Global VPI Insulated Indirectly Hydrogen-Cooled Turbine Generator for Single-Shaft Type Combined Cycle Power Generation Facilities

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ABSTRACT

Fuji Electric has a great deal of experience in air-cooled turbine generators for global VPI insulation systems. We designed and built global VPI indirectly hydrogen-cooled turbine generators for the Yoshinoura Thermal Power Station Unit No. 1 and No. 2 of the Okinawa Electric Power Company, Incorporated. These are double-end drive generators for a single-shaft type, combined cycle power generation facilities that use many of the same basic construction and manufacturing methods as air-cooled turbine generators. Using data obtained through experience and results from ventilation analysis and strength analysis, we are achieving optimization and increased reliability.

Through each type of test, we are obtaining results that satisfy performance expectations and we are seeing favorable operating conditions at the power plants.

1. Introduction

The method of combined cycle power generation using a gas turbine and a small steam turbine has the advantages of good power generation efficiency and operability and a low environmental burden. It has therefore been adopted widely in recent years. Furthermore, a rapid start-up is possible with this power generation method. Thus, it is easy to carry out daily start and stop (DSS) operations and it is possible to deal with situations where there is a large difference in demand for power between the daytime and the nighttime hours. It is therefore expected that demand for the method will continue to increase.

The electricity generator that Fuji Electric has designed and built for the Yoshinoura Thermal Power Station Unit No. 1 and Unit No. 2 of the Okinawa Electric Power Company, Incorporated, is an indirectly hydrogen-cooled turbine generator using a global vacuum pressure impregnation (VPI) insulation system for single-shaft type combined cycle power generation facilities. This article introduces the characteristics of it and the technologies that were applied.

2. Characteristics of Single-Shaft Type Combined Cycle Power Generation Facilities

Combined cycle power generation facilities include the single-shaft type, where a gas turbine, generator and steam turbine are lined up along one axis, and the multi-shaft type, where the gas turbine power generation facilities and the steam turbine power generation facilities are installed separately. In general, with single-shaft type power generation facilities, multiple systems are installed and each can be operated independently. Individual systems can be stopped when the amount of power generation necessary falls and the other systems can be operated at the rated load. This makes it possible to maintain high partial load efficiency for the plant as a whole. Figure 1 shows an example of configuration of the single-shaft type combined cycle power generation facilities developed jointly by Fuji Electric and Siemens AG.

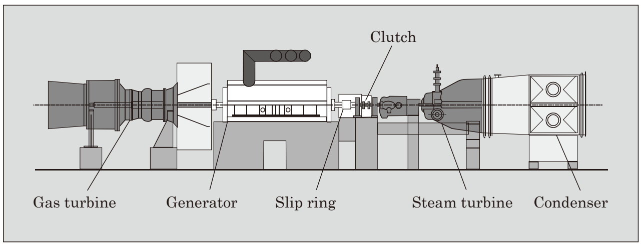

Fig.1 Example of configuration of single-shaft type combined cycle power generation facilities

3. Characteristics of the Power Generator

Table 1 shows the main specifications of the generator and Fig. 2 shows a cross section view. The structures and manufacturing methods used on the stator windings, stator core and rotor windings for this indirectly hydrogen-cooled turbine generator are roughly the same as those used for air-cooled turbine generators. This made it possible to achieve high reliability based on the great deal of experience gained in air-cooled turbine generators and by sharing the common technologies and equipment.

3.1 Cooling methods

This generator uses the indirect hydrogen cooling method for the cooling of the stator. The ventilation

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Table1 Main specifications of 300 MVA indirectly hydrogen-cooled turbine generator

Item	Specification
Output	300 MVA
Voltage	16,000 V
Power factor	0.85
Frequency	60 Hz
Coolant	Stator: Hydrogen indirect Rotor: Hydrogen direct
Hydrogen gas pressure	0.4 MPaG
Coolant gas temperature	43 °C
Speed	3,600 min^{-1}
Excitation	Static
Total length	13.1 m
Total mass	325 t

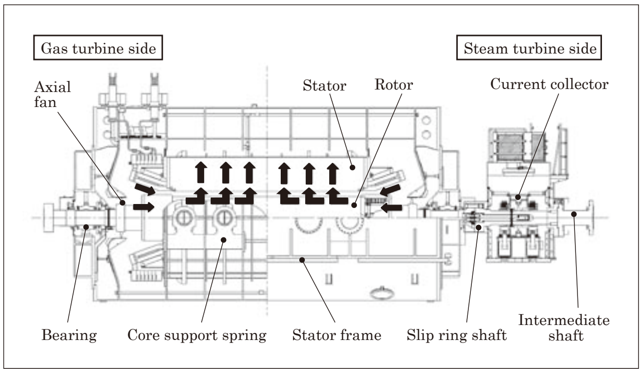

Fig.2 Cross section diagram of 300 MVA indirectly hydrogen-cooled turbine generator

path is as shown with the arrows in Fig. 2. Cooling gas is fed to the stator and rotor parts from an axial fan at both ends of the rotor. All the flow of the stator cooling gas is from the inner diameter side to the outer diameter side.

These cooling and ventilation methods are the same as on air-cooled turbine generators, in which Fuji Electric has a great deal of experience. The design was based on the data obtained from prototype experimental models and actual results. The optimal positioning of cooling ducts and distribution of cooling airflow is used to achieve a uniform distribution of temperature on the windings.

In addition, for the rotors, in order to achieve a uniform cooling flow in each part of the coil, inlet guide vanes were added to the internal diameter of the retaining ring support, as shown in Fig. 3. This improves the cooling performance.

3.2 Rotor structure

As shown in Fig. 1, in single-shaft type combined cycle power generation facilities, the gas turbine and steam turbine are positioned at both ends of the generator. The following consideration is therefore made.

(1) Bending and torsional vibration response calculations for the entire shafting

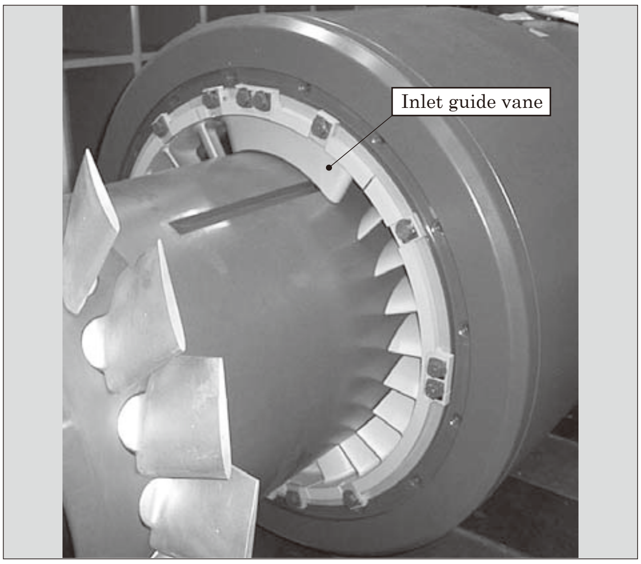

Fig.3 Inlet guide vane

Both gas turbine simple cycle*1 and combined cycle operations are possible on this power generation equipment. For both of these methods of operation, consideration is made so that a rated rotation speed and critical speed of the generator are not approached and there is sufficient consideration made for the vibration response.

(2) Slip ring shaft material

The generator rotors are double-end driven and the driving torque is transmitted. In addition, it is necessary to prepare sufficient strength to endure short-circuit accidents, and thus the same NiCrMoV steel material as on the generator shaft was adopted as the slip ring shaft material.

(3) Insulating coupling

There is a risk on the rotor axis that the electromotive force generated during operations may result in a return current between the main axis, the bearings and the structures connecting the two bearings, and this may interfere with the operation of the generator. Insulation is therefore installed on the bearings to cut off the electrical circuit and prevent a circulation of current flow. This time, in order to prevent the circulation of current flow through the intermediate shaft bearings, an insulating coupling is used in the connection between the slip ring shaft and the intermediate shaft.

3.3 Stator structure

The stator core is supported through the core support plate shown in Fig. 4 on the cylindrical stator frame, which is a pressure vessel. The structure has an appropriate spring effect to suppress the transmis-

*1: Simple cycle: An energy system where just power generation is performed with a motor using fuel.

Fig.4 Core support spring

sion of electromagnetic vibration from the core to the stator frame.

4. Global VPI Insulation Technology

The stator insulation is performed using the global VPI insulation technology that Fuji Electric has accumulated in many years of experience and a global VPI insulation system with global VPI manufacturing facilities that are the biggest in Japan and one of the greatest in the world.

Figure 5 shows the global VPI insulated stator. The stator windings and core are impregnated with insulating resin as one whole, the core, windings and wedges are therefore strongly attached and less likely to become loose. This improves the reliability and makes it possible to reduce maintenance work. Furthermore, as the spaces between the windings and core are filled with resin so that there are no gaps, there is the advantage that the heat dissipation from the windings to the core is improved, and the cooling performance is better than with impregnation of the windings alone.

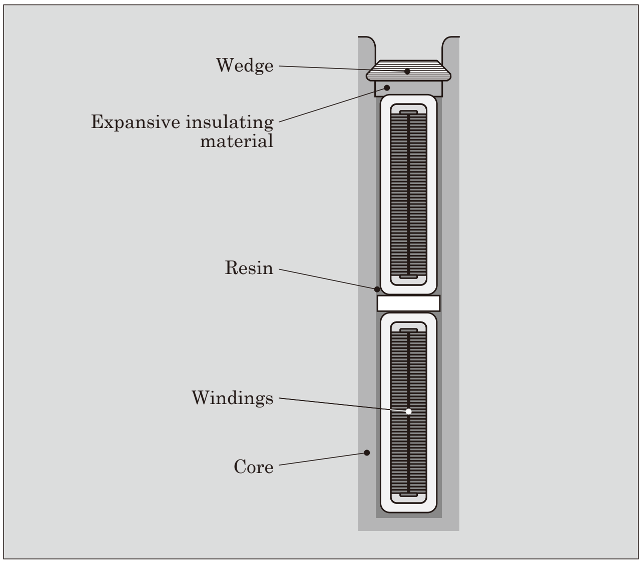

Fig.5 Global VPI insulated stator

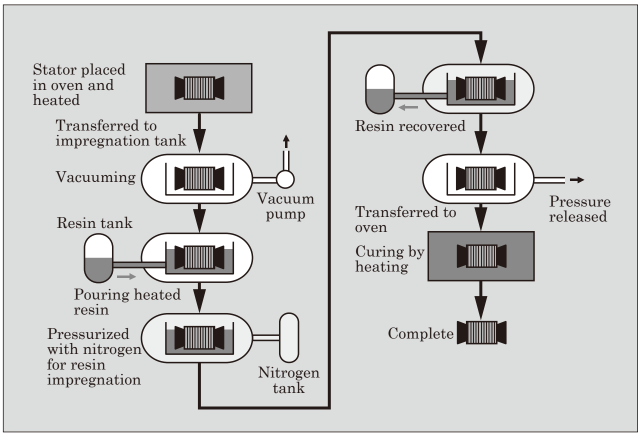

Fig.6 Global VPI insulation processes

Figure 6 shows the impregnation processing stages in global VPI insulation. After winding the mica glass tape or other on the conductors as the main insulating material, the windings are inserted into the stator core slot and the specified winding connections are made. Next, the stator core and windings are placed as one into an epoxy resin tank for vacuum pressure impregnation. With this process, all the windings are impregnated with resin at one time, and consequently it is extremely important for large-scale generators. For this reason, factors such as the viscosity of the resin and the compounding ratio of curing agent are strictly controlled, and a monitoring system takes measurements during the impregnation processing of a temperature, degree of vacuum, pressure during pressurization and capacitance of the windings for the constant monitoring and control of the status of the resin impregnation.

5. Analysis Technology

5.1 Ventilation analysis

In ventilation analysis, the improvements in hardware and software performance in recent years have made it possible to increase the number of elements in the analysis model and it has become possible to calculate complex flows such as the cooling ventilation in a generator with comparatively high accuracy. Furthermore, it is extremely difficult to actually measure the flow inside the rotor during operations, but it is now possible to understand the distribution of flow and other matters to a high level of accuracy by using thermo-fluid analysis. Fluid analysis is also used to realize optimal ventilation cooling in the design of global VPI insulated indirectly hydrogen-cooled turbine generators.

The following is an example of flow analysis on the rotor coil end part. Figure 7 shows a ventilation analysis model for the rotor. The outlet part of the axial fan at the shaft end, the space on the inner side of the coil end, the rotor coil cooling duct and air gaps have been modeled. Flow distribution was calculated for the con-

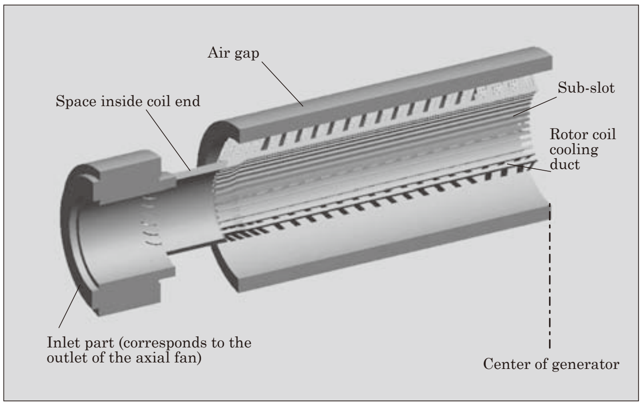

Fig.7 Ventilation analysis model for the rotor

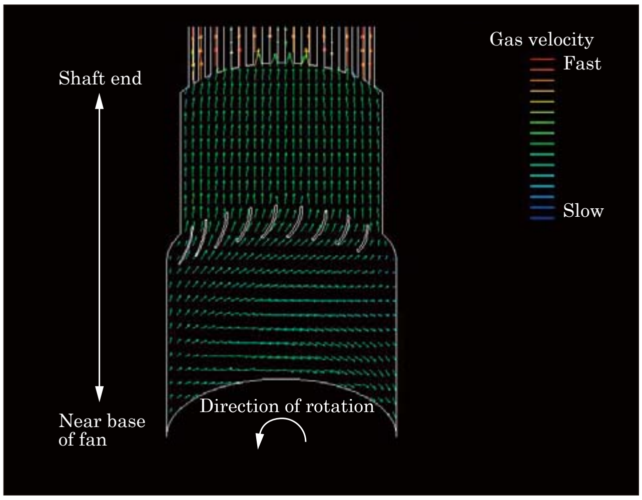

Fig.8 Example of results of ventilation analysis on the rotor coil end part

dition that the rotor rotates at its rated speed. For the boundary conditions for the axial fan part, which is the inlet to the analysis area, and the air gap, which is the outlet, flow distribution values calculated separately were used for the analysis. Figure 8 shows an example of the results of ventilation analysis on the rotor coil end part.

5.2 Strength analysis

Strength analysis was performed on the rotor retaining ring shrink fit area in order to secure reliability in frequent start-up/stop operations, which are a characteristic of combined cycle power generation. In order to retain the rotor coil end under the centrifugal force during rotation, the rotor-retaining ring is shrink-fitted to the rotor shaft end with a certain shrink-fit allowance. When stationary, compressive stress occurs on the shrink fit part on the rotor shaft end. When rotating, the centrifugal force means that the retaining ring diameter expands and the compressive stress is released. Consequently, start-up/stop operations mean that the stresses occur repeatedly. For this reason, in addition to avoiding the concentration of stress, consideration was also given to the reliability against repeated stress.

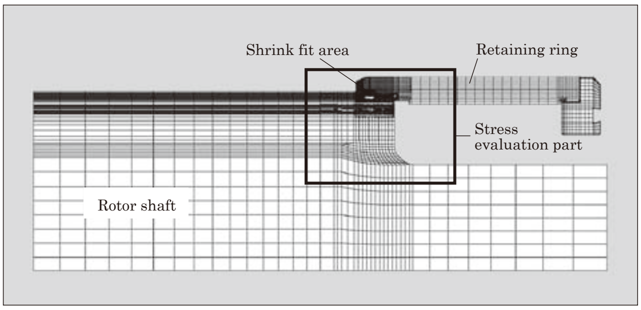

Fig.9 Strength analysis model of retaining ring

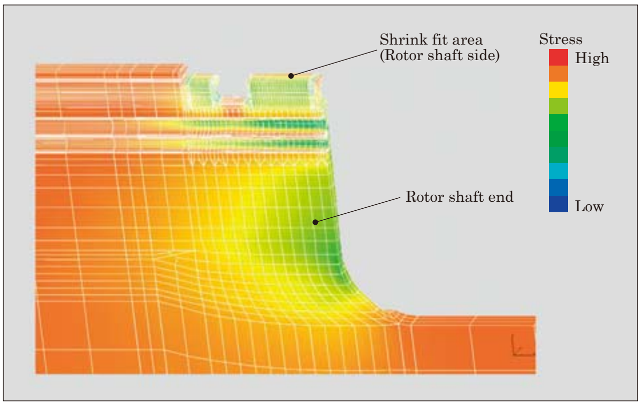

Fig.10 Results of stress distribution analysis on the rotor shaft end (Stress evaluation part)

Figure 9 shows the retaining ring strength analysis model. The structure of the retaining ring shrink fit area is very complicated, the strength analysis is therefore performed using a three-dimensional model. In addition, in order to correctly model the state of the stress, consideration was given to the non-linearity of the strain and stress, and the shrink fit surfaces of the rotor and the retaining ring were taken to be contact elements. Figure 10 shows the results of stress distribution analysis as an example of strength analysis at the rotor shaft end.

6. Related Equipment

6.1 Adoption of clutch

In between the generator and steam turbine, there is a clutch installed that can absorb the differential expansion and be automatically attached and removed. This means that the gas turbine and steam turbine can be designed independently for the thrust loading and the difference in thermal expansion that occurs due to changes in temperature during start-up/stop operations. Furthermore, the starting and stopping of the gas turbine is possible with no effect on the steam turbine. Thus the loss at the starting and stopping can be reduced.

6.2 Adoption of static frequency converter (SFC)

The method used for starting up the gas turbine is to use an SFC to drive the generator as a synchronous motor. This SFC is made up of a converter and an inverter, and it supplies the generator stator with the voltage and frequency necessary for the starting up and speeding up of the gas turbine. In addition, the generator excitation power supply during the speeding up is supplied from an excitation system. The use of this method means that a starting motor is not necessary and the shafting and overall arrangement is simplified. Furthermore, maintenance work is also simplified as the configuration includes only electrical equipment.

7. Factory Test Results

Fig.11 Global VPI insulated indirectly hydrogen-cooled turbine generator during factory testing

In June 2010, the various aspects of performance were verified in a no-load saturation test, three-phase short-circuit test, loss characteristic test, temperature rise test, sudden three-phase short-circuit test and overspeed test. Figure 11 shows a global VPI insulated indirectly hydrogen-cooled turbine generator during factory testing. The factory testing results were good, which satisfied the specifications and had good agreement with the design values.

8. Postscript

This article was centered around the characteristics and technologies of the global VPI insulated indirectly hydrogen-cooled turbine generators for single-shaft type combined cycle power generation facilities at the Yoshinoura Thermal Power Station Unit No. 1 and Unit No. 2 of the Okinawa Electric Power Company, Incorporated. Unit No. 1 started trial operations in May 2012 and commercial operations in November, and the status of operations is good. Moreover, commercial operations at Unit No. 2 started in May 2013. Fuji Electric will continue to respond to the needs of the market and to carry out technology development to produce high quality and highly reliable turbine generators.

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