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Development of Air Cooled Combustor for Mitsubishi G Class Gas Turbine

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ABSTRACT

Mitsubishi Heavy Industries (MHI) pioneered the introduction of steam cooling technology for gas turbines with the introduction of the M501G in 1997. To date, 62 Mitsubishi G units have been sold making this series the largest steam cooled fleet in the market. The turbine inlet temperature (TIT) for this gas turbine is 1500 deg. C. The original M501G has been upgraded for air cooling applications. This upgraded version is called as M501GAC (G Air Cooled). Several Dry Low NOx (DLN) and cooling technologies from existing F and G series were applied to the upgraded M501GAC. The new GAC combustor was installed in the in-house verification Combined Cycle Power Plant, called T-Point, and verification tests of the combustor were conducted from November 2008. The air cooled M501GAC combustor demonstrated less than 15ppm NOx operation, stable combustor dynamics at all load levels, and high combustor ignition reliability making it suitable for daily start and stop operation at T-Point. Long term verification test is currently under way.

1. Introduction

Steam cooling technology applied to MHI G series gas turbines made possible to achieve low NOx emission at 1500℃ turbine inlet temperature more than a decade ago. The combustion technology has evolved allowing operation with a more uniform flame temperature distribution and stable combustion dynamics behavior as described by Lieuwen et al. [1,2] The air cooled combustor can improve the flame temperature distribution by applying the same nozzle and swirler technologies used in the latest G series steam cooled combustor. This article describes the design features of the air cooled combustor used in the new M501GAC and the verification test results at T-Point. The results demonstrated 15ppm NOx capability at 1500℃ TIT conditions. Additionally, a combustor inspection performed after the initial operation found the hardware in sound condition. The verification process will be completed in 2010.

1.1 MHI G series Design Features

The original design feature in the G series gas turbine was to allow increased turbine inlet temperature taking advantage of the steam cooled combustor. Figure 1 shows the latest Steam Cooled DLN (Dry Low NOx) combustor system which demonstrated 15ppm NOx capabilities at 1500℃ TIT conditions. Consistent with the precursor F class gas turbine, the DLN combustion system consists of one pilot nozzle for diffusion flame at the center of the fuel nozzle and eight main nozzles surrounding the pilot nozzle for pre-mixed flame. The F and G gas turbines incorporate MT Fin (Mitsubishi Takasago Fin) cooling structure for the combustor wall, however the transition piece cooling is different between these two models. In the case of G gas turbine, steam extracted from the bottoming cycle is applied in a closed-loop circuit for cooling of the combustor liners whereas the F gas turbine utilizes compressor discharge air.

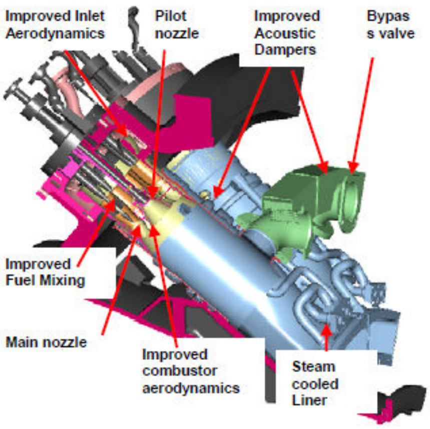

Figure 1. Steam Cooled DLN Combustor System

1.2 Verification at in house Power Station

The validation process of the G gas turbines covered a wide range of extensive verification, including component test at the R&D center and fundamental test in a scaled gas turbine. The final stage of the verification program was to demonstrate the entire engine under commercial operation conditions at the in-house verification combined cycle power station (T-Point), located in Takasago, Japan (Figure 2). T-Point consists of a multiple axis 1:1 configuration with one full scale M501G gas turbine. T-Point operates as an IPP plant dispatch power into the local grid while testing new technologies and modified parts. T-Point operation and output are determined by demand of the local utility. Operational history shows a predominant cyclic operating mode or DSS (Daily Start and Stop). The parts installed in the T-Point engine can be verified under real operating conditions allowing thorough reliability and performance demonstration prior to commercial introduction. This plant has accumulated more than 33,000 actual operating hours and 2,000 starts in more than 10 years operating history.

Figure 2. MHI in-house verification combined cycle power station, T-Point

1.3. G Engine Evolution and Experience

Since the G frame introduction at T-Point, the G technology has evolved by incorporating several enhancements. In 1999, the 50 Hz version M701G, , went commercial in a Japanese plant. Since then, several technologies had been developed to upgrade both 50Hz and 60Hz engines. In 2002 and 2003, the M701G2 and the M501G1 were introduced, as summarized in Figure 3.

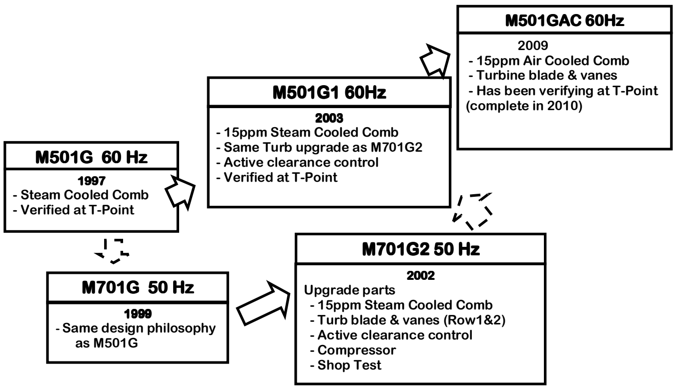

Figure 3. Evolution of G Series Gas Turbine

1.4 Operating experience of MHI Steam Cooled G Gas Turbine

The G operating fleet has grown to 35 units (62 units sold) and has accumulated more than 734,000 actual operating hours and 9,400 starts (as of January, 2009). The lead units for each frame are summarized in Table 1.

Table 1. Operating Record of MHI G Engines

	M501G series (60Hz)			M701G series (50Hz)			TOTAL
	In Operation	New Order	Sub-total	In Operation	New Order	Sub-total	
G	15	0	*15*	4	0	*4*	*19*
G1	14	22	*36*				*36*
G2				2	5	*7*	*7*
Total	*29*	*22*	*51*	*6*	*5*	*11*	*62*

G Fleet (M501G/G1, M701G/G2) Total : 62 Units (35 In Operation, 27 New Order)
- Accumulated Experience : 734,900 hours / 9,400 starts
- Lead M501G unit by hours : 43,500 hrs
- Lead M501G units by starts : 1,070starts
- Lead M701G unit : 67,400 hrs / 110 starts

M501G1(60Hz) Fleet Total : 34 Units (14 In Operation, 22 New Order)
- Accumulated Experience : 76,400 hours / 1,800 starts
- Lead M501G1 unit : 18,500hrs / 1,140starts

M701G2 (50Hz) Fleet Total : 7 Units (2 In Operation, 5 New Order)
- Accumulated Experience : 20,800 hours / 180 starts
- Lead M701G2 unit : 10,000hrs / 80starts

2. Development of the Air Cooled Combustor

2.1 Background

The combined cycle efficiency can be increased by raising the TIT, however, this also induces higher NOx emissions and higher metal temperature of the combustion components. The introduction of the steam cooled combustor allowed higher TIT while preventing increased NOx emission levels and maintaining low combustion system metal temperatures. By introducing steam cooling technology, the turbine inlet temperature can be increased while maintaining the flame temperature (see Figure 4).

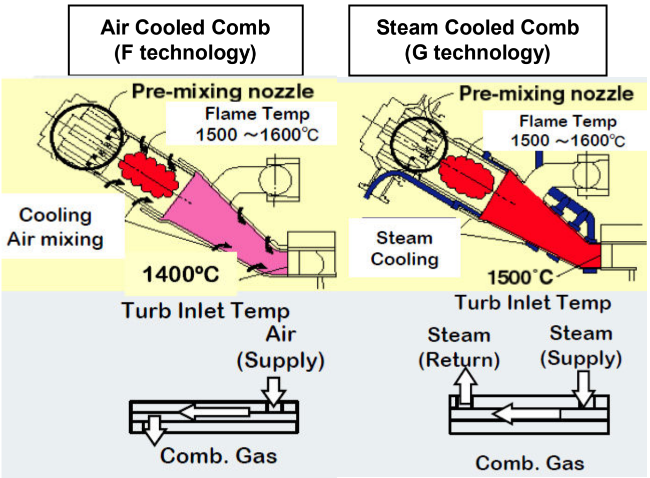

Figure 4. Air Cooled Comb vs Steam Cooled Comb

Despite the high reliability and durability of the steam cooled components, units operating under a highly cyclic regime can benefit from the simpler air cooled arrangement. By taking advantage of the latest combustion and cooling technologies, an air cooled combustor was developed for the G class machines. The latest F class air cooled combustor technology was introduced into the G engine to create an upgraded G called the M501GAC (G Air Cooled). The application of air cooled technology to the G class gas turbine does not imply MHI's departure from steam cooling applications. The highly reliable and durable steam cooled G engines continue to be offered and supported. Additionally the steam cooling technology is the backbone of the higher turbine inlet temperature applications currently being manufactured to achieve even higher performance in the next generation machines.

2.2 Evolution in Combustor Technology

Similar to the F design, the air cooled combustor applied to the M501GAC uses compressor discharge air for the combustor cooling and does not require any external cooling air source. The key technologies applied for the air cooled combustor include:

(1) Cooling air management to reduce flame temperature while maintaining the turbine inlet temperature
(2) Reduction of the peak flame temperature to decrease NOx emissions

These technologies were already applied and verified in the latest steam cooled G combustor currently in operation.

2.2.1 Cooling Air Management for Combustor

Cooling air is induced into the combustor and reduces the combustion gas temperature. As a result, higher flame temperatures are needed to achieve the same turbine inlet temperature, which may result in higher NOx emissions. Therefore, the cooling air for combustor should be minimized while maintaining the durability of the components. These counteracting requirements are the main challenge to introduce air cooled combustor in the 1500℃ class gas turbines. In order to minimize the impact of applying air cooled combustor on NOx emissions, the following technologies are incorporated:

(1) Improved TBC application (composition, thickness, process)
(2) Leakage air reduction (exit area etc)
(3) Improved cooling air application instead of steam cooling

2.2.2 Combustion Technology

NOx is generated exponentially as a function of the local flame temperature. One of the key technologies to achieve lower NOx is to realize uniform flame temperature distribution. The air cooled combustor can improve the flame temperature distribution by applying the same nozzle and swirler technologies used in the latest G series combustor.

Figure 5, 6 shows the fuel and air mixing improvement achieved by applying a new nozzle design called the "V Nozzle". Combustor with V nozzle (called Mk8-4) exhibits a more uniform temperature distribution than the previous combustor (called Mk7-4).

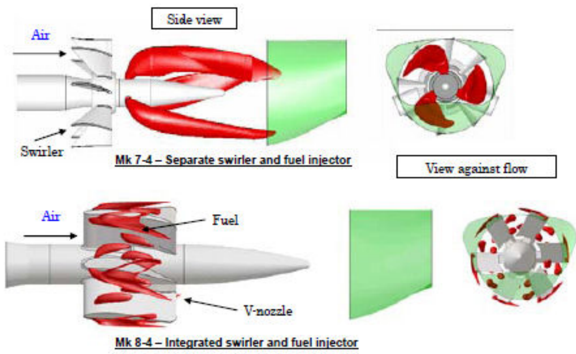

Figure 5. Fuel and air mixing at swirler Mk7-4, Mk8-4 combustor

Figure 6. V nozzle

These improvements have been applied to the latest G class steam cooled combustor. The same technologies will be applied to the air cooled combustor for the M501GAC.

2.3 Verification Test Result at T Point

The M501G1 gas turbine at T -Point was converted to GAC and operated in November, 2009. More than 1,500 special measurements were collected during the verification. Long-term verification is also ongoing. The results demonstrated the following capabilities:

- ✓ Less than 15ppm NOx operation at full load. (Figure 7)
- ✓ Lower metal temperature than the allowable limit. (Figure 8)
- ✓ Stable combustion dynamics. (Figure 9)
- ✓ High reliability in combustor ignition.
- ✓ Suitable for daily start and stop operation.
- ✓ Confirmed reliability and durability of hot parts at March 2009 inspection. (Figure 10,11)

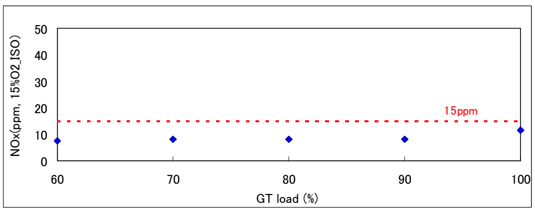

Figure 7. GT load vs NOx

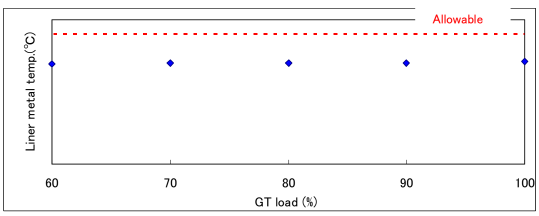

Figure 8. GT load vs liner metal temperature

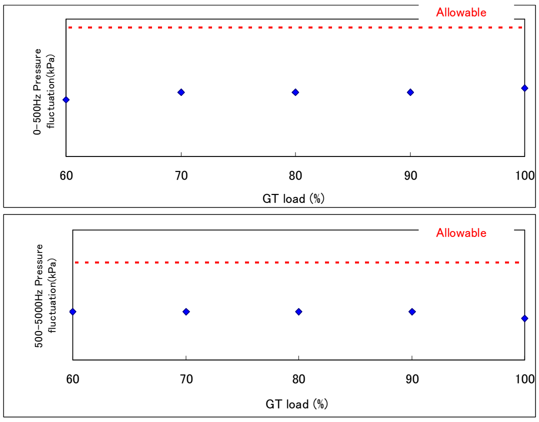

Figure 9. GT load vs Combustion dynamics

Figure 10. Picture of combustion liner at inspection
(Verification operating time 681 hour/51 start and stop)

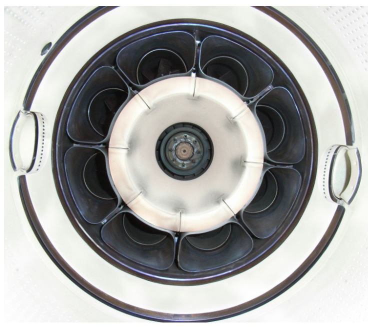

Figure 11. Picture of swirler at inspection
(Verification operating time 681 hour/51 start and stop)

3. Summary

The air cooled M501GAC operation at T-Point demonstrated less than 15ppm NOx capabilities, stable combustor dynamics, high reliability in combustor ignition, and suitable for daily start and stop.
The M501GAC verification at T-Point will be completed in 2010.

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