Design and Operating Experience of a 1 000 MW Steam Turbine for The Chugoku Electric Power Co., Inc. Misumi No.1 Unit

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Steam conditions for large-capacity fossil-fuel-burning thermal power plant in Japan have conventionally been 24.1 MPa 538/566°C. Mitsubishi Heavy Industries, Ltd. (MHI) has, through wide-scale development programs, set techniques for steam turbine design and materials at a high steam temperature and steam conditions of 24.1 MPa and 593/593°C applied to large-capacity 1 000 MW turbines, the Matsuura No. 2 Unit for the Electric Power Development Co., Ltd. Based on our high-temperature design development, MHI has developed and manufactured the 1 000 MW turbine, Misumi No. 1 Unit, for The Chugoku Electric Power Co., Inc., for the first time in the world with steam condition of 24.5 MPa and 600°C and a steam reheating temperature of 600°C. The first steam admission of this unit was completed in December 1997, and underwent test runs and other tests before starting commercial operation in June 1998. This paper describes the design and operating features of Misumi No. 1 Unit.

1. Introduction

In recent years global warming due to CO_2 emissions and resource conservation have come to the fore front and an effort is being made to upgrade power generating efficiency by using higher temperature and pressure in turbine inlet steam condition as well as upgrading turbine internal efficiency in large-capacity coal-fired thermal power plants. For these reasons MHI developed and manufactured the 1 000 MW Misumi No. 1 turbine for the Chugoku Electric Power Co., Inc., aiming at the highest possible efficiency for a coal-fired thermal power plant. This turbine's steam conditions are: a main steam of 24.5 MPa and 600°C and a 600°C reheat steam, the first domestically and internationally to use such high steam conditions and the plant started commercial operation in June 1998. In order to put a 600°C steam temperature into practical use, wide-scale development programs including the Electric Power Development Co., Ltd. Wakamatsu high-temperature verification turbine have been performed and design and material techniques for higher temperature steam turbines have been verified[(1)].

These techniques for higher temperatures have been successfully applied to the following power plants: Chubu Electric Power Co., Inc. Hekinan No. 3 Unit 700 MW (24.1 MPa, 538/593°C), Hokuriku Electric Power Co., Inc. Nanao-Ota No. 1 Unit 500 MW (24.1 MPa, 566/593°C), Electric Power Development Co., Ltd. Matsuura No. 2 Unit 1 000 MW, (24.1 MPa, 593/593°C)[(2)].

Since the 1 000 MW Misumi No. 1 turbine uses 600°C main and reheat steam, these established techniques for large capacity high-temperature turbines were applied and also reliability for strength at high temperatures was improved by employing new 12 Cr forged steel (TMK-2)[(3)] as the high-pressure turbine rotor material. Furthermore, maintainability has been improved by employing a 4-valve vertical type main stop valve (MSV), a governing valve (GV) and a 25-inch intercept valve (ICV) and by changing the layout of the main valves which are conventionally installed on the turbine side.

2. Outline of the steam turbine

Fig. 1 shows the appearance of Misumi No. 1 Unit steam turbine and its bird's-eye view and **Table 1** shows the main specifications of the steam turbine. The turbine is a cross compound type turbine with a primary shaft having a HP turbine and an IP turbine and a secondary shaft having two LP turbines.

The HP turbine has a double-flow design with four main steam inlets and each flow consists of one control stage and ten reaction stages. The IP turbine also has a double-flow design with two reheat steam inlets and each flow consists of seven reaction stages. 12 Cr rotor material is used for the HP and IP rotor material to deal with the 600°C main steam and reheat steam. In particular newly developed new 12 Cr forged steel (TMK-2) material which is superior in strength at high temperatures is used. The inlet of the IP turbine is cooled by the introduction of some of the exhaust steam from the HP turbine and is structured so that the 600°C reheat steam does not directly touch the rotor, therefore improved 12 Cr forged steel (TMK-1) material is used for the IP rotor, the same as a turbine for 593°C steam.

A double-flow design is used for the LP turbines as well and each flow consists of nine reaction stages including a 46-inch ISB last blade which is the largest of any thermal power plant turbine in Japan.

Reaction blades including the last blade in each turbine employ integral shroud blades (ISB) which were designed using three dimensional flow analysis and the steam turbine internal efficiency was improved in addition to the improved cycle efficiency due to the improved steam condition.

Conventionally four ICVs (17-inch) are employed in a 1 000 MW turbine, but a newly developed 25-inch ICV is employed in this unit, therefore two ICVs were eliminated. Furthermore, all main valves (MSV, GV, RSV, ICV) which are conventionally installed on the turbine side have been able to be installed under the turbine floor by employing a 4-valve vertical type MSV and GV. The main valves are installed as locations where they can be overhauled using an overhead crane without removal of the turbine enclosure. Through these improvements, when only the main valves need to be inspected in a simplified inspection, etc., working hours can be reduced and workability can be improved. Furthermore, because the main valves above the turbine floor are eliminated, workability in

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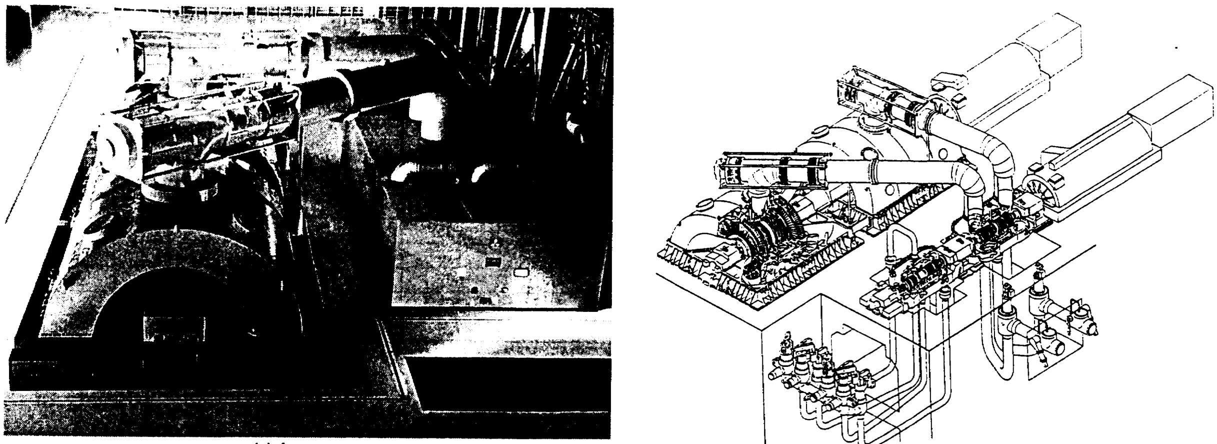


(a) Appearance (b) Bird's-eye view

Fig. 1 Misumi No.1 Unit 1 000 MW steam turbine appearance and its bird's-eye view

Table 1 Major specification of steam turbine

Item	Specification
Type	2-shaft 4-flow exhaust type reheat condensate type
Output (rated)	1 000 MW
Steam condition	
Main steam press.	24.5 MPa
Main steam temp.	600℃
Reheat steam temp.	600℃
Number of revolutions	Primary shaft : 3 600 rpm Secondary shaft : 1 800 rpm
Degree of vacuum	96.259 kPa
Last blade length	46-inch
Feed water heater	8-stage

overhauling turbines, etc. during periodic inspections can be improved.

3. Design features of the Misumi No. 1 Unit

3.1 Design for a 600°C main steam temperature

Table 2 shows comparison between the materials used for HP turbine of No. 1 Unit and those used for the HP turbines with main steam temperatures of 538°C and 593°C. In HP turbines, ferritic heat resistant steels such as 12 Cr cast steel and 9 Cr forged steel are widely used. Furthermore, austenitic refractory alloy is used for moving blades at high temperatures. These materials are used for large capacity turbines employing a steam temperature of 593°C. Although turbines can be designed using these experienced materials with a main steam temperature of 600°C, improved reliability is obtained by employing a new 12 Cr forged steel (TMK-2) having sufficient creep strength for operation at a main steam temperature of 600°C as a high pressure rotor material.

For this rotor material the Mo equivalent (Mo + 1/2 W%) is to be 1.0—1.5 and W/Mo ratio is controlled to be 3.0 and above to enhance creep rupture strength. For the material of the stationary parts, 12 Cr cast steel (MJC 12) having excellent creep strength is used for the nozzle chamber, inner casing and first blade ring.

9 Cr forged steel is used for the main steam stop valve and governing valve. Also tenons in the moving blades are eliminated and integral shroud blades (ISB) which are manufactured by one piece-machined shroud and blade are employed to improve higher temperature reliability.

3.2 The 25-inch intercept valve

Four 17-inch ICVs are conventionally used for the 1 000 MW turbines, but maintainability is planned to be improved by reducing the number of valves by employing a newly developed 25-inch ICV. Design of the 25-inch ICV is similar to a 17-inch ICV having hydrodynamic experience. On the other hand, the 25-inch ICV is designed so that the vibration and noise of the valve are below those of a 17-inch ICV by strengthening the effective stiffness of the main vibration mode so as to be more than twice that of a 17-inch ICV. For application of the 25-inch ICV it was confirmed by three dimensional flow analysis and air model test that flow characteristics and vibration features were excellent.

Model tests were conducted to confirm the impact strength of valves and valve seats against load rejection to confirm that they had proper strength.

4. Operating experience and verification results of the actual machine

4.1 New 12 Cr rotor (TMK-2)

The mechanical property and chemical composition of the HP rotor of the actual turbine in the Misumi No. 1 Unit were confirmed using test pieces sampled from various locations. **Fig. 2** shows locations of the test pieces and **Table 3** shows

Table 2 Materials of HP turbine

	Misumi No. 1 Unit (main steam temp. 600℃)	HP turbine (main steam temp. 593℃)	Conventional turbine (main steam temp. 538℃)
Rotor	New 12 Cr forged steel (TMK-2)	Improved 12 Cr forged steel (TMK-1)	Cr-Mo-V forged steel
Nozzle chamber	12 Cr cast steel	12 Cr cast steel	2¼ Cr-1 Mo cast steel
Internal casing	12 Cr cast steel	12 Cr cast steel	1¼ Cr-½ Mo cast steel
First blade ring	12 Cr cast steel	12 Cr cast steel	1¼ Cr-½ Mo cast steel
Second blade ring	2¼ Cr-1 Mo cast steel	2¼ Cr-1 Mo cast steel	½ Cr-½ Mo cast steel
Outer casing	2¼ Cr-1 Mo cast steel	2¼ Cr-1 Mo cast steel	1¼ Cr-1 Mo cast steel
Moving blade	Refractory alloy (R-26)	Refractory alloy (R-26)	12 Cr forged steel
Main steam stop valve	9 Cr forged steel	9 Cr forged steel	2¼ Cr-1 Mo forged steel
Main steam governing valve	9 Cr forged steel	9 Cr forged steel	2¼ Cr-1 Mo forged steel

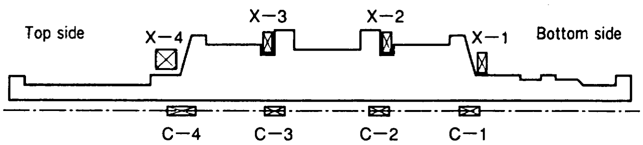


Fig. 2 Location of test pieces for tensile properties

their mechanical properties. All of the results satisfy the target values. **Table 4** shows the chemical compositions by analysis of each test piece.

In general, in the ingot-making process of a large ingot, light elements such as carbon and nitrogen easily segregate in the top central part of the ingot where is the last area to solidify. However in this rotor, for example, when the analysis results of the components at X-1 (bottom side of outer periphery part) and C-4 (top central part) were compared, it was obvious that no such trend of segregation was found. Furthermore, good results were obtained in the ultrasonic examination of the central hole.

4.2 The 25-inch intercept valve (ICV)

Fig. 3 (a) shows the vibration response in various locations of the valves during load operation. From this result it was verified that the vibration level of the 25-inch ICV was 0.15 G rms or below and was controlled to an extremely small level and there was no problem with the vibration level from start-up of the turbine to the rated load of 1 000 MW.

When the vibration level of the 25-inch ICV is compared with that of a conventional 17-inch ICV as shown in Fig. 3 (b), a lower vibration level is shown. The propriety of the design strengthening effective stiffness was confirmed.

Fig. 4 shows the measured results of the noise level near the valve when the rated load is applied. From the results it was verified that the generated sound of this 25-inch ICV unit was sufficiently low, the same as that of a 17-inch ICV and this is a low-noise valve.

4.3 Shaft vibration

The shaft vibration is an important element of the maneuverability of the unit. The shaft vibration data measured at each bearing during rated output operation are shown in **Fig. 5**. The Misumi No. 1 Unit was shipped after rotor-balancing was performed at MHI, and stable operation with all shaft vibration values of 38 μm or below in both amplitudes was attained as shown in Fig. 5 without readjustment of

Table 3 Results of tensile and impact testing performed with rotor material

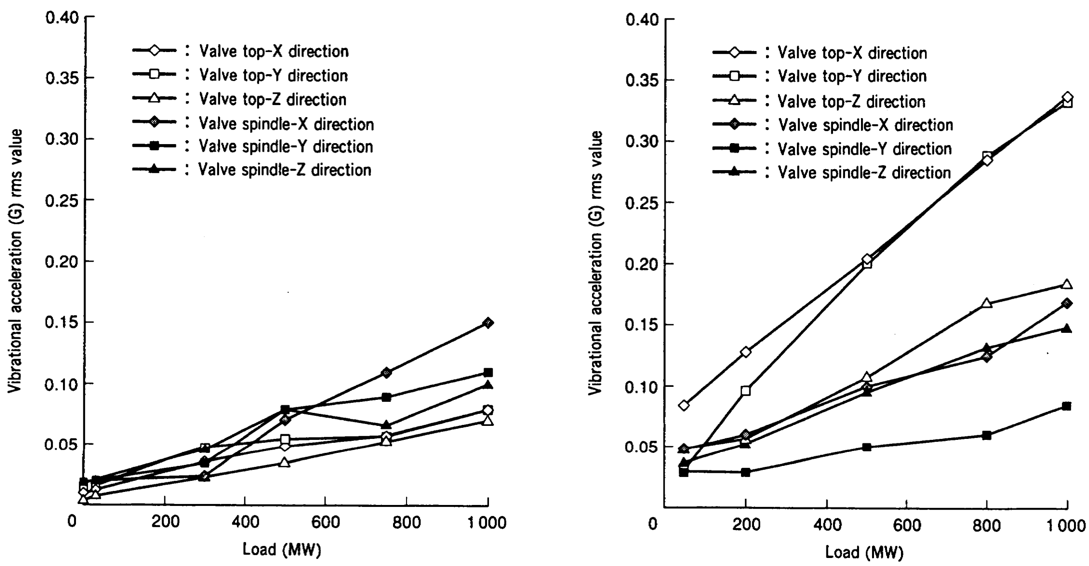
Sampling location of test piece	0.2% proof stress (MPa)	Tensile strength (MPa)	Elongation (%)	Contraction (%)	Room temp. impact absorption energy (J)	50% FATT (℃)
X-1	735	860	20	62	96	14
X-2	720	853	20	61	65	17
X-3	728	858	19	61	55	23
X-4	733	867	21	61	72	22
C-1	710	845	20	61	114	1
C-2	697	835	20	59	104	5
C-3	708	840	21	62	110	10
C-4	725	851	20	63	100	13

(Note) FATT : Fracture Appearance Transition Temperature

Table 4 Chemical composition of rotor material at various regions

(wt%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	W	N
X-1	0.12	0.07	0.47	0.008	0.001	0.03	0.51	10.59	0.37	0.17	0.045	1.84	0.052
X-2	0.11	0.06	0.48	0.007	0.001	0.03	0.51	10.61	0.37	0.18	0.045	1.84	0.050
X-3	0.11	0.06	0.48	0.007	0.001	0.03	0.50	10.52	0.36	0.18	0.043	1.84	0.049
X-4	0.11	0.06	0.48	0.007	0.001	0.03	0.51	10.57	0.37	0.18	0.045	1.83	0.051
C-1	0.12	0.07	0.47	0.007	0.001	0.03	0.53	10.49	0.38	0.18	0.043	1.82	0.050
C-2	0.12	0.06	0.47	0.006	0.001	0.03	0.52	10.49	0.38	0.18	0.045	1.83	0.050
C-3	0.12	0.06	0.47	0.006	0.001	0.03	0.52	10.48	0.37	0.18	0.044	1.83	0.049
C-4	0.11	0.05	0.47	0.006	0.001	0.03	0.51	10.40	0.36	0.18	0.040	1.84	0.049



(a) Relationship between the 25-inch ICV load and the vibrational response in various regions of the 25-inch ICV valve

(b) Relationship between the 17-inch ICV load and the vibrational response in various regions of the 17-inch ICV valve

Fig. 3 Measured results of 25-inch ICV vibration properties
Lower vibration is shown than that of 17-inch ICV.

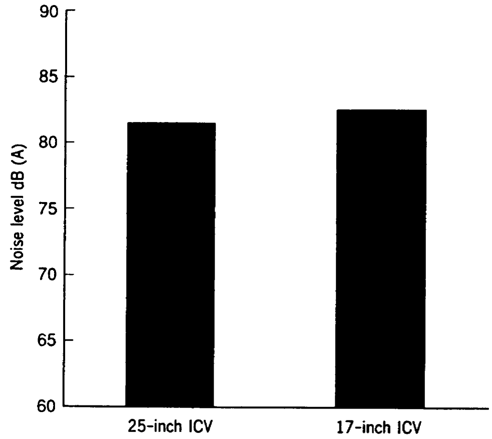


Fig. 4 Measured results of 25-inch ICV noise properties
Noise of a 25-inch ICV is sufficiently low, the same as that of a 17-inch ICV.

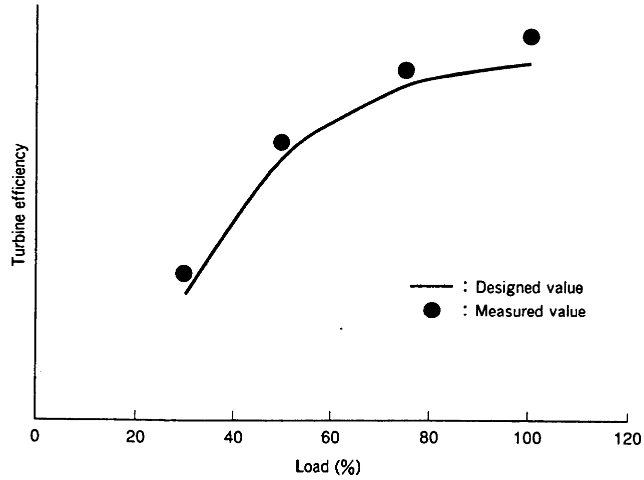


Fig. 6 Performance test results of Misumi No.1 Unit
It was confirmed that the measured values of the turbine efficiency exceeded the designed values at all loads

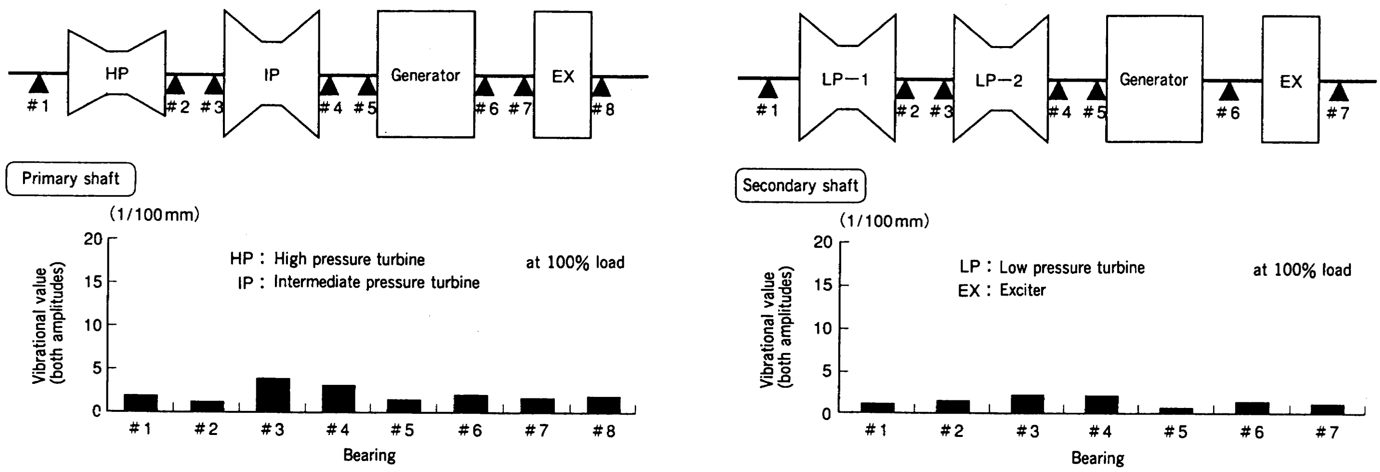


Fig. 5 Shaft vibration data of Misumi No. 1 Unit
Stable operation with both amplitudes of less than 38 μm was achieved without field balancing.

balancing during trial operation.

4.4 Performance

This unit is a high efficiency turbine planned to improve cycle efficiency by employing both main steam and reheat steam temperature of 600°C in a 1 000 MW turbine for the first time in the world, to improve internal efficiency by employing high efficiency reaction blades and to reduce exhaust loss by using 46-inch last blade that is the longest in any thermal power plant in Japan.

As a result, as shown in **Fig. 6**, the values at all loads in the performance test sufficiently exceeded the designed values (guarantee values), and it was confirmed that this turbine achieved the world's highest efficiency in its class of steam turbine.

5. Conclusion

The Misumi No. 1 Unit employs both a main and a reheat steam temperature of 600°C in a 1 000 MW supercritical unit, for the first time in the world and started commercial operation in June 1998.

This unit is the most up-to-date turbine generalizing the development in a wide range over 15 years including the Electric Power Development Co., Ltd. Wakamatsu high-temperature verification turbine tackled by MHI and the manufacture and the operating experience of high temperature turbines.

MHI is currently designing and manufacturing the Electric Power Development Co., Ltd. Tachibana-wan 1 050 MW Unit (25 MPa, 600/610°C), and developing the materials for 630°C class turbines aiming at improved steam conditions.

The authors wish to express their appreciation to the persons concerned for guidance and direction in design, manufacture and operation of this unit.

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