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DESIGN FEATURES OF GEOTHERMAL TURBINES FOR OHAAKI POWER PLANT

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ABSTRACT

This paper introduces design features of 2 x 46,900 kW geothermal turbines delivered to Ohaaki power plant in New Zealand.

Mitsubishi manufactured and delivered 56 geotherraal turbines to all over the world and all cumulated technologies obtained so far in the experiments and operation experiences have been adopted for Ohaaki geothermal turbines.

INTRODUCTION

Ohaaki geothermal power plant is located in Broadlands, well known geothermal area, 30km north-east of Taupo in the North Island.
The design and construction of the power plant has been carried out jointly by Ministry of Works and Development and New Zealand Electricity.
The power plant consists of two refurbished 11,000 kW high-pressure turbines from Wairakei power plant and two 46,900 kW intermediate-pressure turbines.
The high-pressure turbines are of back-pressure type and are operated with high-pressure steam.
The intermediate-pressure turbines are of condensing type and are operated with intermediate-pressure steam and exhaust steam from the high-pressure turbines.

Mitsubishi supplied two 46,900 kW intermediate-pressure geothermal turbines which are the largest geothermal turbines delivered to New Zealand.
The design specification of the turbines is shown in Table 1.

Table 1 Specification of Ohaaki geothermal turbine

	Unit Name			Ohaaki Units 1 S 2
Turbine	Type			Single casing double flow impulse-react ion
	Rated output		kW	16,900
	Max. capability		kW	49,900
	Speed		rpm	3,000
	Steam condition at MSV	press	bar abs.	4.5
		temp.	°C	147.9
		gas content	% (by weight)	5.6
	EXhaust pressure	exhaust hood	bar abs.	0.082
		condenser	bar abs.	0.082
	Steam consumption		t/h	340
	No. of stages			5x2 flow
	Last blade length		mm	584 (23 inch)

The big difference between Ohaaki power plant and Wairakei power plant is in cooling water system.
Cooling water for condensers is recirculated through cooling towers in Ohaaki power plant, while it is puraped-up from Waikato river in Wairakei power plant.

Unit 2 in this power plant is scheduled to start commercial operation in October, 1988 and Unit 1 in April, 1989.

TURBINE CONSTRUCTION

The construction of the geothermal turbine is very similar to that of a low pressure turbine for a thermal power plant. However, in terms of impurities in the steam, conditions are excessively worse in a geothermal turbine. Therefore, careful design consideration is necessary with respect to corrosive gas, such as hydrogen sulfide (H2S); salt; scale component, such as silica (SiO2) and calcium (Ca); and solid particles, such as sand and iron contained in the steam. Consideration must also be given to the wetness inside the turbine due to the saturated steam condition at the turbine inlet.

The presence of corrosive gas, such as H2S, in the steam necessitates a careful study as to the corrosion of the material, stress corrosion cracking and lowering of the corrosion fatigue strength. Therefore, the candidate materials were tested at the Broadlands geothermal field, and the best material is selected on the basis of the test results. Table 2 shows the major materials used in the geothermal turbines.

Table 2 Material of geothermal turbine

Main parts	Material
Rotor	Super low sulphur CrMoV forging
Casing	Carbon steel
Nozzle/Stationary blade	12% Cr Stainless steel
Moving blade	12% Cr Stainless steel
Nozzle diaphragm	Steel casting, carbon steel
Labyrinth fin	12% Cr Stainless steel

A specially designed drain catcher and impingement shield, as well as stellite strips on long blades have been adopted to cope with the increased wetness, which may induce drain erosion.

A longitudinal section drawing and the shop-assembly photo of Ohaaki geothermal turbine are shown in figures 1 and 2 respectively. The turbine is of a single casing double-flow, impulse-reaction type provided with 23-inch last blades.

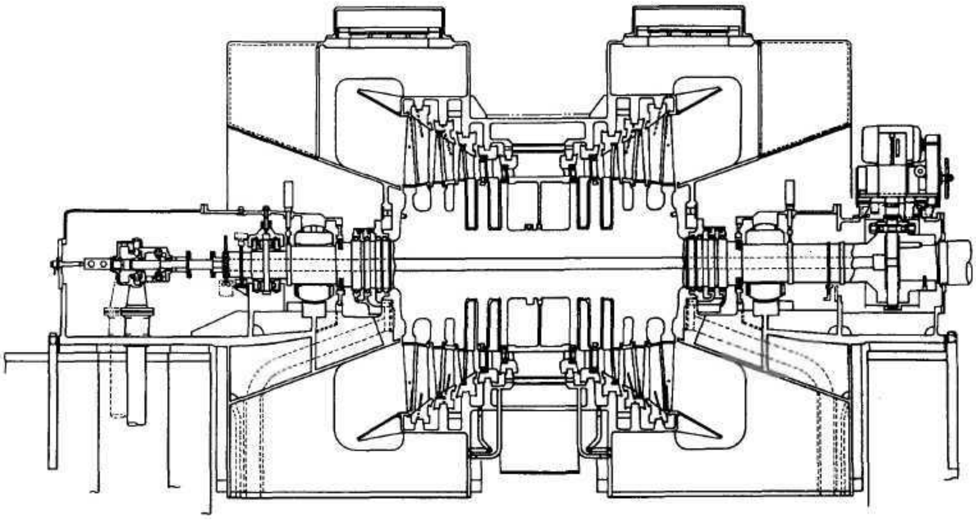

Figure 1 Longitudinal section of Ohaaki geothermal turbine

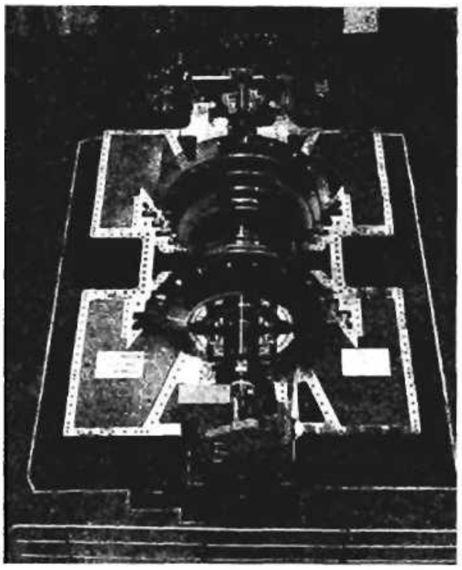

Figure 2 Shop assembly of Ohaaki geothermal turbine

The impulse stages have been provided in the first and second stages for the following reasons: Scale deposit is limited to the stage that corresponds to the alternative dry and wet steam zone of the first and second stages; thus scale deposits on the moving blades have been minimized by a heat drop produced in the nozzles. This prevents vibration due to unbalance and corrosion fatigue of the moving blades caused by scale deposition.

The reaction stages have been adopted for the following stages from the view point of importance of performance at a large volumetric flow and protection against drain erosion by minimizing the steam velocity at the long blade stages where the rotating speed of the moving blade is higher.

Ample axial space has been provided between the stages, and the steam wetness has been reduced by providing a drain catcher, in addition to grooves machined on the concave surface of the stationary blades of the last two stages for collecting drains.

The steam inlet of the turbine is so arranged that the turbine floor can be utilized as wide as possible. Compact construction has been accomplished by adopting bottom-inlet single-wall turbine casing and by locating steam pipes and valves under the turbine floor.

Main valves used with the turbine are swing check type main stop valves and butterfly type governing valves, which minimize the loss of low inlet steam pressure.

DESIGN FEATURES

Mitsubishi has designed, manufactured and delivered 56 geothermal turbines all over the world since completion of Otake geothermal power plant in Japan in 1967. The cumulated experiences have been reflected in the Ohaaki geothermal turbines. In addition, the advanced new technology as shown in Table 3 has been adopted for the improvement of performance and reliability.

Table 3 Advanced new technologies applied to Ohaaki geothermal turbine

Features	Advantages
23" last blade	Minimum exhaust loss
Twisted nozzle	Improvement of stage efficiency
Multi seal fin	Minimum leakage loss
High efficiency drain catcher	Minimum wetness loss, preventing erosion
Super low sulphur CrMoV rotor	Less sensitivity against SCC
Special blade damper	Reducing vibratory stress
900 psig oil system	Improvement of control response and capability

23-INCH LAST BLADE

In order to increase turbine capacity, a long last blade, which has a larger blade annulus area, is necessary to minimize leaving loss. In a fossil unit, 3.5$ NiCrMoV forged steel with enough tensile strength and toughness is used for the turbine rotor, to cope with increasing centrifugal stress accompanying the longer last blades. However, in the case of a geothermal turbine, rotor material containing more than 3$ Nickel is not suitable due to its susceptibility to stress corrosion cracking and excessive lowering of the corrosion fatigue strength in geothermal steam containing H_2S. Therefore, the length of the last blade is inevitably limited. Also the steam wetness at the turbine exhaust becomes 15$ against about 8 -10$ for a conventional fossil unit and, therefore, careful consideration is necessary for selection of the length of the last blade.

The 23-inch last blade was adopted considering the above requirements. The 23 inch last stage blades have similar flow annulus area to that of 3,600 rpm 25 inch last stage blades, which are the largest class last stage blades for geothermal turbines.

Figure 3 shows the leaving loss of the Ohaaki geothermal turbine. As far as the geothermal turbine is concerned, the difference in leaving loss has a great effect upon the efficiency of the turbine due to its small heat drop.

The 23-inch last blades which have large flow annulas area show remarkable advantages in higher vacuum operations in winter, which is realized in the cooling water system combined with the cooling tower.

IMPULSE STAGE

Since the height of the blade for the impulse stage of a geothermal turbine is greater than that of a fossil turbine, it is necessary to analyze the three dimensional flow pattern, considering the direction of blade height and flow in the high mach number expansion of low pressure steam in the stage. The nozzle and blade profile suitable for the above operating condition have been selected.

The twisted nozzle has been adopted to improve the impulse stage efficiency by minimizing the secondary flow loss at the moving-blade base. The proper step-up between nozzle and blade, and multi-seal fins have been adopted, as shown in Figure 4, to minimize leakage loss through the blade tips.

The integral shroud blade shown in Figure 5 have been adopted so that the multi-seal fins at the blade tip can be used.

ROTOR MATERIAL

As for the rotor material for geothermal turbines, the following requirements must be satisfied.

(1) High toughness and ductility
(2) Low sensitivity to stress corrosion cracking

Super low sulphur CrMoV rotor material has been developed as the rotor material that satisfies the above requirements as shown in Figure 6. In this rotor material, the content of Nickel has been limited to less than 0.5$ and sulphur to less than 0.005%. The quenching temperature has been lowered to 910°C.

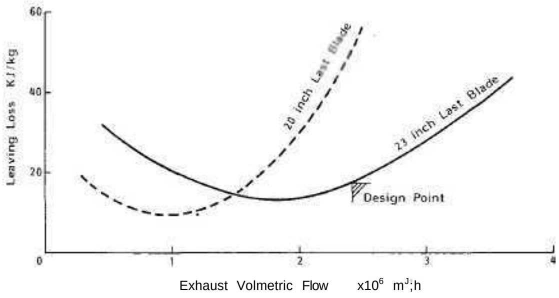

Figure 3 Leaving loss of 23 inch last stage blade

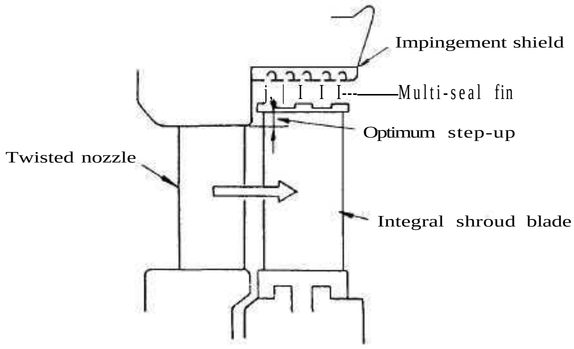

Figure 4 Minimum leakage design

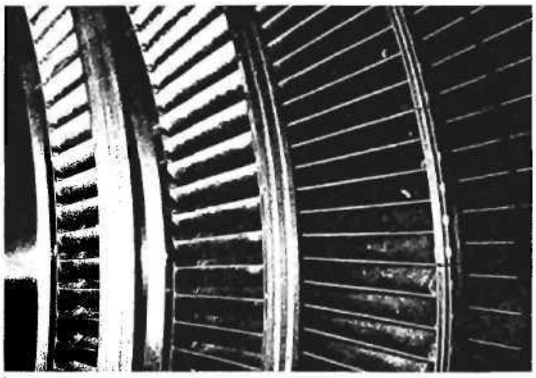

Figure 5 Integral shroud blade

Super low sulphur 0.005%

⇨ Higher toughness and ductility

Low nickel 0.5%

⇨ Less sensitivity against SCC

Lower austenitizing temperature = 910°C

⇨ Less sensitivity against SCC

Figure 6 Features of rotor material

BLADE MATERIALS

The stress corrosion cracking and the reduction of corrosion fatigue strength must be taken into consideration in the selection of blade materials for a geothermal turbine. Stress corrosion cracking tests and corrosion fatigue tests were conducted at several geothermal fields including Broadlands to select the suitable blade materials.

Based on the above test results, the 12% Cr steel has been adopted for the blades. The result of the corrosion fatigue test of 12% Cr steel in geothermal steam is shown in Figure 7.

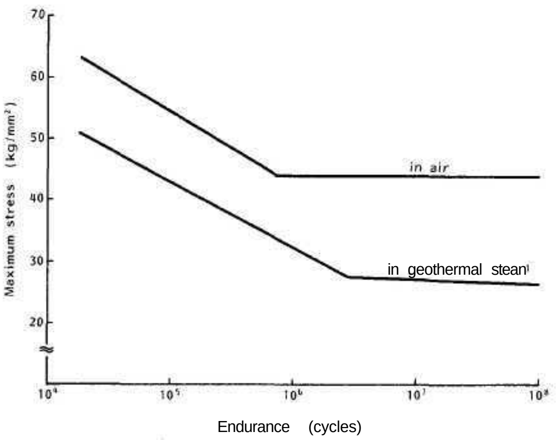

Figure 7 Corrosion fatigue of 12% Cr steel

HIGH EFFICIENCY DRAIN CATCHER

The drain catchers provided at each stage are significantly important devices to avoid drain erosion and to decrease moisture loss.

The water droplet is collected by the drain catcher, as shown in Figure 8, in the outer circumference of the blade path and discharged simultaneously with a small amount of steam to outside of the turbine. In this regard, the space between stages and the shape of the drain catcher, which affects the efficiency of drain catching, has been determined through an analysis of water-droplet behavior and model testing.

Drain erosion of the long blade is prevented by further decreasing the wetness in the steam flowing through the moving blades by means of drain-catcher grooves in the concave surface of the last two stationary blades, as shown in Figure 9.

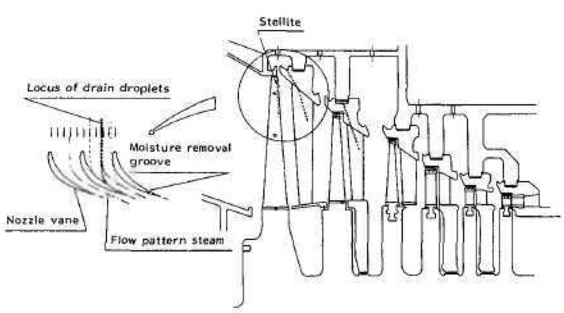

Figure 8 Drain catcher of geothermal turbine

Figure 9 Drain catcher grooves on stationary blades

SPECIAL BLADE DAMPER

In parallel with the selection of the optimum blade material to further upgrade the reliability of the moving blades, special dampers are used to reduce the vibratory stress.

The vibratory stress is reduced by the shroud damper, shown in Figure 10, which connects adjacent blade groups together.

The stub dampers are attached to the last blades, as shown in Figure 11.

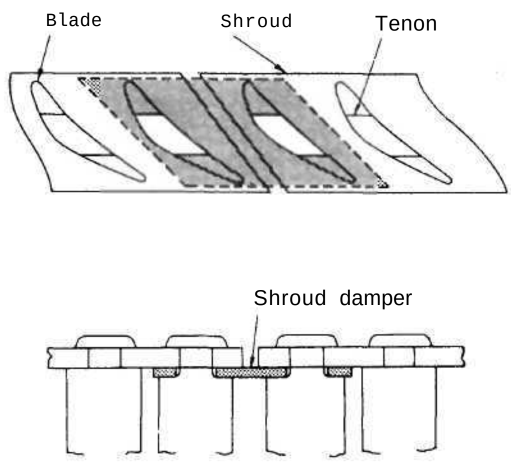

Figure 10 Shroud damper

Figure 11 Stub damper on the last blade

900 PSIG CONTROL OIL SYSTEM

With an increase in capacity of geothermal turbines, main stop valves and governing valves have become larger. In order to actuate the hydraulic servomotor for these large size valves, a large capacity oil system is usually required. However, as it is not economical to increase the size of the servomotor and the capacity of the oil system, 900 psig oil system has been used for the large capacity geotherraal turbine instead of 300 psig conventional oil system. This 900 psig oil 'system can be combined with a conventional lubricating oil system which makes operation and maintenance easy. The 900 psig hydraulic oil pumps are mounted on the lubricating oil reservoir.

The most widely used oil relay type governor system has been utilized in the turbine control with priority given to reliability. The turbine control system has been designed to enable the unit to be operated by both governing operation and load limiting operation.

OPERATION RECORD OF SIMILAR UNITS

Commercial operation of the similar units of Kamojang Units 2 and 3 in Indonesia, each 55,000 kW, were started in September, 1987. The trial operation went on smoothly, reaching full load 7 days after steam admission, and finishing the entire test 15 days after steam admission.

In August, 1988, one year after starting the commercial operation, the inspection of the Unit 3 turbine was conducted, and it was confirmed that the turbine condition is satisfactory. Thus the unit went into continuous operation upon recognition of its soundness. Figure 12 shows the view of Kamojang Units 2 and 3-

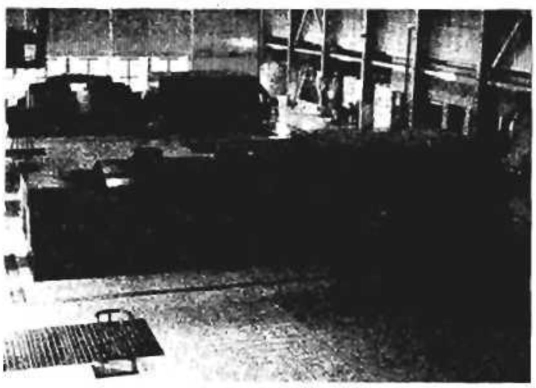

Figure 12 View of Kamojang Units 2 8 3

CONCLUSION

The design features of the geothermal turbines for Ohaaki power plant have been introduced in this paper. These technologies have been applied to geothermal turbines recently manufactured by Mitsubishi to improve efficiency and reliability.

Mitsubishi always wishes to contribute to the development of geothermal power generation in New Zealand with advanced technologies.