Recent Technology of Geothermal Steam Turbines

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1. Introduction

The cumulative capacity of geothermal power plants constructed worldwide has reached 7,974MW, which is a 16.6% increase in the last 5 years(1). The cumulated capacity of the geothermal turbines Fuji Electric has manufactured increased from 1,253MW as of 1995 to 1,566MW as of September 2000, which is a 25% increase in terms of capacity. This reveals that increased international environmental awareness has resulted in a larger total geothermal capacity and that throughout the world, users have appreciated the reliability and performance of Fuji's geothermal steam turbines.

The evolution of geothermal steam turbine technology was introduced in a previous paper(2). Development of the geothermal steam turbine has continued to make progress over the past 5 years. This paper introduces the recent technology of geothermal steam turbines, and also presents the features of two typical geothermal steam turbines that were put into commercial operation in 2000.

Decreasing production well pressure is an inevitable consequence of geothermal power generation. Two solutions to maintain the output of geothermal power plants in cases of decreasing production well pressure will be described.

2. Recent Technology of Geothermal Steam Turbines

Geothermal steam turbines have been developed based upon fossil fueled steam turbines, and therefore several new technologies employed by geothermal steam turbines are the same as those used in fossil fueled steam turbines. This section describes those technologies which are shared with fossil fueled steam turbines as well as specific technology for the geothermal steam turbine.

2.1 Advanced reaction blade airfoil having higher efficiency

An advanced reaction blade airfoil (Fig. 1) was developed to reduce the number of stages in fossil fueled steam turbines by increasing the heat drop per stage. Through employing the new reaction blade airfoil, stage efficiency will be increased by 1.5%.

2.2 Advanced low pressure (LP) blade

A sudden increase in the cross sectional area of the steam line in the last few stages of a condensing steam turbine is necessary due to the huge steam expansion that occurs in a vacuum. Long LP blades are employed for the last three stages.

Progress in computational fluid dynamics (CFD) has enabled the development of advanced LP blades.

Following the development of a 38.5-inch LP blade for use at 3,000 r/min in the latter half of 1980s, a series of advanced LP blades has been completed,

Fig.1 Comparison in efficiency of reaction blade airfoil N1 and T4

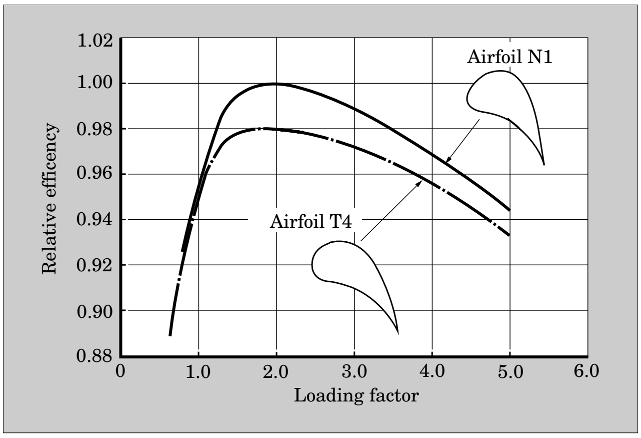
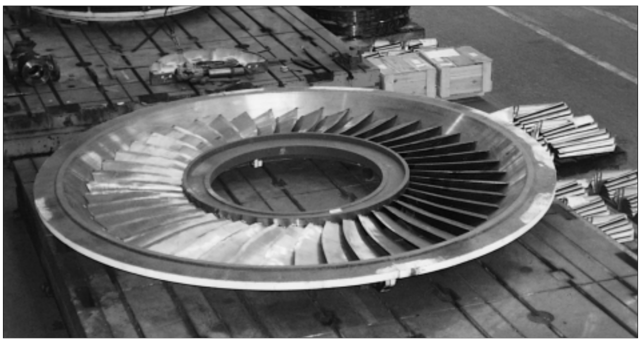


Fig.2 Last stage stationary blade ring



spanning the entire output range.

The last (L-0) stationary blades are radially angled in order to increase reaction degree near the root and to reduce secondary losses (Fig. 2). Airfoils near the tip of the last stage blades (LSB) are contoured to form a so-called convergent-divergent passage that prevents the generation of normal shocks which cause large losses in the transonic cascades (Fig. 3).

By employing the advanced LP blades, stage efficiency will be improved by approximately 3%.

2.3 Large bore sized, triple eccentric butterfly valves

Liquid dominated geothermal power plants tend to employ double flash technology to increase generator output.

In a double flash system, the separated hot water in an HP flasher is fed to an LP flasher to generate low pressure steam. The low-pressure steam is then supplied to the intermediate stage of the steam turbine. The bore size of stop valves and steam control valves for LP steam is normally very large, since the specific volume of the low pressure inlet steam is large.

Double eccentric butterfly valves were employed for the low pressure inlet steam as general stop valves. However, opening a double eccentric butterfly valve usually requires a large torque from an actuator due to the large wedge force generated by the point contact on the sealing surface between the disk and the sheet.

A feature of the triple eccentric buttery valve is that its sealing surface is contoured in the shape of a cone whose center does not coincide with the disk center (Fig. 4). The seal rings installed in the disk are pushed into the disk when the valves closed. As the result, sealing is achieved through surface contact instead of point contact. A comparably small actuator force is sufficient to open these valves smoothly.

Fig.3 Mach number distribution at tip airfoil of LSB

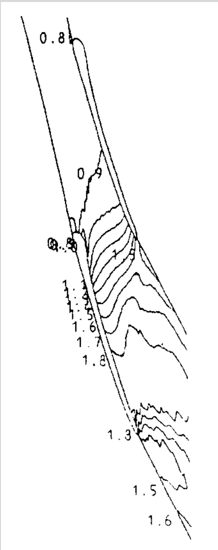
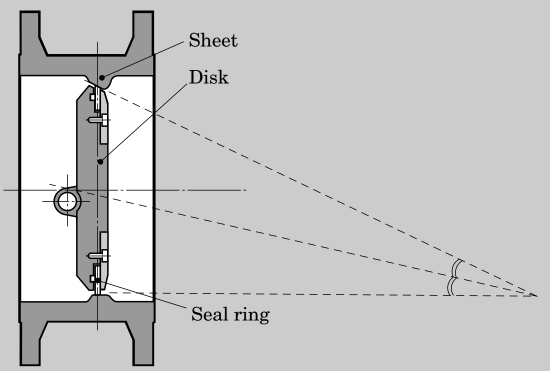


Fig.4 Triple eccentric butterfly valve



3. Recent Geothermal Steam Turbines

Fuji Electric has two types of geothermal steam turbines, a packaged type and a dual exhaust flow type. Packaged type turbines range up to 40MW in capacity, and dual exhaust flow types range from 55MW on up.

The packaged type turbines are completely pre-assembled at the factory and are delivered as a single package in order to reduce the onsite installation work.

The dual flow exhaust turbine is inspected at the factory and then dissembled into parts, which are small enough to be readily transported to the site, such as the rotor and the upper and lower half of the casing.

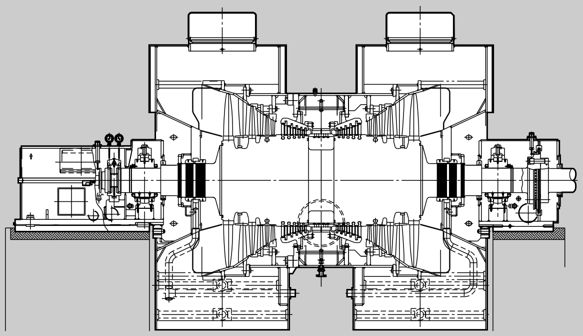
The following describes geothermal steam turbines recently put into the commercial operation.

3.1 Wayang Windu 110MW geothermal steam turbine[3]

Figure 5 shows the cross section of the steam turbine for the Wayang Windu Geothermal Power Plant in Indonesia, which was put into the commercial operation in June 2000. The turbine is of a single flash, dual exhaust flow and single casing type. Major specifications of the geothermal turbine are as follows:

(1) Inlet steam pressure: 1.02MPa
(2) Inlet steam temperature: 181°C

Fig.5 Cross section of 110MW geothermal steam turbine for Wayang Windu Geothermal Power Plant (Indonesia)



(3) Condenser vacuum: 12kPa
(4) Speed: 3,000 r/min
(5) Rated output: 110MW

The rated output of 110MW is the largest in the world for a single casing geothermal steam turbine. Previously, all installed geothermal turbines rated at more than 100MW had been of the dual casing, tandem compound type.

The advanced LP blades with a 27.4-inch LSB enable the realization of a single casing 110MW geothermal turbine.

Moving blades in the last 2 stages are free standing, without lacing wires on the airfoil. Absent of bosses for lacing wires, the airfoil is free from any stress concentrations and deposits of corrosive components. Furthermore, the vibration modes of free standing blades are so simple that natural frequencies of the blades can be precisely predicted by calculation. As the result, the LP blades can operate without limitation within ±5% of the 50Hz rated frequency.

The blade row is composed of 8 double flow stages. The 1st through 5th stages are equipped with reaction blades with an integral shroud. The blades with integral shroud are free from any residual stresses that tend to be generated on riveted shroud blades. This is an advantage of the integral shroud blades. Another advantage of the integral shroud blades is their good damping characteristics.

The 1st through 5th stage stationary blades are installed in a stationary blade holder, which is divided into upper and lower halves. The upper and lower halves of the stationary blade holders are bolted to the respective upper and lower halves of the outer casing. The upper and lower halves of the stationary blade holders are also tightened by bolts at the horizontal joint flange in order to prevent steam leakage and erosion of the horizontal joint flange.

The turbine rotor is of the non-concave, drum type, so that no stress concentrations will be generated. The shaft is formed from CrMoNiV forged steel, consisting of relatively low nickel content in order to prevent stress corrosion cracking (SCC). The large inertia weight of the drum type rotor ensures stable operation.

3.2 Salton Sea 58.32MW geothermal steam turbine

Figure 6 shows a cross section of the 58.32MW geothermal steam turbine for the Salton Sea Unit 5 geothermal power plant in the USA, which began commercial operation in August 2000. The plant employs a triple flash system, that is, standard pressure steam (SP), low pressure steam (LP) and very low pressure steam (VLP) are supplied to the steam turbine. The Salton Sea Unit 5 geothermal steam turbine is the first unit having triple inlet pressure.

The plant employs a dual vacuum condenser, in which one exhaust pressure differs from that of another one.

(1) SP steam pressure : 0.86MPa
(2) SP steam temperature : 174°C
(3) LP steam pressure : 0.367MPa
(4) LP steam temperature : 141°C
(5) VLP steam pressure : 0.137MPa
(6) VLP steam temperature: 110°C
(7) High vacuum side exhaust pressure: 9.6kPa
(8) Low vacuum side exhaust pressure : 13kPa
(9) Speed : 3,600 r/min
(10) Rated output: 58.32MW

The SP steam enters the steam turbine from the bottom of the lower half casing through the stop valve and the steam control valve. The LP steam enters the intermediate stage of the steam turbine from both sides of the lower half casing through two steam control valves branched from a single stop valve. The VLP steam enters from four inlet ports located on the upper half of both exhaust sides, through four steam control valves branched from two stop valves (Fig. 7).

The SP stop valve is a swing-check-type valve with a 14-inch bore size. The LP and VLP stop valves are triple eccentric butterfly valves with 44-inch bore sizes. The 44-inch bore size is the largest size in the world for butterfly valves of geothermal use. The SP steam control valve is a butterfly type valve with a 14-inch

Fig.6 Cross section of 58.32MW geothermal steam turbine for Salton Sea U5 (USA)

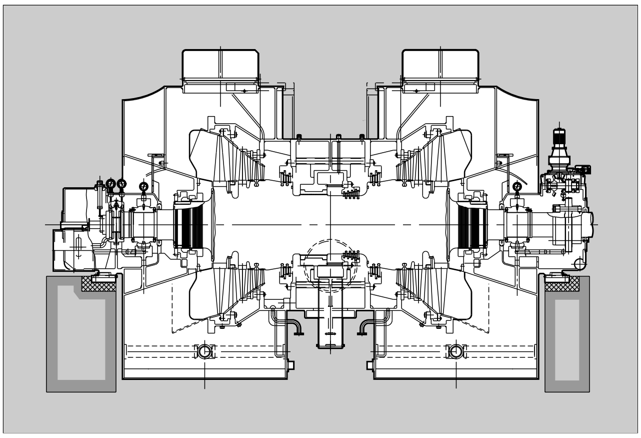


Fig.7 Casing upper half of geothermal steam turbine for Salton Sea U5

bore size, and the LP and VLP steam control valves are butterfly type valves with 30-inch bore sizes. During normal operation, the SP and VLP steam control valves are used to control the corresponding inlet steam pressure, and the LP control valves are used to control the turbine load.

The blade row is composed of 4 single-flow stages, followed by 5 dual-flow stages. The four single-flow stages and the next two dual-flow stages are equipped with integral shroud blades. The last three stages are equipped with advanced LP blades with a 26.2-inch LSB.

4. Solutions for Decreased Production Well Pressure

Geothermal resources generally decline over a long-term operation, even when employing a re-injection system in which surplus hot water is injected back to the reservoir underground.

Two solutions where Fuji geothermal steam turbines have employed are described below:

4.1 NCPA U2

The plant was put into commercial operation in 1983. After more than 10 years of operation, the pressure of the production well had decreased. Original specifications of the steam turbine are as follows:

(1) Inlet steam pressure : 0.799MPa
(2) Inlet steam temperature: 169°C
(3) Inlet steam flow: 107.65kg/s (NCG content: 0.4%)
(4) Condenser vacuum : 10.2kPa
(5) Number of blade rows : 2 (flow) × 8 stages
(6) Speed : 3,600 r/min
(7) Rated output: 55MW

The steam turbine was modified so that the generator output can be maintained despite decreasing well pressure.

Specifications of the steam turbine after modification are as follows.

(1) Inlet steam pressure : 0.572MPa
(2) Inlet steam temperature: 157°C
(3) Inlet steam flow: 124kg/s (NCG content: 0.4%)
(4) Condenser vacuum : 10.2kPa
(5) Number of blade rows : 2 (flow) × 8 stages
(6) Speed : 3,600 r/min
(7) Rated output: 55.6MW

As a result of increasing the steam generation of the production well, the generator output of the modified unit became greater than the original output, despite the pressure decrease.

In the re-powering modification, the original turbine casing and the bearing pedestals are used as is, with no modification. The original rotor was employed after exchanging the blade rows. The 1st through 5th blade rows (double flow) are replaced with new blade rows re-designed conforming in accordance with the specifications; the remaining LP blade rows of the last three stages (L-0 through L-2) are unchanged.

Table 1 shows the major modified and replacement parts.

In this modification, future decreases in the well pressure was took into account.

The new specifications taken the future decrease in pressure into account are the following:

(1) Inlet steam pressure : 0.434MPa
(2) Inlet steam temperature: 143°C
(3) Inlet steam flow: 124kg/s (NCG content: 0.4%)
(4) Condenser vacuum : 10.2kPa
(5) Number of blade rows : 2 (flow) × 7 stages
(6) Speed : 3,600 r/min
(7) Rated output: 51.4MW

The generator output decreases from 55.6MW to 51.4MW due to the decreasing pressure of the production well while the steam generation remains unchanged.

A future modification is simply to remove the 1st stage blade row from the rotor and the casing. This can be performed quickly and at low cost.

4.2 Palimpinon Ⅱ

Four geothermal steam turbines for Palimpinon Ⅱ in the Philippines were put into commercial operation in 1993 and 1994. Palimpinon Ⅱ consists of Nasuji Unit 1, Okoy Unit 1 and Sogongon Units 1 and 2.

Table 2 shows the specifications of these power

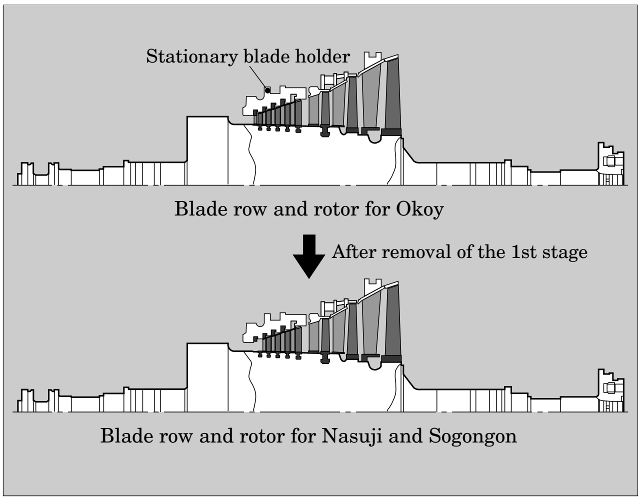
Table 1 Renewed and/or re-constructed parts and their details for NCPA U2

Parts	Details
Blade	1st to 5th stationary and moving blades, stationary blade rings were renewed.
Rotor	The original rotor is applied, being milled for 1st to 5th stage blade root.
Main stop & control valves	Stop valve and steam control valve were replaced.
Steam strainer, inlet steam piping	Replaced steam strainer as well as inlet steam piping with larger size are employed.
Governor	An actuator of steam control valves is modified.

Table 2 Major specifications of the geothermal steam turbines in Palimpinon Ⅱ district

Item / Plant name	Rated output (MW)	Number of unit (unit)	Main steam pressure (MPa)	Main steam temperature (°C)	Exhaust steam pressure (MPa)	Number of stage (stage)	Main steam flow (kg/s)
Nasuji	20	1	0.57	162	0.0137	8	43.89
Okoy	20	1	0.77	174	0.0127	9	40.56
Sogongon	20	2	0.57	162	0.0137	8	43.89

Fig.8 Geothermal steam turbine blade row as well as rotor for Palimpinon II district



plants.

The turbine inlet pressure of Okoy is higher than that of the other two plants, and the turbine for Okoy has 1 more stage than the other units.

The design philosophy is to maintain the generator output of Okoy by removing the 1st stage blade row in case there is a future decrease in production well pressure (Fig. 8).

By removing (machining off) the 1st stage blade row of the Okoy turbine, the turbine rotor will be common among these three geothermal power plants. A spare rotor can be used in any of the four units.

4.3 Selection of the appropriate solution

As described above, two solutions are available to maintain the generator output in case of a decrease in production well pressure, removal of the 1st stage and modification of the blade rows.

Selection of the appropriate solution depends on the characteristics of the production well.

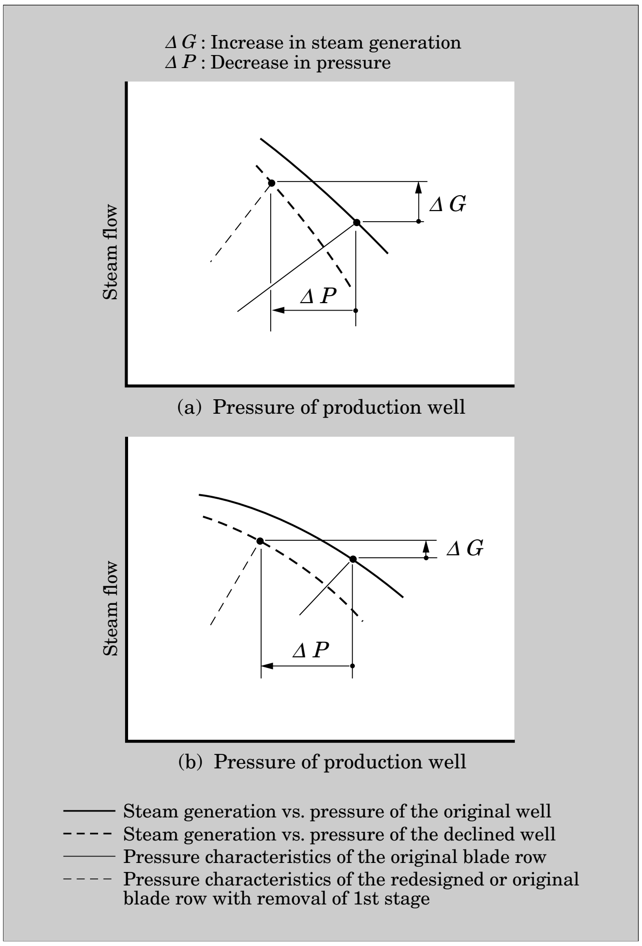
Figure 9 shows the pressure versus steam generation in the production well with inlet pressure versus steam flow of the turbine blade rows.

When the pressure versus steam generation characteristic of the production well is similar to that shown in Fig. 9 (a) in which steam generation simply increases with decreasing pressure, the large capital investment would pay off due to the increase in output despite the decrease in well pressure.

In this case, modification of the blade rows is selected to obtain greater output than that obtained by just removing the 1st stage.

However, the large capital investment might not pay off if the steam generation increases only moderately as the pressure decreases [Fig. 9 (b)]. In such a case, removal of the 1st stage may be selected to maximize the generator output.

Fig.9 Reduction of production well and pressure characteristics of turbine blade row



5. Conclusion

Fuji's geothermal steam turbines have consistently evolved through employing state-of-the-art technologies developed for fossil fueled steam turbines as well as through improvements base on our wealth of experience with geothermal steam turbines. Should production well pressure decrease in the future, two solutions are available to maintain generator output of Fuji Electric's geothermal steam turbines.

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