Latest Steam Turbine Technologies for Thermal Power Plants

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ABSTRACT

With features such as high power-generating efficiency and low CO_2 emission, combined-cycle power generation, combined with gas turbine and steam turbine, is gaining wider use. For the Yoshinoura Thermal Power Station of the Okinawa Electric Power Company, Incorporated, which is a combined-cycle power generating facility, we supplied single-cylinder reheat steam turbines with axial-flow exhaust that feature a clutch between the generator and the steam turbine. Also, for SUR power plant in Oman, we supplied two-cylinder reheat steam turbines with dual-sided exhaust that feature exhaust directions are left and right.

As the latest technologies in steam turbines for thermal power plants, we are developing welding technology, USC turbine technologies and technologies to improve reliability of low-pressure blades.

1. Introduction

Combined cycle power plants (CCPP) that use a gas and steam turbine in combination have been used increasingly in recent years in order to increase economic efficiency at power plants and in response to societal needs for reducing the emissions of greenhouse gases. Compared to conventional thermal power plants that combust fossil fuels in a boiler, CCPPs are more efficient, and because they use natural gas as fuel, have lower CO_2 emissions, and the combination of a gas turbine with a small steam turbine enables rapid start up and provides a high level of operability.

The Yoshinoura Thermal Power Station of the Okinawa Electric Power Company, Incorporated, which began operation in November 2012, is a 1-on-1 type CCPP in which the gas turbine, generator and steam turbine are arranged on a single shaft, and uses a single-cylinder reheat steam turbines with axial-flow exhaust (91 MW).

The Oman-SUR CCPP, shipped by Daewoo E&C in January 2013, is a 2-on-1 type CCPP configured from 2 sets of gas turbines and generators, and 1 set of a steam turbine and a generator, and uses a two-cylinder reheat steam turbines with dual-sided exhaust (330 MW).

This paper outlines the characteristics of the steam turbines for these two CCPPs, and also describes Fuji Electric's latest technology for steam turbines.

2. Steam Turbine for the Yoshinoura Thermal Power Station

This facility is a single-shaft type combined cycle power generating facility, and is the first facility in which the Okinawa Electric Power Company, Incorporated used LNG as fuel. Installation of the Unit No. 1 exhaust heat recovery boiler began in April 2011, and installation of the gas turbine unit began in July of the same year. The Unit No. 1 began trial operation in May 2012, and then started commercial operation in November 2012. In addition, the Unit No. 2 began commercial operation in May 2013. Features of the steam turbine used are listed below.

(a) To support a single-shaft type combined cycle system, a clutch for engaging and disengaging with the gas turbine and generator is provided at the end of the steam turbine rotor.

(b) The steam turbine is a compact-size, high, intermediate and low-pressure integrated-type turbine in which high, intermediate and low-pressure turbines are consolidated into a single casing. Figure 1 shows the external view of the

Fig.1 Steam turbine for Yoshinoura Thermal Power Station

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stream turbine for the Yoshinoura Thermal Power Station.

2.1 Use of a clutch

In the single-shaft type combined cycle system used at the Yoshinoura Thermal Power Station, the gas turbine, generator and steam turbine rotor are aligned in tandem. Compared to a multi-shaft system in which the gas turbine and the steam turbine each have their own generator, a single-shaft type combined cycle system enables the power plant building to be made much smaller in size. Figure 2 shows the single-shaft and multi-shaft configurations. With a single-shaft system, the gas turbine and steam turbine are aligned in tandem, with a generator positioned between them.

With combined cycle power generation, the exhaust heat from the gas turbine is used to supply steam to the steam turbine, and therefore the start timings of the gas turbine and steam turbine are different. For this reason, a clutch is used that can temporarily engage and disengage the steam turbine.

First, with the clutch in the disengaged state, the gas turbine and generator are started, and at the stage when the steam is ready to be supplied to the steam turbine, the steam turbine valve opens and the steam turbine begins to speed up. Then, after the rotational speed of the steam turbine rotor reaches its rated speed and at the stage when it exceeds the rotational speed of the gas turbine rotor, i.e., when the torque from the steam turbine toward the generator becomes positive, the clutch engages mechanically and the torque from the steam turbine is transmitted to the generator.

Figure 3 shows the clutch structure. The clutch lubricating oil is supplied from the bearings located at both sides of the clutch. The clutch is kept constantly lubricated so that it may be engaged at any time. The lubricating oil also functions as a damper that absorbs mechanical shocks at the time when the clutch engages. As a result of the viscosity of the oil in the interior of the clutch, even before opening the valve prior to starting the steam turbine, the rotation of the gas turbine will cause the steam turbine to speed up to about 400 rpm.

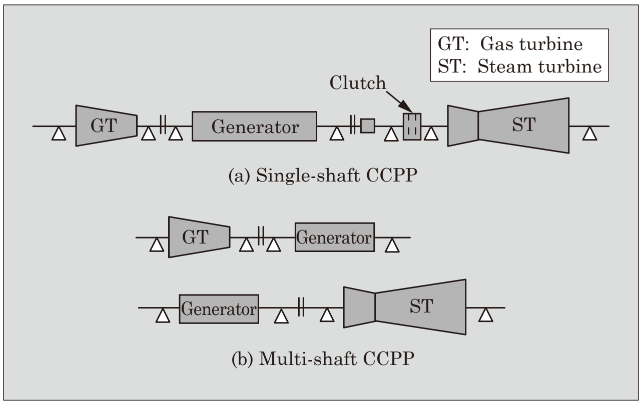

Fig.2 Single-shaft and multi-shaft CCPP configurations

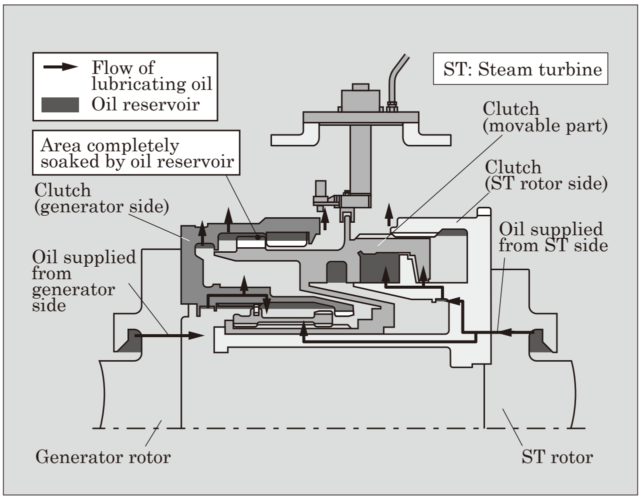

Fig.3 Clutch structure

2.2 High and intermediate pressure integrated-type turbine

Figure 4 is a cross-sectional view and Fig. 5 is a bird's-eye view of the steam turbine used at the Yoshinoura Thermal Power Station.

The turbine is composed of a high-pressure section, an intermediate-pressure section and a low-pressure section. The main steam, at high temperature and pressure, flows into the high-pressure section of the casing via a main steam valve located on the top of the casing, and the steam, after expanding and completing its work, is discharged through a cold reheat steam pipe. The reheated steam is directed back to the turbine via a reheat steam valve located in the middle of the casing. Then, after the steam completes its work at the intermediate-pressure section, it is additionally mixed with the low-temperature steam that has been

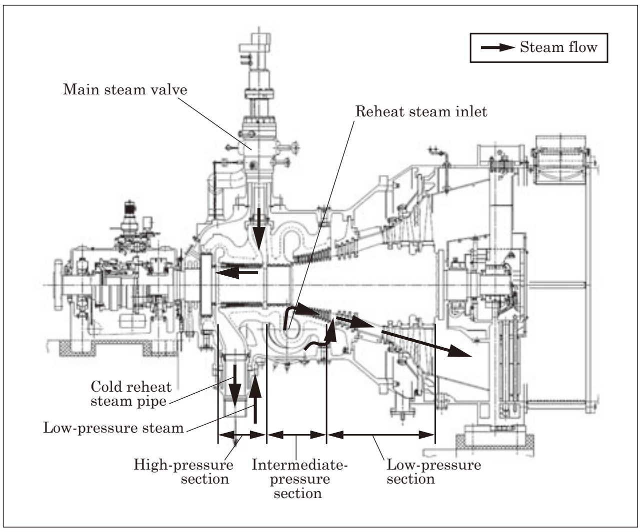

Fig.4 Cross-section of steam turbine for Yoshinoura Thermal Power Station

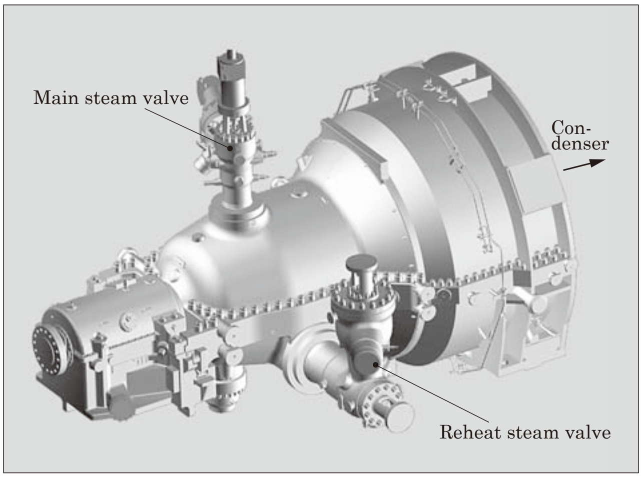

Fig.5 Bird's-eye view of steam turbine for the Yoshinoura Thermal Power Station

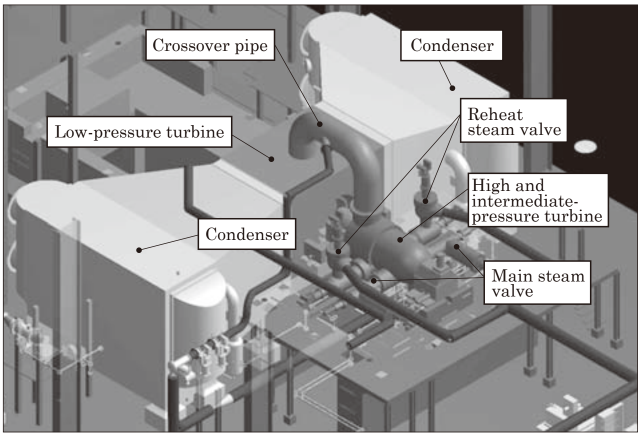

Fig.6 Bird's-eye view of steam turbine for SUR plant CCPP

supplied to the casing, directed to the low-temperature section and discharged in the turbine axial direction to reach the condenser.

So that a turbine conventionally configured with two casings can be configured with a single casing, the following structure was used.

(a) One set of main steam valves are positioned on the upper side of the turbine casing and one set of reheat steam valves are positioned on the side of the turbine casing.

(b) Because the high-temperature sections are concentrated in the center, the high-pressure section and the intermediate-pressure section utilize counterflow.

(c) By locating the low-pressure steam inlet at the front of the casing and creating a flow of steam between inner and outer casings, the structure makes it less likely for a top/bottom temperature difference of the casing.

In the trial operation of the Units No. 1 and No. 2, a good operating state, with minimal vibration and top/bottom temperature difference of the casing, was confirmed for both continuous operation and start-up/shut-down process.

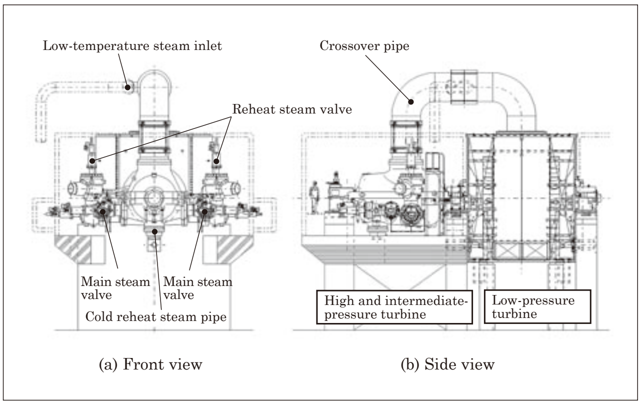

Fig.7 Outline view of steam turbine for SUR plant CCPP

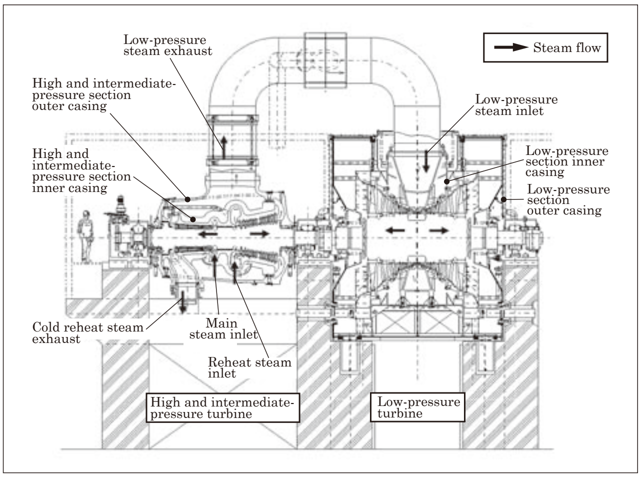

Fig.8 Cross-sectional view of steam turbine for SUR plant CCPP

3. Steam Turbine for the SUR Plant CCPP from Daewoo E&C

This system, a steam turbine that generates power by utilizing the exhaust heat from two gas turbines to generate steam with an exhaust heat recovery boiler, is composed of two components, a high and intermediate-pressure turbine for the high-pressure and intermediate-pressure sections and a low-pressure turbine for the low-pressure section.

Figure 6 shows a bird's-eye view, Fig. 7 shows an external view and Fig. 8 shows a cross-sectional view of the steam turbine.

The high-temperature high-pressure main steam flows through a main steam valve, located at the lower part of the casing, and into the high-pressure section. Main steam then expands toward the front of the turbine, and after completing its work, is discharged through a cold reheat steam pipe. Reheat steam flows through the reheat steam valve, located at the lower central part of the casing, into the intermediate-pressure section. Reheat steam then expands toward the rear of the turbine, and after completing its work, is discharged through cross-over pipe, and then is supplied to the low-pressure turbine. Low pressure steam is mixed at the midpoint on the crossover pipe. After completing work at the low-pressure turbine, the steam reaches condensers located on either side of the low-pressure turbine.

Features of this turbine are as follows.

(a) The largest capacity high and intermediate-pressure turbine for Fuji Electric
(b) Low-pressure turbine with dual-side exhaust system allows for lower building height

3.1 330 MW high and intermediate-pressure turbine

Previously, this class of equipment (330 MW) has used a three-casing reheat steam turbine, consisting of a high-pressure turbine, an intermediate-pressure turbine and a low-pressure turbine. With the Sur CCPP, a more compact size has been realized by combining the high-pressure turbine and intermediate-pressure turbine components together as a two-casing reheat steam turbine. Fuji Electric's previous maximum capacity of a two-casing reheat turbine was 210 MW, but a larger size has been achieved by adopting the measures described below.

In order to cool the compact inner casing, in a double casing structure consisting of an inner casing and an outer casing as shown in Fig. 8, the pressure and temperature acting inside the turbine are apportioned so that a more compact volume can be achieved and intermediate-pressure section exhaust steam is flowed between both casings so that the inner casing can be cooled. Additionally, because the high-pressure exhaust steam is exhausted with an L-ring structure that does not contact the high-pressure outer casing, lower grade cast steel or cast iron is used as the material of the outer casing. Furthermore, to enhance the compactness of the outer casing and facilitate maintenance at the time of regular inspections, main steam valves and reheat steam valves are located at the lower left and right of the high and intermediate-pressure turbine as shown in Fig. 7(a).

3.2 Dual-side exhaust type low-pressure turbine

The low-pressure turbine casing consists of a low-pressure inner casing and a low-pressure outer casing. Steam discharged from the intermediate-pressure turbine is introduced via a crossover pipe to the low-pressure inner casing. Then, the steam expands to a vacuum pressure and passes between the low-pressure inner casing and the low-pressure outer casing and is discharged to the condenser. With a conventional structure, the exhaust steam is output to a condenser located directly beneath the turbine. Such a structure, however, has the disadvantage that the large volume condensers located under the turbine floor result in a turbine building that has a high height and is more expensive to build. In this system, as shown in Fig. 6, condensers are located on either side of the low-pressure turbine so that the turbine building does not have to be as tall, and can therefore be constructed less expensively. In developing the low-pressure outer casing for the dual-side exhaust type turbine, we studied how to ensure the same steam flow area as with a downward exhaust type and how to reinforce the inner structure so as to be able to withstand vacuum pressures, and also reviewed the turbine anchor points and considered a divided approach to improve the ease of maintenance. By applying a proven structure for the low-pressure inner casing, the same level of quality as in a conventional structure is ensured.

4. State-of-the-art Steam Turbine Technologies

4.1 Welding technologies

(1) Welding technology for rotor made of dissimilar materials

The material used in the rotor of a single-casing steam turbine is required to have the opposing characteristics of good creep strength at locations exposed to high temperature steam and good toughness at locations exposed to low temperature steam. Previously, 2% Cr steel, which is expensive but high toughness, or 1% Cr steel, which has poor toughness but is inexpensive, was used according to the magnitude of the centrifugal force acting on the center of the shaft, i.e., the length of low pressure blade or rotational speed. Recently, some plants require the use of longer low-pressure blades for which even 2% Cr steel provides insufficient toughness. For this reason, Fuji Electric has developed welding technology for a 1% Cr steel rotor having high creep strength at high temperatures and a 3.5% Ni steel rotor having higher toughness than 2% Cr at low temperatures. This technology can also be applied as an alternative to 2% Cr steel rotors for which material manufacturers are limited. Figure 9 shows a steam turbine that uses a rotor made from welded dissimilar materials.

(2) Rotor repair welding technology

In aged plants, cracks due to thermal fatigue may,

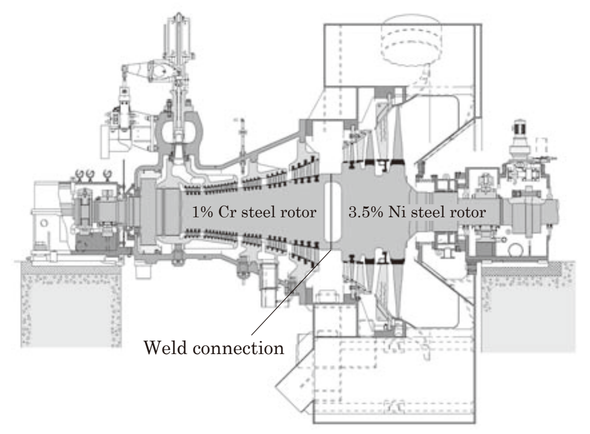

Fig.9 Steam turbine using rotor made from welded dissimilar materials

in some cases, be observed on the surface of rotors used at high temperatures. The operation of a turbine in which cracks exist in this state would be extremely dangerous. The manufacture of a new rotor requires that a plant be stopped for an extended period of time and thus results in a tremendous loss of profit to the customer. In order to minimize the duration of plant stoppage, Fuji Electric has developed weld repair technology for locations in which cracks have occurred.

(3) Weld repair technology for cast iron products

Because cast iron does not require complex heat treatment processing and has few material defects, for use at intermediate and low-temperatures where high thermal strength is not required, it is advantageous compared to cast steel in terms of a shorter manufacturing period and lower cost. With cast iron, however, defect areas are difficult to repair by welding and if a defect exceeds the allowable size in an area where strength is required, disposal and remanufacture will be necessary.

Welding tests were conducted on a test sample cut out from the excess material of an actual iron casting, and based upon the results of non-destructive testing, optimal welding conditions were established. The welding tests were performed using two welding methods, gas shielded tungsten arc welding (GTAW) for welding in a narrow range and shielded metal arc welding (SMAW) for welding in a broad range, two welding orientations, downward and horizontal, and three types of filler materials, Ni alloys, Fe-Ni alloys and Inconel alloys.

4.2 USC turbine technologies

(1) Domestic production of materials for use in USC turbines

In contrast to oil and natural gas that are concentrated in regions of political instability, coal is widely distributed over the earth, and thus from an energy-security perspective, coal-fired power generation is positioned as an important source of power.

On the other hand, coal-fired power generation has the largest amount of CO_2 emissions among the various types of thermal power generation that use fossil fuels (oil, gas or coal). Therefore in recent years, in the construction of large capacity coal-fired power generation facilities, ultra super critical (USC) plants that utilize high temperature and higher pressure to achieve higher thermal efficiency in power generation plants have become mainstream.

In 2002, Fuji Electric worked on a USC plant that used a steam turbine manufactured by Siemens AG and in which the main steam temperature was 600 °C and the reheat steam temperature was 610 °C. At that time, the main material of improved 12% Cr steel that was used in high temperature components was made all in Europe.

Because there are a limited number of suppliers of the main material used in USC plants, the domestic manufacture of USC turbines is considered to be an important factor in facilitating procurement of the main material. In collaboration with domestic materials manufacturers, Fuji Electric carried out prototype testing of rotor material and casing material of improved 12% Cr steel, established manufacturing technology and methods of evaluating material deterioration and embrittlement, and set domestic production of the main material as a goal. Figure 10 shows a prototype of a rotor made from improved 12% Cr steel.


Fig.10 Improved 12% Cr steel prototype rotor

(2) Remaining life assessment technology

Because of the significant cost and preparation time required for the renewal of a steam turbine in an aged plant, assessment of the remaining life and plans for renewal must be made at appropriate times.

For the 1% Cr steel used in subcritical pressure plants and supercritical pressure plants that have lower steam conditions than in a USC plant, master curves relating to the deterioration characteristics and embrittlement characteristics of the material have already been obtained. On the other hand, for the improved 12% Cr steel used in USC plants, however, master curves relating to deterioration characteristics and embrittlement characteristics have not yet been obtained. For this reason, in collaboration with Kagoshima University, Fuji Electric is advancing research to obtain master curves, with the goal of establishing basic technology for performing remaining life assessments.

4.3 Technologies for improving the reliability of low-pressure blades

(1) Corrosion monitoring technology

It is known that the likelihood for stress corrosion cracking at the low-pressure blades increases as

*1: Cation conductivity: The electric conductivity of a solution after having passed through a cation exchanger resin whereby the cations were exchanged for hydrogen ions. Cation conductivity is used to detect harmful anion concentrations such as trace quantities of chloride ions, sulfate ions, and the like.

the cation conductivity*1 of the main steam increases. Since the main steam properties are controlled at the boiler side, and because stress corrosion cracking occurs at the low-pressure blades which are located far away from the boiler outlet, real-time monitoring of the steam properties inside the turbine and accurate assessment of the risk of stress corrosion cracking are necessary.

For this reason, in collaboration with Tohoku University, Fuji Electric has developed a corrosion monitoring sensor and is conducting field tests. Figure 11 shows a drawing of the installation of a corrosion monitoring sensor. The corrosion monitoring sensor consists of sensors able to measure pH, chloride ion concentration and the corrosion potential, and enables the online monitoring of the corrosive environment at clearance gaps where corrosive components are likely to concentrate. Furthermore, a micro sampling device enables the steam inside a turbine to be sampled and analyzed.

(2) Vibration monitoring technology

The vibration characteristics of long low-pressure blades are complex and therefore if unproven low-pressure blades are to be used in an actual device, an acceleration sensor is attached at the time of shop balance testing, and rotation vibration tests are performed to verify the actual characteristics.

However, in contrast to shop balance tests that are conducted in a vacuum chamber at room temperature, the actual conditions in a turbine are a steam environment of changing temperature, pressure and flow rate. Thus, in order to ascertain the actual characteristics, low-pressure blade vibration must be measured under various operating conditions in a power plant. Therefore, we measured the vibration of low-pressure blades in operation. Figure 12 shows a drawing of the installation of a vibration monitoring sensor. By attaching multiple non-contact type eddy current sensors along the circumference of the stationary blade ring opposite the tip of the low-pressure moving blade, we successfully recorded continuous online measurements of the vibration of individual blades in operation. The sensors are housed in a titanium case so that long-term blade vibration monitoring will be possible.

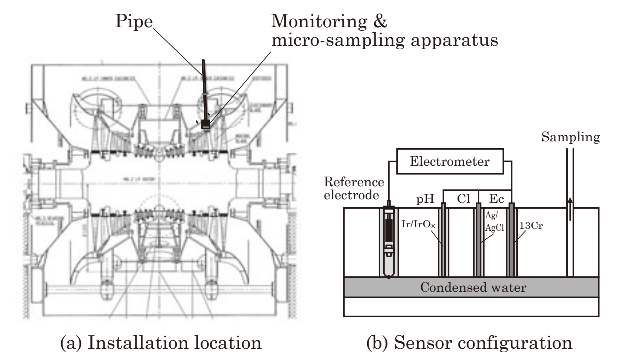

Fig.11 Installation of corrosion monitoring sensor

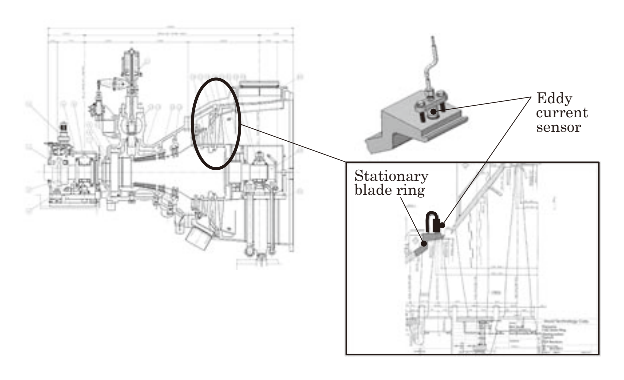

Fig.12 Installation of vibration monitoring sensor

5. Postscript

After the Great East Japan Earthquake that occurred on March 11, 2011, nuclear power plants in Japan have successively shutdown, and there are as yet no prospects for restarting them. During this period of prolonged shutdown of nuclear power plants, renewable energy and combined cycle power generation are seen as the future leaders for power generation.

In the field of coal-fired power generation, research and development of advanced ultra super critical (A-USC) power generation and integrated gasification combined cycle (IGCC) power generation, which are capable of further reducing CO_2 emissions below the levels of USC power generation, are being advanced. Fuji Electric intends to continue to pursue technical development in order to supply steam turbines that have high levels of performance and operability.

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