Recent Technology for Improving Corrosion-Resistance and Performance of Geothermal Turbines

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ABSTRACT

Geothermal energy is a clean form of energy that produces almost no CO_2 emissions. Fuji Electric has supplied approximately 60 geothermal turbines to power plants in Japan and other countries. We have developed several technologies for improving corrosion-resistance of geothermal turbines, including shot-peening of turbine blade root and grooves, rotors made from 2% chromium steel and spray-coating technology. In the area of performance-enhancing technology, together with new-generation, low-pressure turbine blades for geothermal energy production and high-load, high-efficiency reaction turbines development, we have also achieved the creation of a high-performance, compact exhaust casing through optimized design. Furthermore, through use of triple-flash power generation, we have achieved the creation of a geothermal turbine with the greatest output for single-unit capacity in the world.

1. Introduction

In geothermal power generation, a fluid mixture (geothermal fluid) of steam and hot water heated by subterranean heat is extracted through a well (geothermal well) dug deep into the earth. The thermal energy of the mixture is then used to generate electricity. The amount of thermal energy in the earth is so vast that it could be said to be an inexhaustible supply for humankind. However, the energy that can be utilized is limited to the very small fraction of it that is in the earth's crust close to the surface of the earth. This is what is particularly referred to as geothermal energy. Geothermal energy differs from the generation of electricity by burning fossil fuels in that it is a clean energy that produces almost no CO_2 emissions, which are a cause of global warming. The energy density is high compared with other renewable energy sources such as wind and sunlight, and it also has the characteristic that the generation of electricity is stable and unaffected by factors such as the weather.

In 1960, Fuji Electric delivered to Hakone Hotel Kowakien, Fujita Kanko Inc. the first geothermal power generation equipment for practical use in Japan. Since then, Fuji Electric has supplied approximately 60 geothermal turbines to power plants in Japan and other countries and is noted as one of the top manufacturers in the field globally. This article introduces the anti-corrosion and performance enhancing technologies used in the latest geothermal turbines from Fuji Electric.

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2. Technologies to Improve Corrosion-Resistance [1][2]

2.1 Corrosion-resistance evaluation technologies

Large volumes of corrosive impurities are contained in the geothermal fluid. It is therefore essential for designing the geothermal turbines to evaluate the resistance of the materials to corrosion and the stress level at which use is possible. For this reason, in addition to implementing materials testing in a simulated geothermal environment in a laboratory, Fuji Electric installed test equipment at geothermal sites around the world and performed materials tests in the geothermal steam and condensates and accumulated data related to corrosion-resistance.

2.2 Measures against stress corrosion cracking and corrosion fatigue

In the designing of geothermal turbines, particular

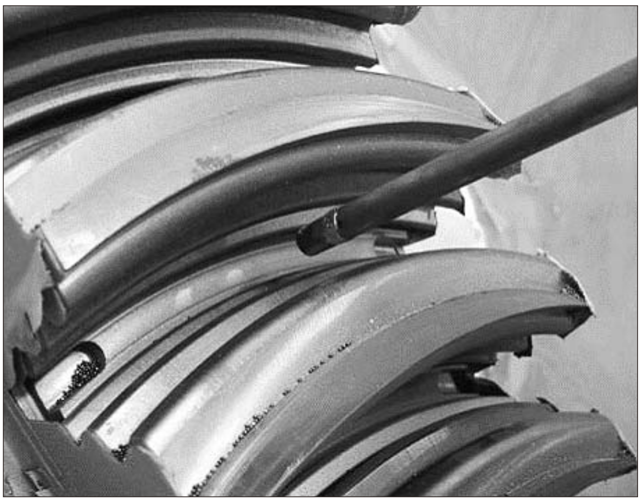


Fig.1 Shot-peening of rotor moving grooves

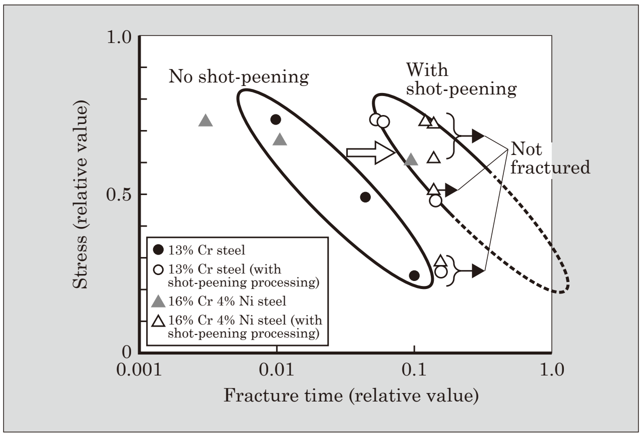


Fig.2 Improved proof stress through shot-peening (Results of stress corrosion cracking tests)

Fig.3 Coating with high velocity oxy-fuel spraying

problems arise with the turbine blades root and rotor grooves, which are exposed to high centrifugal force and steam pressure during operation. A technology was developed to improve the corrosion-resistance by performing shot-peening on the parts of the blade root and grooves where the stress is concentrated, and this technology was applied to actual equipment (see Fig. 1). In the results of comparative testing performed in a simulated geothermal environment, it was verified that the shot-peening greatly improved the strength of the components against stress corrosion cracking (SCC) and corrosion fatigue (CF). Figure 2 shows the results of SCC testing.

2.3 Measures against erosion-corrosion

In recent years, progress in exploration techniques and drilling technology for geothermal wells has resulted in the development of geothermal resources at comparatively deeper depths. Accordingly, the steam pressure at the inlet of the geothermal turbine has tended to be higher, rising from the conventional value of approximately 1 MPa to a value of approximately 2 MPa. With wet steam turbines*[1], increased steam pressure at the inlet results in a greater tendency for erosion corrosion to occur. Erosion corrosion is a degradation of material surface due to the combined effects of chemical and mechanical action of the steam flow. The stationary blade holders and rotor are made using carbon steel and low alloy steel, and their surfaces are prone to erosion corrosion. As a measure to erosion corrosion, Fuji Electric developed a rotor with 2% chromium steel, which has greater resistance to erosion corrosion than the 1% chromium steel conventionally used as a rotor material.

Technologies were also developed to coat the surface of the rotors with a WC-CoCr material using high velocity oxy-fuel (HVOF) spraying (see Fig. 3).

*1: Wet steam turbine: This refers to turbines where the main steam is saturated or nearly-saturated. They are also called saturated steam turbines.

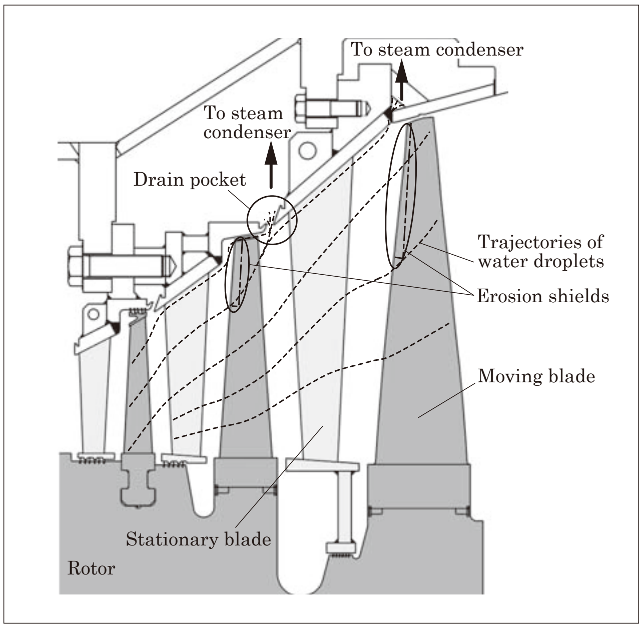


Fig.4 Drain removal structure

2.4 Countermeasures to erosion

Erosion caused by the impact of water droplets (drain attack) is the same phenomenon as in thermal power turbines. In geothermal power generation plants, where there is more hot water than steam, all stages are operated in wet steam, so it is necessary to consider drain attack and erosion in the design process. In addition to adding drain pockets to remove the water droplets that cause the erosion, protective measures are taken with the brazing of an erosion shield onto the leading edge of the moving blades (see Fig. 4).

2.5 Scale countermeasures

Silica, calcium carbonate and other substances contained in geothermal steam are deposited on the surface of components such as the blades, casing and rotor. Those impurities accumulate and become scale.

The scale that builds up on the surface of the blades narrows the passage for the steam and causes a fall in output. Furthermore, the scale that builds up in the gaps between the rotating parts and the static parts becomes a cause of abrasion on the components. Fuji Electric has developed blade washing technology with water droplets sprayed at the inlet of the turbine as a countermeasure to scale.

3. Technologies to Enhance the Performance of Geothermal Turbines[1]

3.1 New-generation, low-pressure turbine blades for geothermal use

Low-pressure blades (for the last 2 to 3 stages) have long blade lengths and are also used in wet steam, so they need to be resistant to excessive stress and erosion. A great deal of time and effort is therefore required in their development. For this reason, a range of products have been prepared as a low pressure blade series and makes it possible to select the optimal low-pressure blade design for a particular plant.

The new-generation, low-pressure turbine blades for geothermal use are based on a wealth of experience in geothermal turbine operation and are highly reliable. As geothermal turbines are used in a corrosive atmosphere, it is essential that special consideration is given in their design to matters such as stress corrosion cracking and corrosion fatigue. For this reason, in the development of the new series, by advancing the development based on established conventional development methods and adding three-dimensional viscous flow analysis and FEM analysis for the high-level optimization of the profile, we have achieved great improvements in efficiency compared with conventional models while securing reliability.

Figure 5 shows an example of flow analysis (Mach number distribution) on a low-pressure blade stage part for geothermal use. There has been minimization of the development of a boundary layer in the interference range slipstream caused by interference between an oblique shock wave from the trailing edge and an adjacent blade back edge boundary layer.

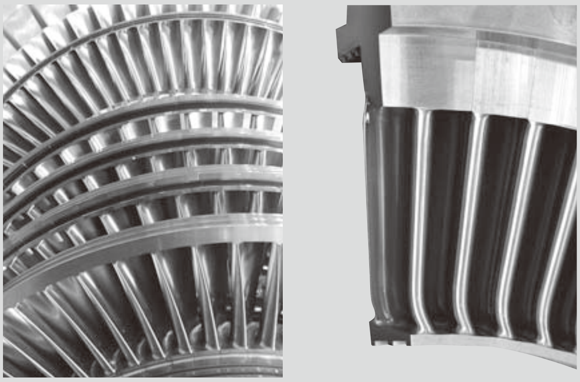
Fig.5 Example of flow analysis on a low-pressure blade stage part for geothermal use (Mach number distribution)

3.2 High-load, high-efficiency reaction blades

In stages other than low pressure blade stages, by using the latest design techniques for twisted blade stages, the stage efficiency was increased by 1 to 2% by adopting high-load, high-efficiency reaction blades that maintain high efficiency while increasing the load per stage. The high-load, high-efficiency reaction blades are integral shroud blades, with the blade and shroud machined together from one piece of bar material. This achieves high reliability against the highly corrosive geothermal steam (see Fig. 6).

3.3 High-performance, compact exhaust casing

The exhaust casing decelerates the steam discharged from the last stage blades and forms the flow passage leading to the condenser. The last stage discharged steam cannot be converted into rotational energy on the rotor and no longer contributes to the generation of electricity. Furthermore, the total pressure loss in the exhaust casing reduces the effective



(a) Moving blade (b) Stationary blade

Fig.6 High-load, high-efficiency reaction blades

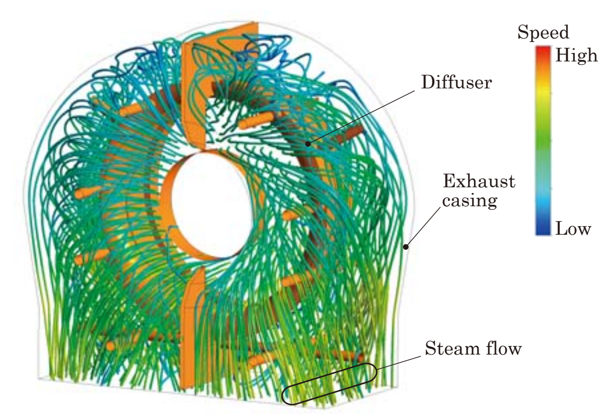


Fig.7 Results of three-dimensional viscous flow analysis on exhaust casing for geothermal use

heat drop on the turbine stage, so the result is that the performance of the turbine is reduced.

In general, if the exhaust casing is made more compact, then the reduction in the passage cross section increases the speed of the steam flow, which is disadvantageous for the performance. Fuji Electric has therefore optimized the profiles of the exhaust casing and the diffuser using three-dimensional viscous flow analysis. This results in a diffuser profile that has a deceleration effect greater than conventional models. By increasing the effective heat drop on the stage and reducing the total pressure loss after the diffuser outflow, a more efficient and compact exhaust casing was achieved (see Fig. 7).

4. Characteristics of the Latest Geothermal Turbines

The geothermal turbine for the Nga Awa Purua (NAP) Geothermal Power Station in New Zealand, which began operations in 2008 (see Fig. 8), uses a 798 mm blade at the final stage, the biggest in the world for geothermal power generation use. Figure 9 shows a cross section diagram of the geothermal turbine for the NAP geothermal power station. Figure 10 shows the geothermal turbine rotor installed and Fig. 11 shows the external appearance of the geothermal turbine for the NAP geothermal power station.

Fig.8 Overview of the Nga Awa Purua Geothermal Power Station

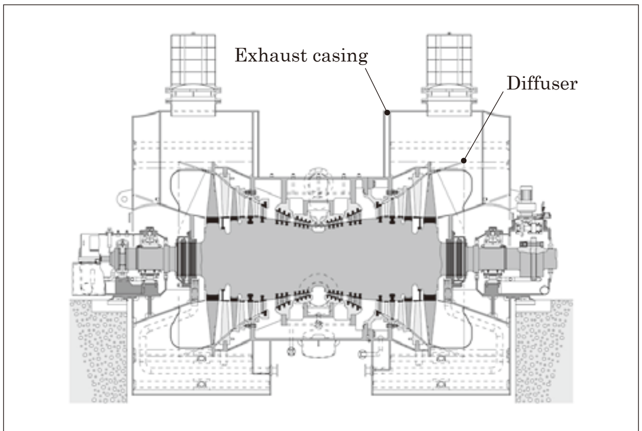


Fig.9 Cross section diagram of the geothermal turbine for the NAP geothermal power station

Fig.10 Geothermal turbine rotor installed

Fig.11 External appearance of the geothermal turbine for the NAP geothermal power station

While most geothermal power generation plants use either single-flash power generation or double-flash power generation, the NAP geothermal power station uses triple-flash power generation. After some hot water vaporizes in the first flash tank, the remaining heated fluid is flashed further in 2 additional tanks and the resulting steam is introduced into the intermediate pressure and low pressure sections of the turbine. This makes it possible to maximize the use of the geothermal energy and the maximum output of 140 MW is achieved, which is the greatest output for single-unit capacity geothermal power generation equipment in the world. Fuji Electric received many prizes for the development of this equipment, including the 59th Electrical Science and Engineering Promotion Award and the Low CO_2 Kawasaki Brand 2012 grand prize.

5. Postscript

Geothermal power generation does not consume fossil fuels and is a clean form of power generation that generates almost no CO_2. It is expected that geothermal power generation will develop even further, and Fuji Electric will work as a top manufacturer of geothermal power generation equipment to improve the reliability and performance of geothermal turbines.

We will steadily promote our products development so that we can continue to supply high performance geothermal turbines that are easy to use.

Reference

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