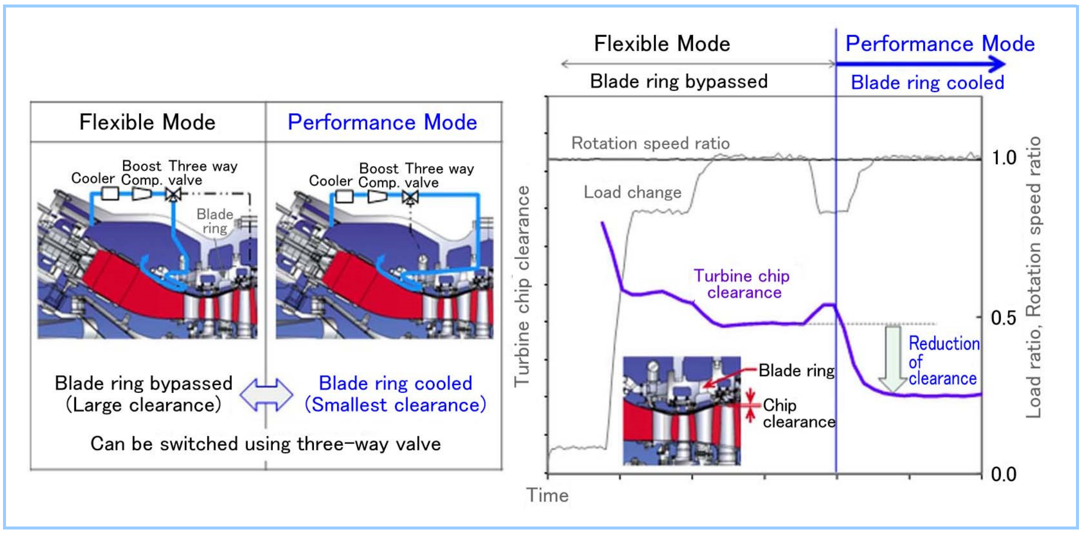


Figure 9 Turbine clearance control using enhanced air-cooled system

4. Development of 1650°C class next-generation JAC gas turbine

In the spring of 2015 we verified that there was no problem with the operation of the enhanced air-cooled system, conducting actual equipment verification at T-point. Even now, the enhanced cooling system is being verified at Point-T for its long-term operation. The JAC gas turbine, a 1650°C class next-generation gas turbine adopting this enhanced air-cooled system as the core technology, is being developed (**Figure 10**). Although the inlet temperature of the turbine becomes 50°C higher than that of the M501J, ultra-thick thermal barrier coating (TBC) developed based on the technology from the national project is adopted to achieve both high performance and reliability. In addition, by adopting a compressor with a high-pressure ratio design equivalent to that of the H-series gas turbine, the rise in the exhaust gas temperature at the gas turbine outlet is suppressed.

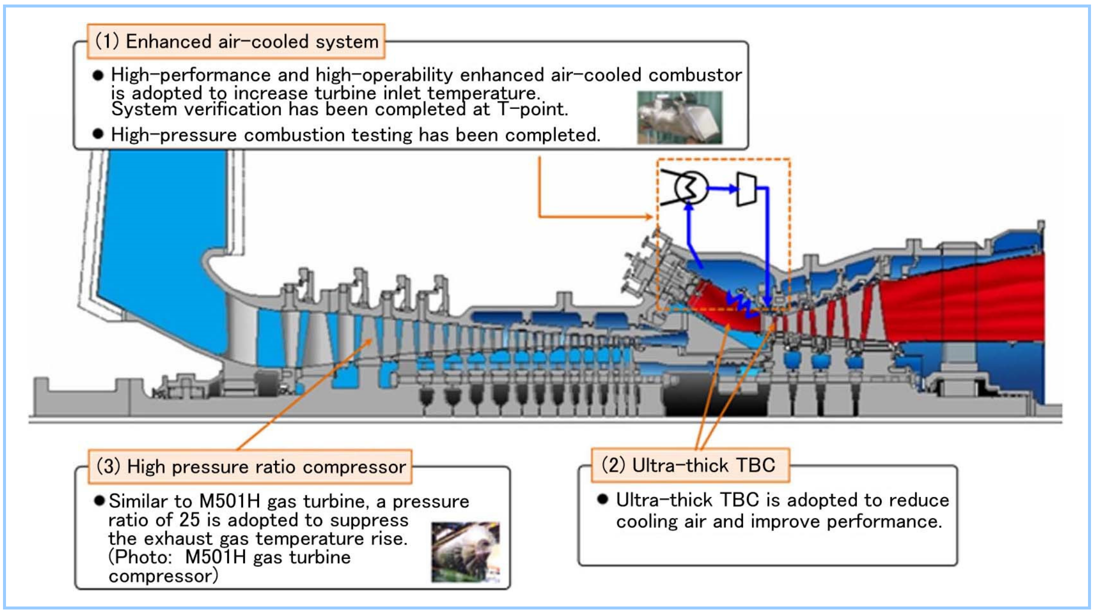


Figure 10 Characteristics of next-generation gas turbine using enhanced air-cooled combustor

We plan to close the existing demonstrator (T-point) and renew it as a new demonstration facility because it is necessary for conducting verification test operation of a newly-developed GTCC to renew not only the main body of the gas turbine, but also the main equipment such as the existing generator, the main transformer, the heat recovery steam generator, etc., to meet the specifications of the next-generation gas turbine. **Figure 11** shows the expected completion of the new demonstration facility. Currently, we are carrying out development with the goal of starting verification in 2020. Similar to the past G- and J-series gas turbines, we will steadily verify the newly-developed gas turbine using the new demonstration facilities, and respond to social needs for further energy saving and the reduction of pollution.

Next-generation gas turbine demonstration facility
(expected appearance after completion)

	Current state	Future state
Output	389,000 kw	518,000 kw
Fuel	City gas, Diesel fuel	City gas, Diesel fuel
Start of operation	June 1997	2020

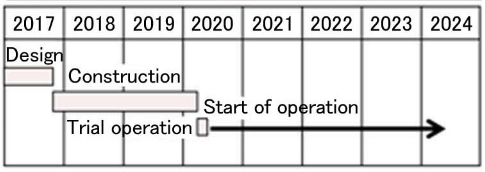


Figure 11 Next-generation gas turbine demonstration facility and its schedule

5. Conclusion

For the improvement of the efficiency of GTCC, increasing the gas turbine temperature plays an important role. MHPS developed the highly-efficient M501J, which achieved the world's first turbine inlet temperature of 1600°C, utilizing the development results from the national project "1700°C class Ultrahigh-Temperature Gas Turbine Component Technology Development," which we have participated in since 2004, and has been steadily accumulating operating results. To further improve the efficiency and the operability of GTCC, we have devised the enhanced air-cooled system that enables air cooling of a high-temperature gas turbine. This enhanced air-cooled system was verified by actual an equipment demonstrator in the MHPS Takasago Works in 2015, and there was no problem in its operation. Since then, the system has been operating for a long time to the present. Currently, we are developing the next-generation 1650°C class JAC gas turbine using this enhanced air-cooled system as a core technology. We will close the existing T-point demonstrator, and verification using a new demonstration facility will commence in 2020.

References

1. Hada, S., Masada, J., Ito, E. and Tsukagoshi, K., Evolution and Future Trend of Large Frame Gas Turbine for Power Generation - A new 1600 degree C J class gas turbine -, ASME Turbo Expo, GT2012-68574
2. Hada et al., High-efficiency Gas Turbine Development applying 1600°C class "J" Technology, Mitsubishi Heavy Industries Technical Review Vol. 52 No. 2 (2015)
3. Tsukagoshi, Evolution and Future Trend of the Gas Turbine for Power Generation, GTSJ Vol.41 No.1 (2013-1)
4. Takada, Development of the Next Generation Gas Turbine Combined Cycle, the 43th GTSJ Seminar material (2015-9)
5. Yamazaki et al., the development of the Next Generation Gas Turbine Combined Cycle, The Thermal and Nuclear Power (special edition on CD-ROM version) (2013-2)