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UPGRADED M501G OPERATING EXPERIENCE

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ABSTRACT
In 2003 the M501G at Mitsubishi's in-house combined cycle power plant facility located at Takasago (T-Point) was upgraded. The upgrade was accomplished by replacing some of the existing hardware in the M501G gas turbine, for further improvements in output and heat rate. The verification testing at this power plant has been continuing with MHI's latest upgraded combustor technology, that has successfully demonstrated NOx levels at 15ppm and 9ppm or lower emission levels in Mitsubishi's G and F gas turbines, respectively. The upgraded M501G has been officially designated as the M501G1 gas turbine. This paper describes the upgraded hardware and the operating experience at the T-Point power plant.

INTRODUCTION
Mitsubishi's verification procedure for newly designed technology and upgrades entails full-scale operation at load under actual load at the in-house T-Point power plant. This design verification approach provides a better quantitative assessment of the hardware capability as compared to alternate approaches, such as full-speed and no load testing (a.k.a FSNL testing). This is because the T-Point power plant also dispatches electricity to a local utility's power grid for supplementing peak load demand during summer and winter seasons. This provides good verification conditions for Mitsubishi's newly designed technology and/or upgrade due to the fact that the new design hardware is exposed to the operating variables of actual power plants, such as daily start-stop cycling, and operation at various load regimes. Therefore, this type of the design verification approach by Mitsubishi is able to establish quicker quantification of design capability, performance, hardware durability and reliability prior to its commercialization (as compared to relying only on FSNL testing).
The 1x1 combined cycle power plant at T-Point with the M501G began operation in 1997. By March 2003 it had logged a total of 15,416 hrs and 911 start-stop cycles under the verification approach described above. References 1 to 4 have reported the verification experience of the M501G gas turbine. The changes that were implemented based on inspections after the very early stages of this type of design verification procedure, that otherwise would not have occurred prior to commercialization, were also presented in the abovementioned references. It should be noted that inspection intervals at this particular power plant are purposely conducted at shorter intervals (i.e. between the peak demand seasons) so that detailed examinations of hardware condition are achieved for supporting the design evaluation, and are executed in between the peak summer and winter demand periods.

In March 2003 some of the components in the M501G gas turbine at the T-Point power plant were replaced with upgraded components, for better output and heat rate, at the same firing temperature without changing the materials. The following describes the hardware that was replaced in the original M501G gas turbine for effecting the abovementioned improvements in output and heat rate:

(1) The row 1 turbine blade, row 1 vane, and row 2 vane were replaced in May 2003 with improved airfoil profiles, and internal cooling circuits without changing materials or coatings.
(2) The brush seals were replaced by leaf seals in May 2001, for reducing air leakage in the rotor. The location of the leaf

seal is shown in Figure 1. A more detailed description of the leaf seals is described in Reference [5].

(3) Airfoil shaped wrappers were installed on the exhaust struts in May 2003 for reducing pressure loss.

(4) Combustor fuel nozzles and swirlers were replaced with MHI's latest low NOx combustor technology in May 2003. The steam-cooled transitions were not changed. However, an acoustic damper was added for additional stability over ambient temperatures and fuel regimes.

(5) Steam-cooled blade rings for managing blade tip clearance at start-up and steady state operation were enabled in April 2000 by simply routing the existing cooling-steam delivery line for the combustor liner, through the row 1 turbine blade ring (Figure 2). This clearance control approach is designed for better row 1 blade tip clearance control during operation. This approach was confirmed in the verification testing of Mitsubishi's M501H and M701G2 gas turbines. More details regarding the steam-cooled blade ring effect for clearance control are described in References 6 and 7.

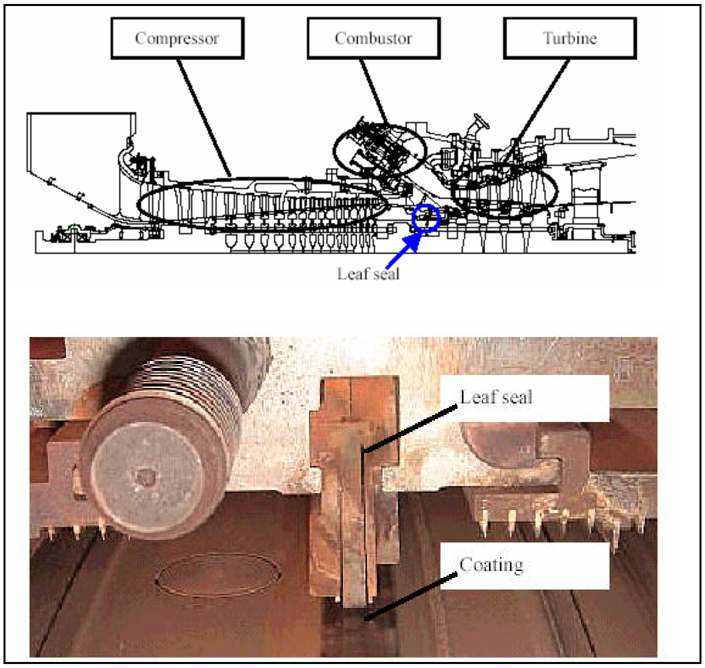

Figure 1: Leaf seal

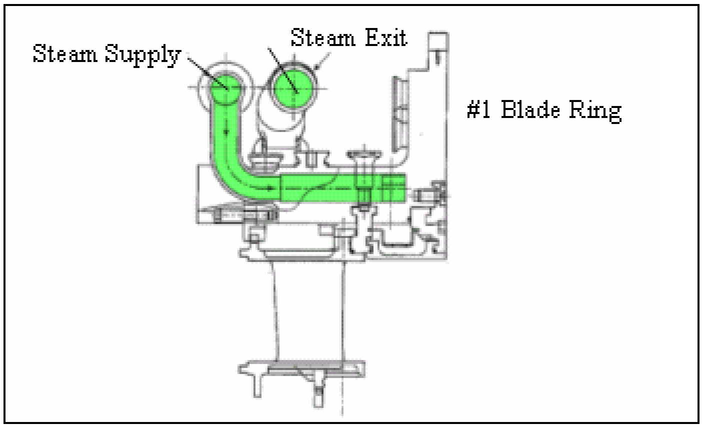

Figure 2: Cooling Steam Line of Blade Ring

M501G1 Gas Turbine

(a) Compressor

There were no changes made to the original compressor. Reference 1 provides a detailed description of the compressor which consists of 17 stages at a 20:1 pressure ratio. The operating experience for the M501G fleet with this compressor had accrued more than 125,000 hrs as of end of August 2004 on the fleet of 16 gas turbines under various ambient conditions ranging from cold winter weather in New England, to hot and humid tropical weather in the Philippines.

(b) Combustor

As mentioned above, Mitsubishi's latest low NOx combustor technology was applied during the verification testing of the M501G1. There were no changes in the transitions, and steam-cooling scheme or in the materials from the M501G gas turbine. An acoustic damper was added to the transition for operating under wider fuel calorific value regimes. With this combustor technology, the NOx emissions are 15 ppm or lower in the G gas turbine (and 9 ppm or lower in Mitsubishi's F gas turbines). The main features of this low NOx combustor are:

Better fuel air fixing: The fuel injector nozzles and swirler were re-designed so that local flame hotspots are reduced.

Acoustic resonator was added for better damping. The acoustic resonator provides stable combustion over a wider range of ambient temperatures, fuel composition and load levels.

Improved aerodynamics of the combustor: The re-designed fuel mixing swirler and flame holding baffle provide improved flame holding and flame stability.

Wider turn down capability and lower CO and unburned hydrocarbons (UHC) at lower load operation. (CO/UHC at no load decreases to 75% of that of conventional DLN combustor).

(c) Turbine

As mentioned previously the airfoil shapes and internal cooling circuits of the row 1 vane, row 1 blade and row 2 vane were upgraded using advanced CFD and latest heat transfer technologies. The remaining stages use the same M501G airfoil profiles for blades and vanes. Figures 3 and 4 show pictures of the row 1 vane and row 1 blade, respectively.

(d) Materials

There were no changes in materials – i.e. same materials for combustor, hot gas path and rotor materials.

All four stages of the turbine blades use MGA1400 nickel-based super alloy. It is used as a directionally solidified (DS) casting for blades rows 1 and 2, and as conventionally cast (CC) for the blade rows 3 and 4. The stationary vane material is made of conventionally cast MGA2400 alloy which is a nickel-based super alloy with excellent thermal fatigue, creep, oxidation, corrosion and weldability. The high temperature coatings are the same as those in the M501G. Rotor disks are made from low alloy steel.

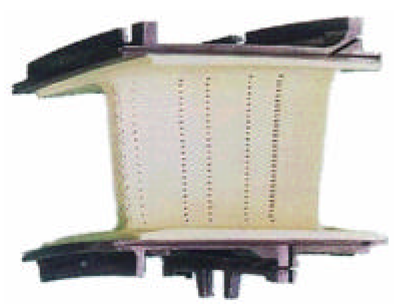

Figure 3: Row 1 Vane

Figure 4: Row 1 Blade

(e) Exhaust Diffuser

Airfoil shaped wrappers are installed on the exhaust tangential struts for better turbine exhaust diffuser efficiency. (see Figure 5).

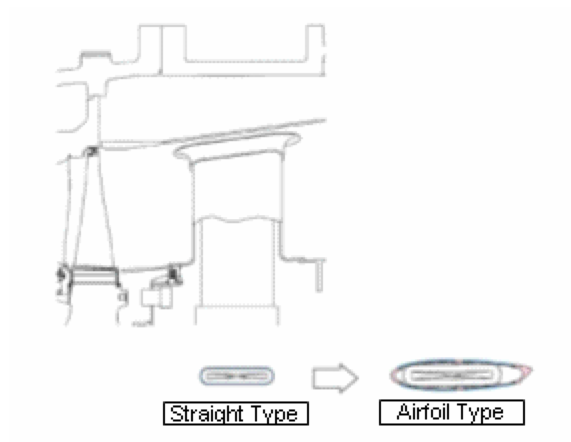

Figure 5: Airfoil shaped cover

(f) Cooling

There is no change in the cooling scheme of the M501G1 with the exception of the row 1 turbine blade ring, as mentioned previously (see Figure 2). Compressor discharge air cools the row 1 vane, while bleed air cools the stage 2, 3 and 4 vane segments, rotor disks, interstage seal flow and the ring segments of stage 2 and 3.

The cooling-steam that is used to cool the turbine blade rings, and the combustor transition piece is supplied from the Heat Recovery Steam Generator (HRSG), and is subsequently returned to the HRSG at a higher temperature after extracting heat from the combustor.

(g) Seals

In order to reduce air leakage, leaf seals are applied between the compressor and the turbine section of the M501G1 (Figure 1). The leaf seal has a structure of multiple leaf plates arranged in the circumferential direction [5]. The leaf seal is designed to have minimal gap between each leaf plate to prevent an individual leaf from being constrained with respect to each other. The tips of leaf plates are in contact with the rotor at shut down of the gas turbine, but are lifted up by hydrodynamic lifting force during operation. Therefore, a non-contact condition with the rotor is maintained.

VERIFICATION RESULTS

The abovementioned upgraded parts were installed into the M501G for verification at the T-Point combined cycle power plant. The verification testing began on May 21, 2003. Prior to that, the T-Point power plant operation with the M501G gas turbine had logged a total of 15,416 hrs and 911 start-stop cycles. In the upgraded configuration, (i.e. row 1 blade and vane, and row 2 vane, leaf seals, airfoil shaped exhaust struts, steam cooling of the blade rings, and combustor) this M501G1 gas turbine has logged an additional 3883 hrs and 258 start-stop cycles with the upgraded hardware. (Note: Some of the hardware were installed at earlier calendar dates, as discussed earlier.)

Special measurements were also installed for supporting design verifications. A sample of such measurement results for the combustor is shown in Figure 6 for NOx levels, and Figure 7 showing stable dynamics even at low turn down ratio conditions.

The T-Point facility supplements the peak load demand for the local utility company during the summer and winter seasons. Because this is specifically for design verification purposes, Mitsubishi's design engineers use the interim periods for examining and quantifying the design predictions versus actual observations. During March 2004, such an inspection was performed. Figure 8 shows the condition of the hardware which was very good.

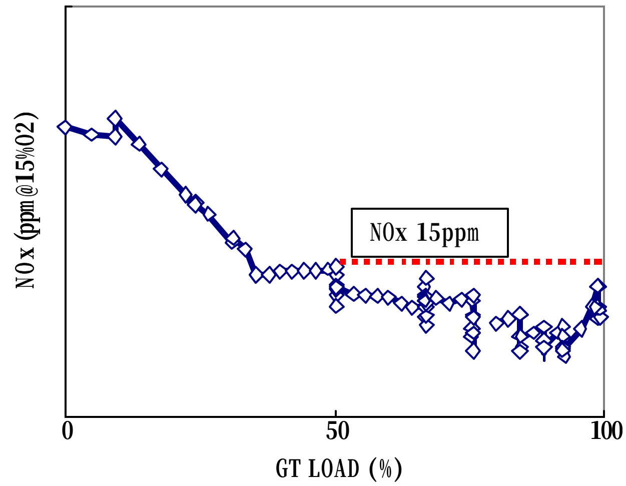

Figure 6: NOx Emission Measurement Result

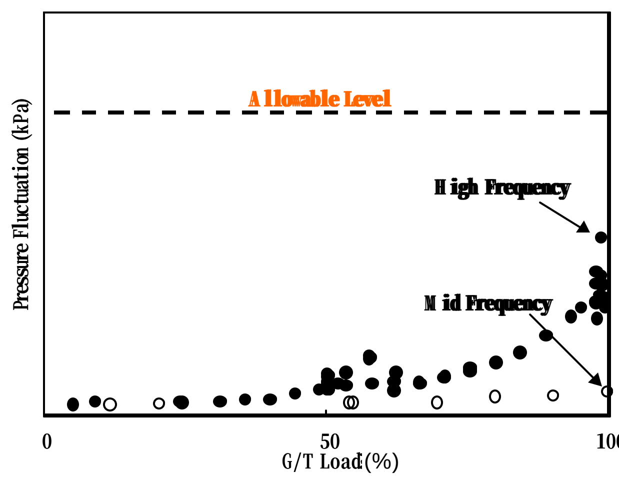

Figure 7: Combustion Dynamics Measurement Result

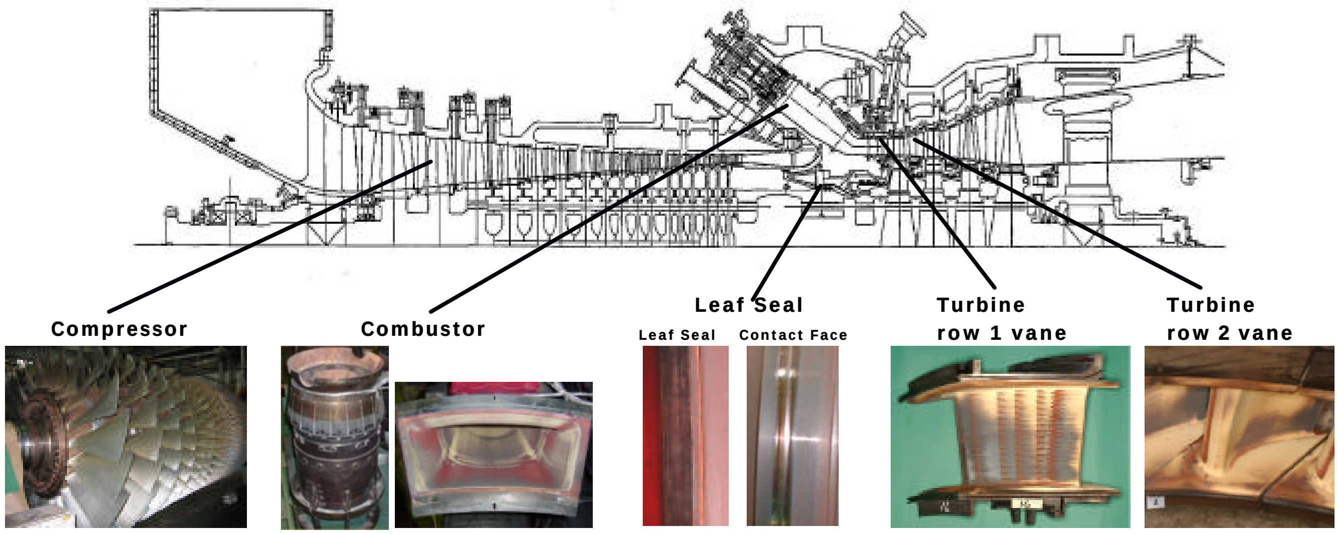

Figure 8: Hardware condition during M501G1 inspection

SUMMARY

The evolution of the M501G1 gas turbine has been accomplished without changing the firing temperature and materials, while maintaining many of the original hardware in the M501G gas turbine. The upgraded hardware and the low NOx combustor technology are demonstrating good performance, combustor stability and emissions capability. The operation at T-Point will continue (as in the case of the original M501G) on a long-term basis for gathering fleet leader experience for the M501G1 commercial fleet. At the time of writing this paper a total of nine M501G1 gas turbines have been ordered.

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