Recent Technologies for Steam Turbines

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ABSTRACT

In response to global environmental issues, higher efficiency and improved operational reliability are increasingly being requested for steam turbines, essential equipment for thermal power generation. By increasing the temperature and pressure of the steam turbine operating conditions, more efficient power generation is realized, and in order to realize a turbine applied with the higher temperature conditions of 700 °C for the future, Fuji Electric is participating in the METI-sponsored development of advanced ultra-supercritical power generation, and is evaluating and verifying the reliability of materials used for high-temperature valves. In addition, for geothermal steam turbines, Fuji has developed surface coatings and other technology for enhancing corrosion resistance in order to improve reliability. Fuji is also moving ahead with the development of geothermal binary power-generating turbines that utilize a low boiling point medium.

1. Introduction

In recent years, environmental measures such as for reducing CO_2 emissions have been implemented on a global scale. Demand for more efficient thermal power has also intensified than ever. Higher efficiency is also being required of steam turbines, which are a mature energy conversion technology. Improved reliability, operability and ease of maintenance are requested simultaneously in order to ensure the continued long-term supply of stable power.

To increase the inlet steam temperature and improve efficiency significantly throughout a plant, Fuji Electric is working to develop materials that have higher strength, longer life, and are capable of withstanding usage in higher temperature steam than in the past, and is also developing application technology. Meanwhile, to improve the efficiency of the steam turbine itself, Fuji Electric is also developing and commercializing new technology for the turbine blade row and steam seal areas which have a large effect on efficiency.

Fuji Electric manufactures not only conventional steam turbines, but, in the field of renewable geothermal energy, has also manufactured and delivered more than 60 geothermal turbines over a period of nearly 50 years, beginning with the construction of a practical geothermal power plant in 1960. At present, Fuji Electric is counted among the top manufacturers worldwide. This paper also introduces the technology in this field.

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2. Improved Efficiency Through Utilization of High-Temperature High-Pressure Steam Conditions

2.1 High-temperature materials technology for major components

The long-term rise in energy prices and heightened awareness of environmental issues, coupled with CO_2 emissions restrictions, are factors prompting improvement in plant thermal efficiency. New turbines tend to employ high temperature and high pressure conditions. In the large capacity turbines currently being manufactured, steam conditions of 25 MPa (abs) main steam pressure, 600 °C main steam temperature, 620 °C reheat steam temperature have become mainstream.

Figure 1 shows the high-temperature materials technologies used in the major components of a large capacity steam turbine, and these items are described in detail below.

(1) Development of materials for high-temperature turbines

In the pursuit of higher temperatures, high reliability can be ensured by using advanced materials having excellent high temperature creep characteristics, without changing the basic turbine structure. In particular, in a 600 to 620 °C class steam power plant, advanced 12% Cr steel is used in the rotor (Fig. 2), a main component, and as the casing material (Fig. 3).

(2) Overlay welding

Rotors made from 12% Cr steel are used in the high-pressure and intermediate-pressure rotors that require high-temperature strength. For the following reasons, however, these rotors have poor friction characteristics compared to low-Cr steel rotors.

(a) Thermal conductivity is low.

(b) Oxide film is difficult to form on the surface.

Fig.1 High-temperature materials technology for large-capacity steam turbines

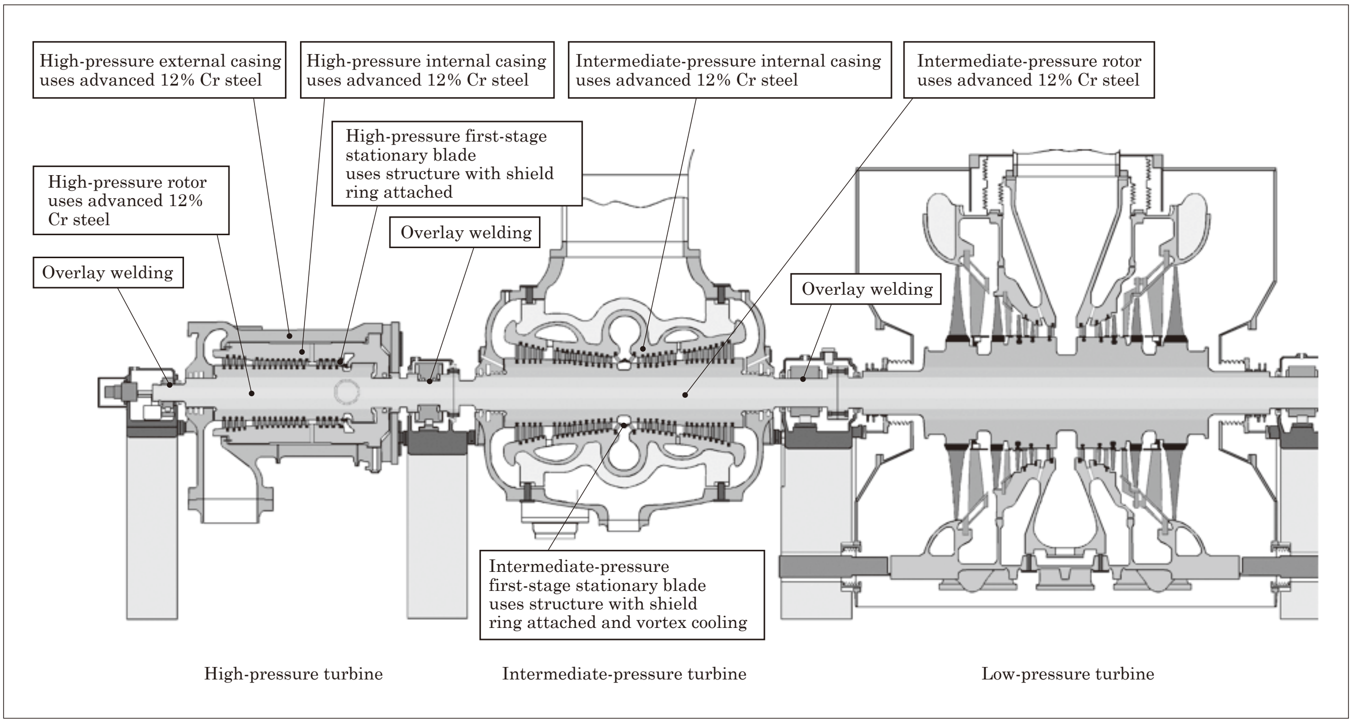


Fig.2 Rotor prototype under construction

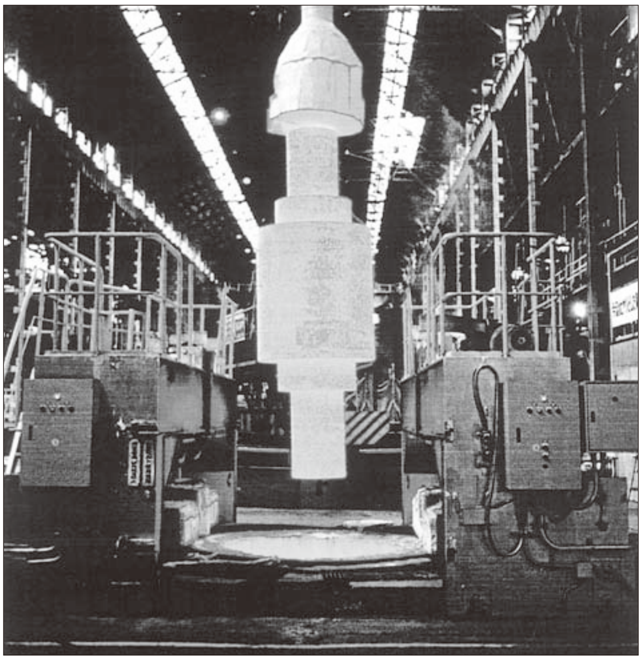
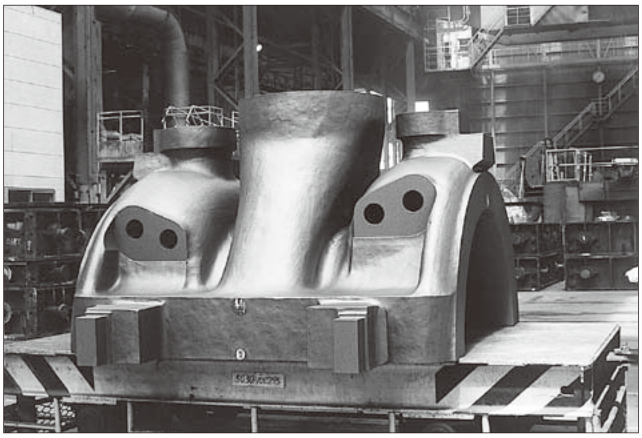


Fig.3 Intermediate-pressure internal casing under construction



(c) Carbonized compounds are formed easily from the carbon in the lubricating oil and Cr.

As a countermeasure, low Cr steel is overlay-welded onto rotor surfaces in the journal area, the thrust collar area and the pass-through areas of the bearing pedestals, and Cr content in the rotor surface layer is set to an amount equivalent to that of 1% Cr steel to prevent damage to the axle from burn-in or scraping.

(3) Stationary blade with shield ring (Fig. 4)

In the first stage of high-pressure and intermediate-pressure turbines, a stationary blade with a shield ring is employed so the high temperature inlet steam does not make direct contact with the rotor surface. Low temperature steam, after having passed by the initial-stage stationary blade, flows toward the rotor surface so that the rotor surface is maintained at a low temperature and the increase in creep life consumption is suppressed.

(4) Vortex cooling (Fig. 4)

In the first stage of a double-flow type intermediate-pressure turbine, a portion of the reheat steam from the tangential steam flow inlet open to the shield ring forms a swirling flow and is discharged, and vortex cooling is used to cool the rotor surface. In intermediate-pressure turbines, vortex cooling combined with the aforementioned shield ring prevents the rotor surface from reaching a high temperature and suppresses an increase in creep life consumption.

2.2 Elemental technical development for 700 °C class high-temperature valves

For the practical application of advanced-ultra supercritical (A-USC) pressure thermal power generation technology, with which thermal efficiency is expected to be dramatically higher than conventional coal-fired power generation, a large capacity boiler turbine system for use in the power industry and capable of withstanding steam conditions of a steam temperature of 700 °C or higher and steam pressure of 24.1 MPa or higher must be developed. To develop this elemental technology, in 2008, the Japanese Ministry of Economy, Trade and Industry began funding project grants related to the development of practical elemental technology for A-USC thermal power generation. Fuji Electric is working to develop high-temperature valve elemental technology, one of the items for technical development in this grant-aided project.

(1) Overview of elemental technical development

A high-temperature valve is installed at the inlet to a steam turbine, and plays an important role in operations related to the safe running and stopping of the steam turbine, i.e., steam flow control and emergency shutdown when a protection device has been activated, and is required to be highly reliable at all times. Because it is exposed to high temperature steam, the sliding part is processed with a surface hardening

Fig.4 Stationary blade with shield ring and vortex cooling at intermediate-pressure turbine inlet

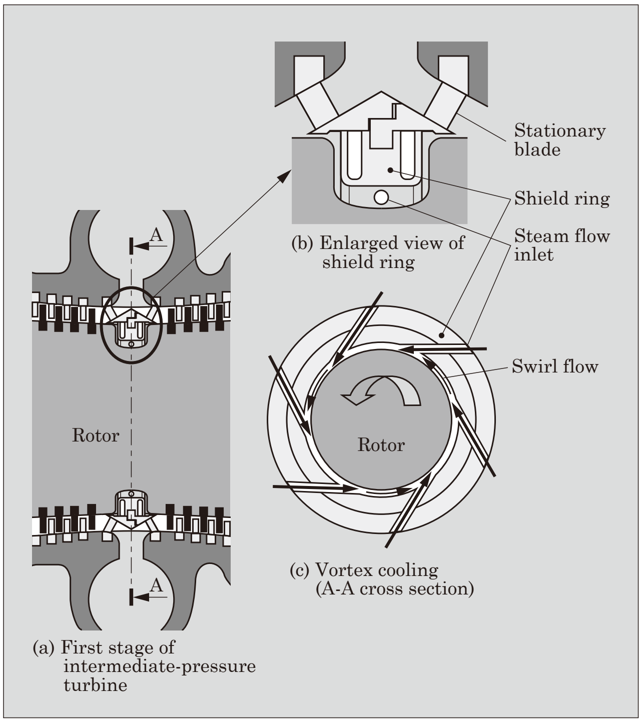


Fig.5 High-temperature wear tester

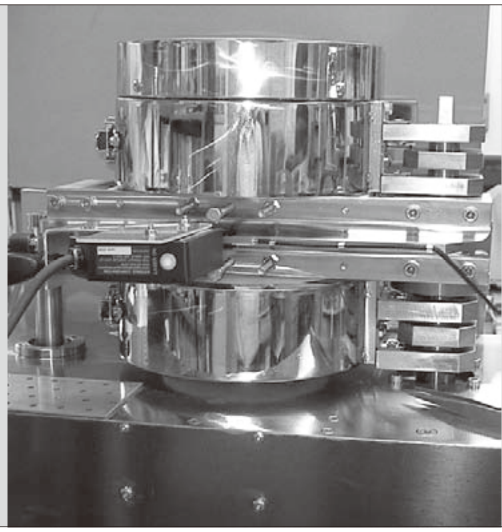
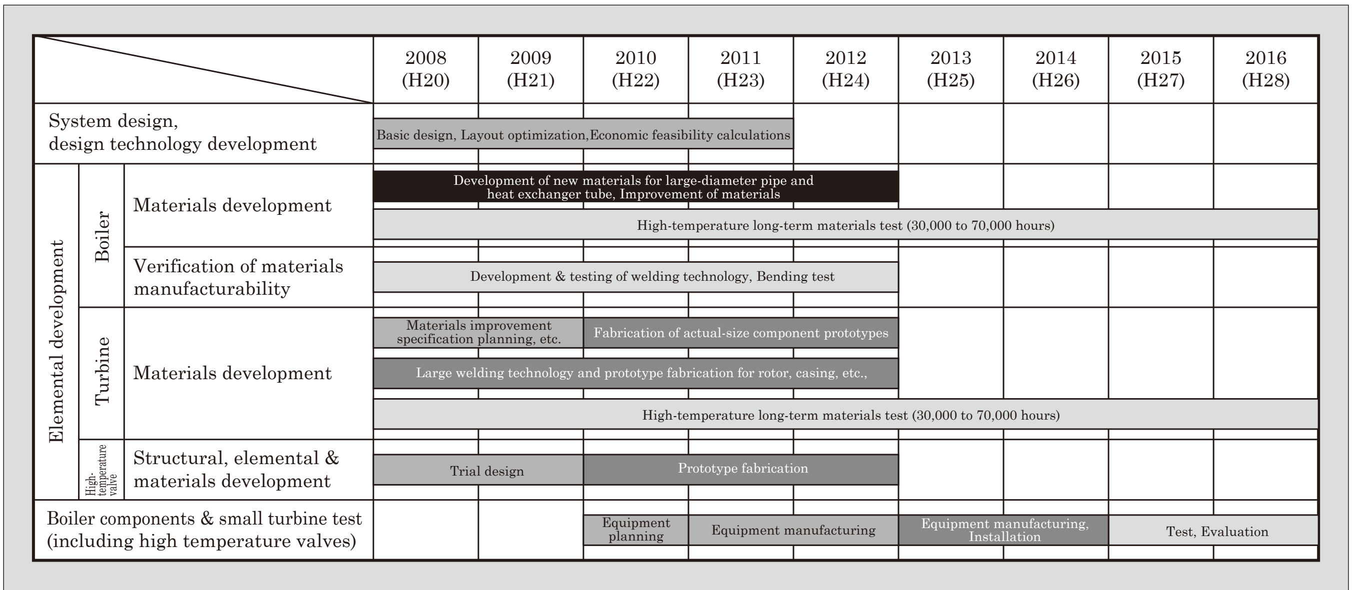


Fig.6 A-USC development schedule



treatment that results in excellent oxidized scale resistance, wear resistance, seizing resistance and sliding resistance. In a high-temperature A-USC plant environment where the steam temperature is 700°C or higher, in consideration of material strength, nickel-based alloys must be used as the main material. The friction characteristics and high-temperature oxidation characteristics of nickel-based alloys and surface-hardened conventional materials have not yet been clarified.

Fuji Electric has built a high-temperature wear tester (Fig. 5), and by measuring the amount of wear, has verified wear resistance and evaluated friction characteristics. Additionally, steam oxidation testing is being considered for evaluating the resistance to oxidized scale.

Based on the results of each verification test, materials are selected for the sliding parts and airtight parts, and this step leads to the design of the gap (clearance) in each sliding part.

(2) Development schedule

In this development, as a Japanese national grant-aided project, domestic Japanese turbine and boiler manufacturers joined forces with research institutions and began in fiscal year 2008 to advance elemental technologies development, materials development and system design according to the schedule shown in Fig. 6. Fuji Electric is in charge of consolidating development of high-temperature valves and plans to construct a full-size inlet valve and, beginning in 2013, to verify its functionality under steam conditions that are the same as actual conditions by performing boiler components and small turbine test.

3. Improved Efficiency Through Development of Elemental Technologies

3.1 Advanced small LP blades

By applying the design techniques for advanced low pressure (LP) blades developed for general-purpose large-size steam turbines to the design of LP blades of length of 560 mm or less, a series of high-efficiency small LP blades that aim to improve performance significantly has been developed (Table 1).

The main features of Fuji Electric's series of advanced small LP blades are as follows.

(a) Higher efficiency from a design that utilizes the latest CFD (computational fluid dynamics) technology

(b) Realization of a more compact size by increasing the load on each stage of the LP blades, and reducing the total number of stages of turbine blades

(c) High reliability based on extensive operating experience with prior-generation blades

Moreover, the application of this series of advanced small LP blades to geothermal turbines was considered during the planning stage, and in addition to the abovementioned characteristics, the following characteristics are also provided.

(a) High reliability as a result of materials selection and strength design for a corrosive environment

(b) Use of simple inverted T-shaped root at all stages to prevent deterioration of strength and reliability due to stress concentration

(c) Higher efficiency by attaching a shroud to all stages to reduce leakage loss at the blade tip

Figure 7 shows a rotor using a 555 mm blade, which is the largest size blade in the series.

Table 1 High-efficiency small LP blade series

50 Hz-use (nominal circular area)	60 Hz-use (nominal circular area)
555 mm blade (3.2 m^2)	462 mm blade (2.2 m^2)
487 mm blade (2.5 m^2)	406 mm blade (1.7 m^2)
348 mm blade (1.6 m^2)	290 mm blade (1.1 m^2)

3.2 Seal technology

To improve the performance of steam turbines, in addition to the aforementioned turbine blade development, technical development for improving efficiency is also needed.

Fig.7 Rotor using 555 mm blade (during implementation of rotational vibration test)

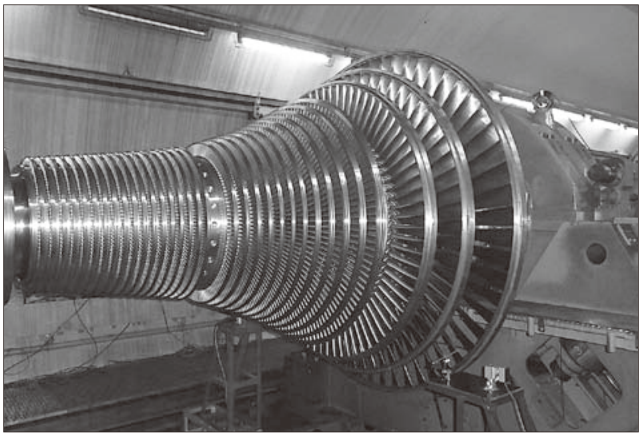
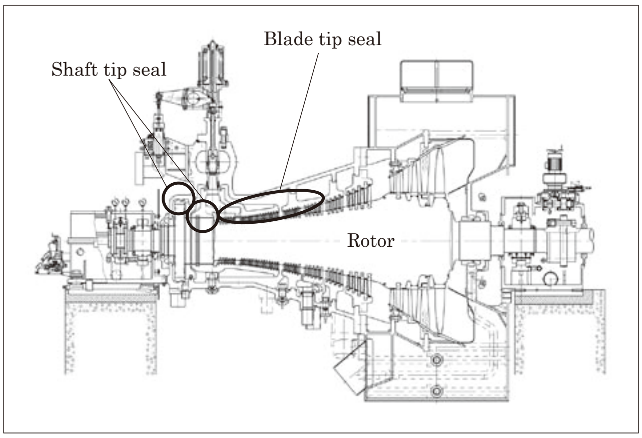


Fig.8 Locations where seal technology is applied

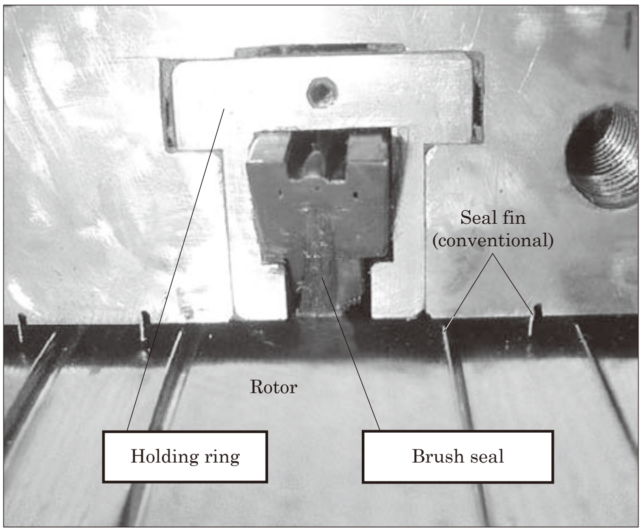


A clearance must be provided between the rotating body and stationary body in a steam turbine so that, throughout all operation zones, i.e., startup, normal operation and stopping, the rotating and stationary bodies will not contact each other. Consequently, the clearance must be larger than that required for normal operation, and this had become a limiting factor for improving efficiency. By applying the following seal technologies, the amount of steam leakage at the steam turbine blade tip and at the shaft end seal is reduced, efficiency is improved and reliability during operation is ensured as shown in Fig. 8.

(1) Brush seal

A brush seal is an aggregation of wear-resistant wires installed on the stationary side of the seal area. Figure 9 shows a verified example in which a portion of the seal fin of the shaft tip seal area has been replaced with a brush seal. With the wires of a brush seal, the effect from contact with a rotating body is much smaller than in the case of a conventional seal fin, and a minimum clearance can be maintained during operation.

Fig.9 Brush seal



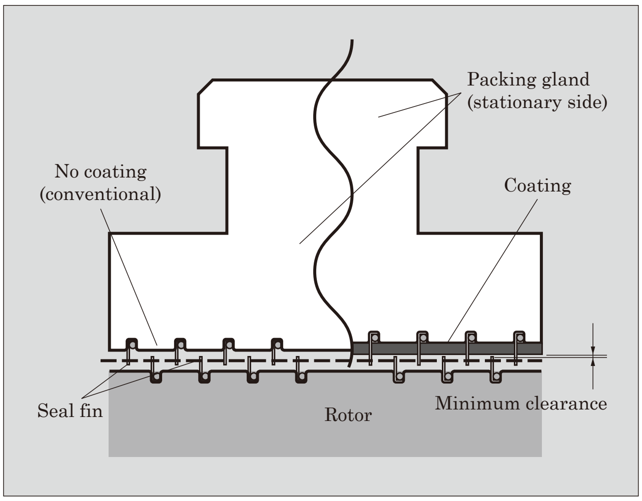
Assembly verification tests, the wear resistance tests and leakage characteristic tests have been completed, and brush seals are beginning to be used in steam turbines at power plants in Japan.

(2) Abradable coating

Abradable coating is a coating applied to free machining metal on the stationary-side inner surfaces that face the seal fin of the rotating side of the blade tip and shaft tip seal areas. Figure 10 shows a schematic diagram of a packing gland to which an abradable coating has been applied. The abradable coating reduces the effect of contact with the seal fin during operation of the steam turbine. Moreover, because the seal fin cuts into to the coating material on contact, the optimal and minimum clearance can be formed during operation.

The wear characteristics resulting from a contact test between the coating material and the seal fin have been verified, and abradable coating will be used in practical applications as of 2010.

Fig.10 Abradable coating



4. Utilization of Renewable Energy

Geothermal energy is a renewable clean energy source, and its utilization is expected to increase in the future to help prevention of global warming.

4.1 Geothermal turbines

Geothermal steam contains various corrosive chemical substances such as chlorides, sulfates, hydrogen sulfide and carbon dioxide. Even after geothermal steam is processed with a separator (steam separator) and flasher (vacuum evaporator) to remove those substances, the amount of corrosive components contained in the steam entering the turbine is 100 to 1,000 times that of a conventional steam turbine. Technology to improve resistance to such types of corrosion as whole surface corrosion of components, stress corrosion cracking (SCC), corrosion fatigue, erosion-corrosion and the

Fig.11 Application of thermal spray coating to rotor

like is needed. As the main techniques for addressing these issues, coating and shot peening techniques have been developed.

(1) Coating technology

Coating is a technique in which a thermal spray coating is applied to the surface of components in order to limit the whole surface corrosion and erosion-corrosion of components, such as the rotor and stationary blade holder, which are exposed to a highly corrosive geothermal steam flow (Fig. 11).

Basic testing at laboratories and corrosion testing at geothermal sites have been carried out, and coating technology for applying WC-CoCr-based thermal spray material with a HVOF (High Velocity Oxy-Fuel) thermal spray has been established and is being applied to actual turbines as a technique providing excellent corrosion resistance and erosion-corrosion resistance.

(2) Shot peening technology

Shoot peening technology has been developed and applied to actual turbines. With shot peening, high stress areas of the rotor are struck with a steel ball, generating compressive residual stress on the component surface and improving the resistance to SCC and corrosion fatigue.

The results of SCC tests and corrosion fatigue tests on blade materials and rotor materials treated with shot peening revealed significantly improved resistance.

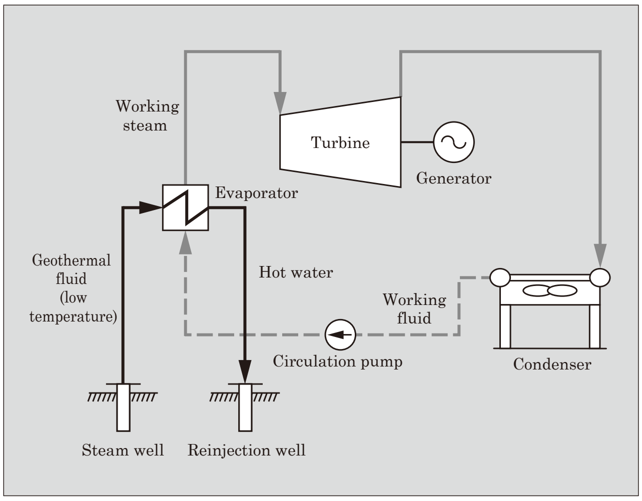
4.2 Turbine for geothermal binary power generation

In recent years, binary power generation systems, capable of recovering power from not only high-temperature geothermal wells but also from low-temperature geothermal energy sources that had not been utilized previously because of the difficulty of extracting energy, have been attracting attention due to the large number of available locations (Fig. 12).

Because low-temperature thermal energy has a low heat drop and is difficult to extract, it is often discarded without being used. In order to recover energy from low-temperature thermal energy, a medium having a lower boiling point than conventional steam vapor must be used. To commercialize power generation that uses low-temperature thermal energy, the technical challenges specific to low-boiling point media must be identified. That is, methods for analyzing and evaluating their (1) energy characteristics, (2) fluid characteristics, (3) strength characteristics, (4) seal characteristics and the like, must be developed.

In binary power generation, the main machinery is a steam turbine, and a low-boiling point medium is used as the working fluid. Accordingly, development is moving forward to meet the following two technical challenges.

Fig.12 Geothermal binary power generation system conception diagram



(1) Design of optimal flow path and blade row that uses a low-boiling point medium

To optimize the flow path shape, including the blade, the design methodology must be re-established and re-verified. For low-boiling point media that is completely different from steam vapor, design tools optimized for characteristics based on thermal dynamics, fluid dynamics and strength of materials analyses will be developed, and design techniques for the flow path shape and blade row design will be established.

(2) Development of seal technology

Because the low-boiling point medium used is flammable, there must be no leakage to the outside. Typically, however, the seal structure used in steam turbines is susceptible to leaks. Therefore, new seal structures capable of completely preventing the leakage of internal fluids are being developed and the technology is being established and verified.

5. Postscript

Fuji Electric has improved the reliability and performance of steam turbines, including geothermal turbines.

Fuji Electric is committed to development in order to continue to provide high-performance, highly-efficient and easy-to-use steam turbines.