

Fuji Electric's Medium-capacity Steam Turbines "FET Series"

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1. Introduction

Recently, de-regulation of the electric power industry and rising needs for advanced solutions to environmental concerns, have caused a great change in the area of thermal power generation. Further improvement for higher efficiency, a more compact design, optimal operating performance, and better maintainability and higher reliability is increasingly requested of the steam turbine industry.

For medium capacity steam turbines, there has been an increase in the use of combined cycle plants, in addition to their conventional use for private power generation. Accordingly, larger capacity single units, combined with advanced technology for higher efficiency, have been more in demand. Moreover, the axial flow exhaust type and the upward exhaust type steam turbine configurations are more favorable and popular, due to their lower construction costs.

Features of Fuji Electric's "FET Series" of standard medium capacity steam turbines, which achieves high efficiency with low-cost, are introduced below.

2. Concept of the FET Model Series

2.1 Applicable range

Specific demands for medium capacity steam turbines concern not only power generation, but also relate to industrial applications that provide the

function of extracting steam for various uses such as plant processes or utilities. The medium capacity steam turbine FET Series is a standardized model series suitable for a wide range of steam and output conditions.

The types of steam turbines, applicable steam conditions, output range and the rotational speed of the steam turbines are listed in Table 1.

2.2 Block design system

The standard FET Series of steam turbines utilizes a modular "block design system" in which suitable blocks are selected from several standardized components (Fig. 1) corresponding to the various required specifications and steam conditions of each project. This type of modular system design enables the best selection of blocks over a wide application range.

Each standard component has a proven track record of success, and a highly efficient turbine model can be realized by the proper selection of the optimum blocks. Standardization by means of this block design system will shorten the production lead-time and reduce the production cost. As a result, a steam turbine that satisfies customer requirements can be provided with a shortened delivery time.

3. Scaling-up to Larger Capacity FET Turbines

Many steam turbines for private power generation-use and having the capability to provide process steam have been furnished. Due to the worldwide trend toward de-regulation of the supply of electric power, private companies are increasingly joining IPPs (Independent Power Producers), and the need to scale-up the unit capacity of steam turbines has increased.

After the 101 MW FET turbine was put into operation in 1994, larger capacity units have been successively developed within the FET series, in accordance with market trends. The cross-sectional drawing of a recent FET steam turbine is shown in Fig. 2, and the specifications of these turbines are listed in Table 2.

Table 1 Range of Fuji Electric's medium capacity steam turbine "FET Series"

Type	<ul style="list-style-type: none">○ Condensing type○ Back pressure type○ Single / Double controlled extraction condensing type○ Single / Double controlled extraction back pressure type Operable as a mixed pressure type or an extraction / mixed pressure type.
Range of output	20 MW to 180 MW
Steam condition	Main steam pressure : 130 bar or less Main steam temperature : 540°C or less
Rotational speed	50 s ⁻¹ (3,000 rpm) or 60 s ⁻¹ (3,600 rpm)

Fig.1 Block design system of the FET Series

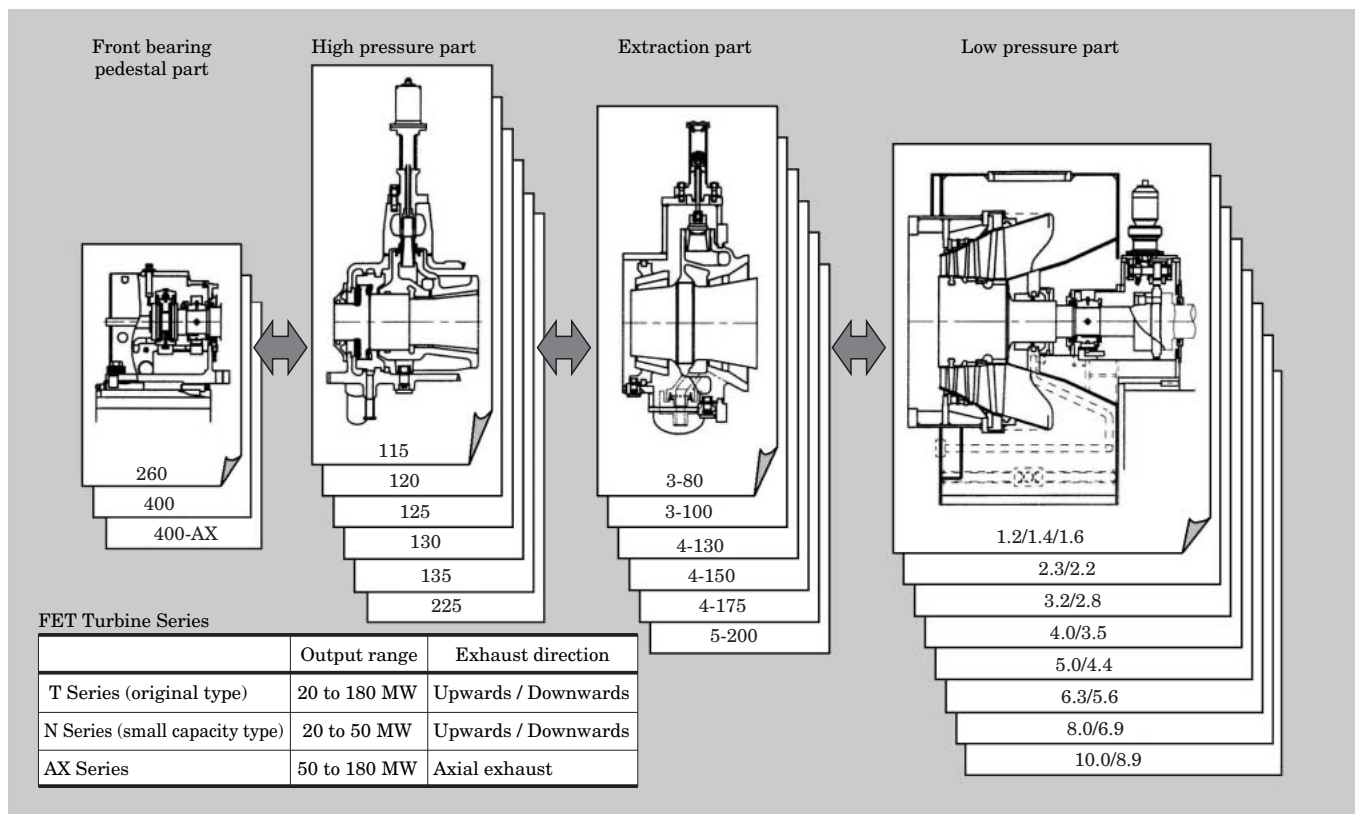
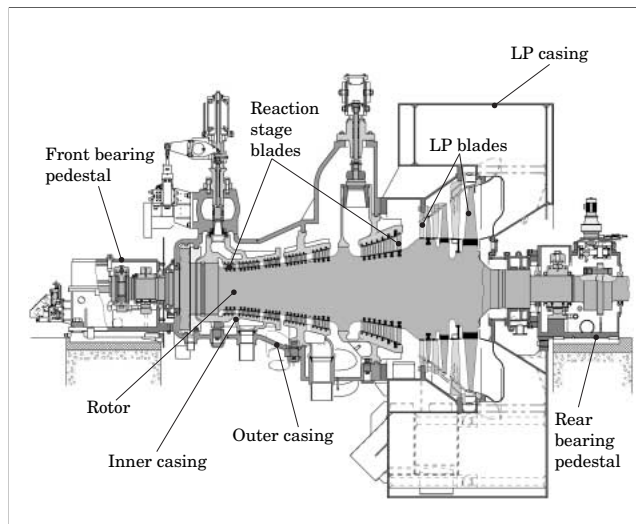


Fig.2 161.99 MW steam turbine, assembled cross-sectional drawing



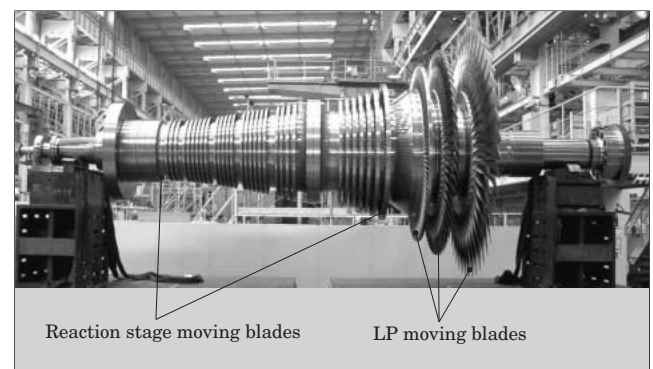
3.1 Highest internal efficiency with throttle governing system

The FET steam turbine has adopted a design that features a throttle governing system and a double shell casing structure with outer and inner casings, similar to that of large capacity turbines for utility power generating use. This design achieves higher efficiency by utilizing reaction blades in all stages, and does not use a nozzle governing impulse blades with partial

Table 2 Steam turbine specifications

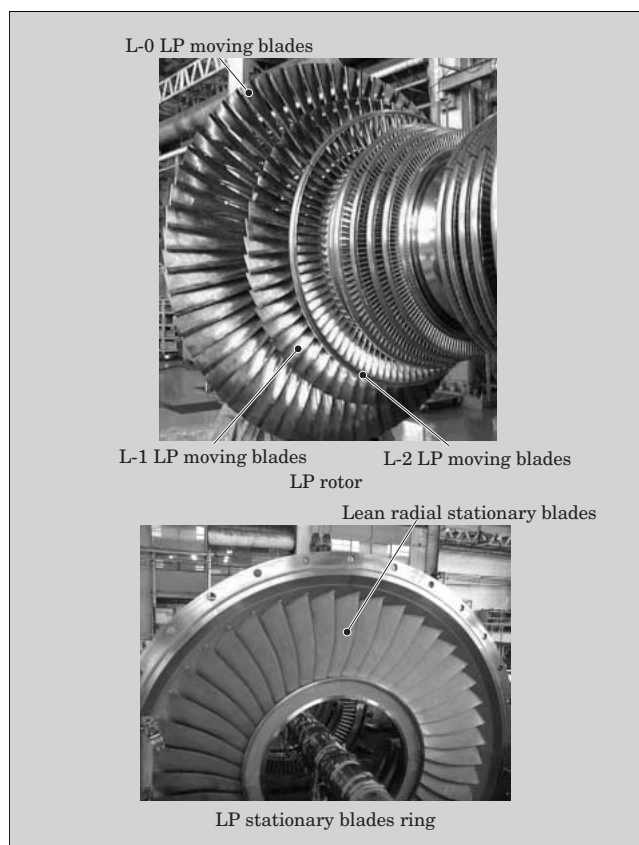
	Formosa Chemicals & Fibre Corporation SK-G4 (Taiwan)	Formosa Power (Ningbo) Ltd. Co. NB-1 (China)
Model	Single-extraction condensing	Single-extraction condensing
Output	147.88 MW	161.99 MW
Steam condition extraction pressure	123.6 bar / 538°C / 7.7 bar	123.6 bar / 538°C / 8.3 bar
Vacuum	0.088 bar	0.088 bar
Rotational speed	60 s ⁻¹ (3,600 rpm)	50 s ⁻¹ (3,000 rpm)
Operation start date	May 2000	July 2004

Fig.3 Reaction type steam turbine rotor



admission loss (see Fig. 3). Moreover, wear due to the

Fig.4 Advanced series low pressure blades



impact of solid particles (particle erosion) or deterioration of the blade surface can be reduced and deterioration of performance with aging will be minimal, due to the lower steam velocity with reaction blades than in the impulse stages.

3.2 Adoption of advanced series low-pressure blades

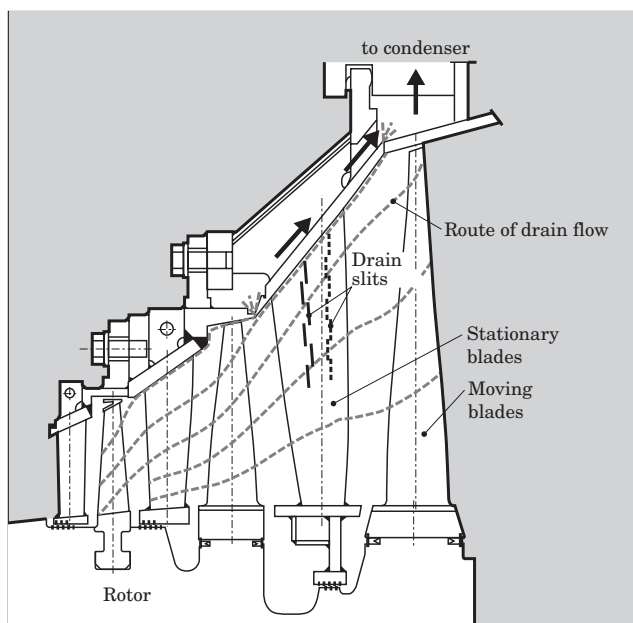
Highly efficient low-pressure blades, designed using compressible supersonic flow analysis (three-dimensional time marching method), are utilized. A lean radial stationary blade, which curves toward the direction of the circumference is adopted in the final stage (L-0) (see lower half of Fig. 4). Moreover, enhanced performance is achieved by adopting a shroud ring in the first stage (L-2) moving blade, while continuing to maintain the wide range frequency allowance of -5 to $+3$ %, which has been a characteristic feature of existing free standing blades (see upper half of Fig. 4).

3.3 Erosion prevention

Operated in wet steam, low pressure moving blades erode due to the impact of water droplets, and this erosion increases in severity as the blade length grows larger. To reduce this damage, the following measures have been implemented (see Fig. 5).

- (1) The leading edges of the moving blades have been flame hardened, and the surface hardness of the blade material has been improved.

Fig.5 Erosion-resistant structure



- (2) The final stationary blade (L-0) of larger models has a hollow structure with drain slits provided on its surface in order to drain the water droplets away to the condenser, thereby reducing the drain attack on latter-stage moving blades.
- (3) The axial clearance after the trailing edge of stationary blades has been enlarged sufficiently to decrease the size of water droplets that adhere from the steam flow onto the stationary blades, thereby reducing the drain attack on following moving blades.
- (4) The trailing edge of the stationary blades has been made thinner, so as to minimize the size of water droplets from the edge of the blades, thereby reducing the drain attack on following moving blades.

3.4 Adoption of 2 % Cr steel rotor

According to the increase in rotor diameter and LP blade length corresponding to larger steam turbine capacity, the centrifugal loads on the rotor have grown larger. The strength under actual operating conditions was evaluated using finite element analysis and fracture mechanics procedures. Accordingly, differential heat-treated 2 % Cr forged steel was selected for the shaft material of a 60 s^{-1} machine in which the stress in the core part will be very high. Figure 6 shows the creep rupture test results of this material.

4. Compact FET Turbine (N Series)

The selection of small capacity FET turbines has been improved with the development of the N Series, which was started and completed in 2002.

Figure 7 shows a cross-sectional drawing and typical specifications of the N Series.

Fig.6 Creep rupture test result of 2 % Cr steel

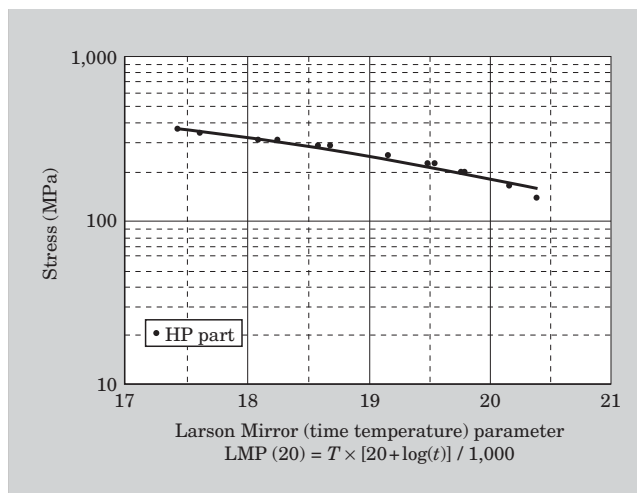
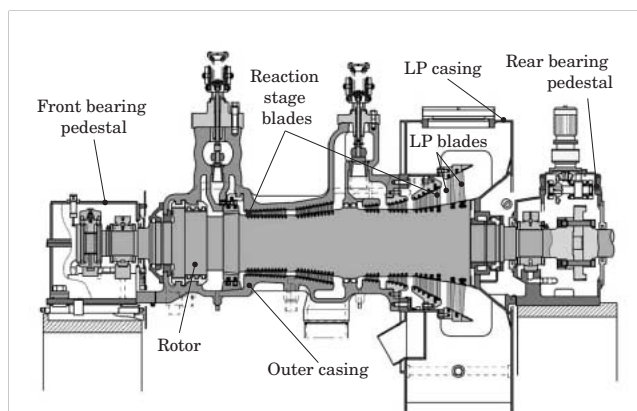


Fig.7 N Series steam turbine, assembled cross-sectional drawing



Steam turbine for Shanghai Chung Loong Paper Co., Ltd. (China).

Model	Single extraction condensing type
Output	26 MW
Steam condition extraction pressure	123.6 bar/538°C/9.8 bar
Vacuum	0.079 bar
Rotational speed	50 s ⁻¹ (3,000 rpm)
Operation started since	March 2005

4.1 Compact design by nozzle governing impulse stages for the small capacity model

The normal FET turbine has a throttle governing system and double shell casing structure as shown above. However, better flexibility for load change by day and night is requested for small-capacity, private power generation turbines, and thus the nozzle governing system will be more suitable for these conditions.

The FET N Series has adopted a nozzle governing system and single shell casing as the most compact and suitable system for this application (see Fig. 8).

The FET N Series has been developed for high

Fig.8 Overview of the N Series casing

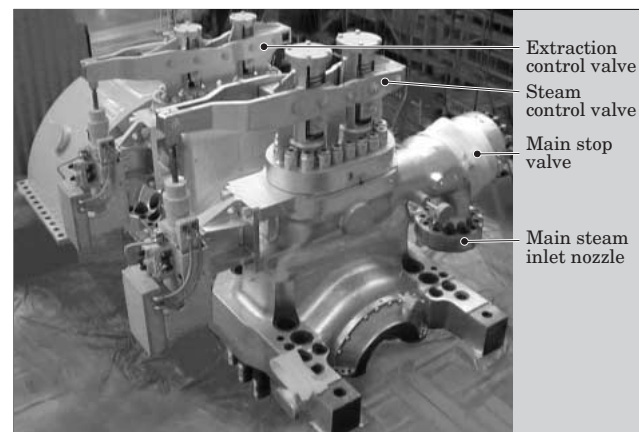
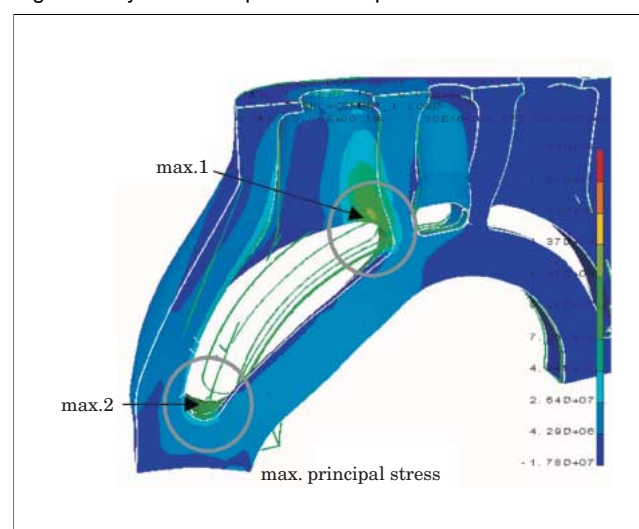


Fig.9 Analysis of inlet part with temperature distribution



efficiency by maintaining the same high steam conditions as the medium class FET (up to 130 bar/538°C). Reliability of the design was confirmed by simulating the operating conditions, including the analysis of temperature and stress distributions or deformations on the casing, on the basis of plenty of well proven FET turbines (see Fig. 9).

4.2 Adoption of high efficiency impulse stages

With the adoption of a nozzle governing system, a Curtis stage is applied as the top stage in order to reduce the wheel chamber pressure and temperature effectively. In an effort to reduce the secondary loss of the Curtis stage, a three-dimensional blade profile design is used in which the profile is curved in the direction of the circumference in order to maintain the characteristic high efficiency of the FET turbine (see Fig. 10).

As a result, a 1.7 % improvement is expected in stage efficiency, compared to the existing blade design.

Fig.10 Three-dimensional impulse stage

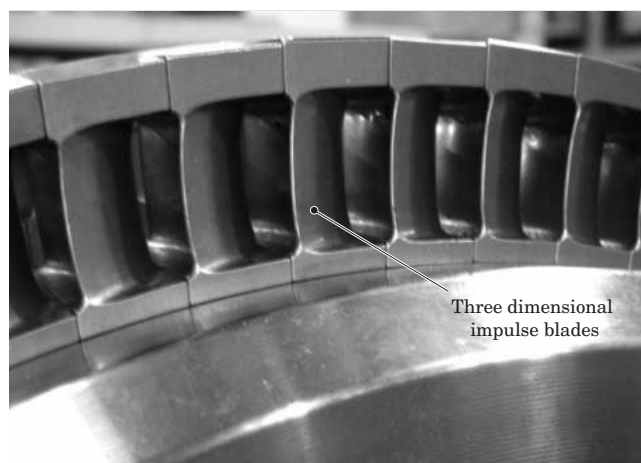
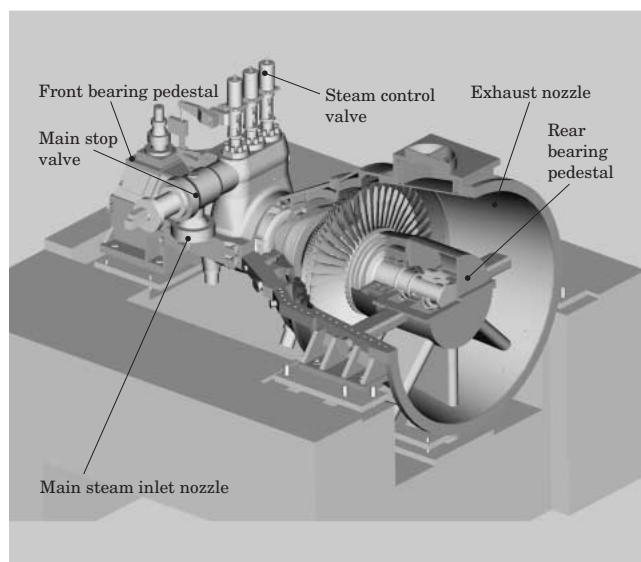


Fig.11 Axial exhaust type AX Series steam turbine

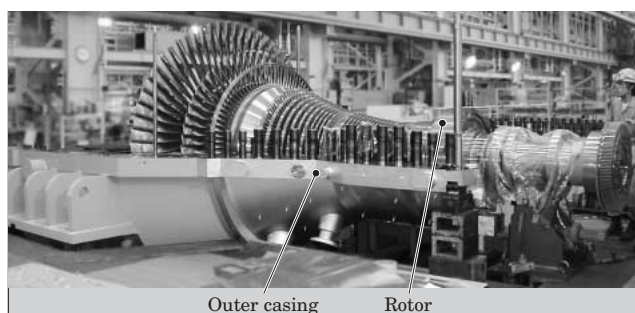


5. Use in Combined Cycle Plants

Due to the growing global environmental awareness in recent years, the major application of thermal power generation equipment has shifted to combined cycle plants (CCPPs), which use gas and steam turbines in combination to achieve higher thermal efficiency. According to this market trend, variations that combine use with a 100 to 200 MW class gas turbine have also been added. For CCPPs, there is great demand for axial flow exhaust type turbines since the cost and period for construction can be reduced greatly by this structure. Accordingly, the axial flow exhaust type AX Series FET was developed, based on existing downward exhaust type FET turbine technology (see Fig. 11).

CCPPs tend to be constructed in the vicinity of the consumers in order to reduce the power transmission loss. An air-cooled condenser is a suitable choice then, since it allows for the unrestricted selection of site

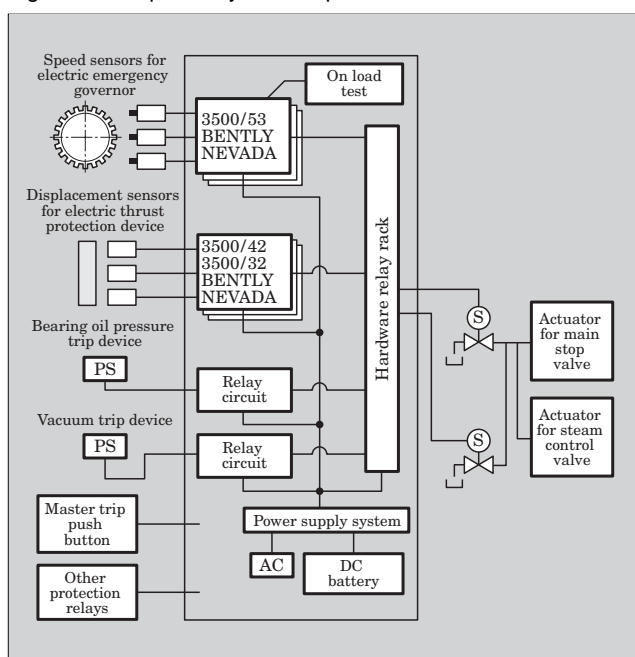
Fig.12 AX Series steam turbine during assembly



Central Geradora Termelétrica Fortaleza S.A. steam turbine (Brazil)

Model	Mixed pressure condensing type
Output	117.8 MW
Steam condition	73.3 bar/517°C
Vacuum	0.065 bar
Rotational speed	60 s ⁻¹ (3,600 rpm)
Operation start date	February 2004

Fig.13 Concept of fully-electric protection device



locations for the power plant, compared to a water-cooled condenser which requires access to a large amount of river or sea water. In order to operate compatibly with the higher exhaust pressure limitation of an air-cooled system, a low vacuum type steam turbine series was added.

5.1 Axial flow exhaust type FET steam turbine

Development of the axial exhaust type AX Series was completed and the first unit was put into operation in 1999. The AX Series has been utilized in many CCPPs.

Figure 12 shows a photograph and lists the speci-

Fig.14 Strengthened low pressure blades



cations of an AX Series turbine.

5.2 Utilization of fully electric protection devices

With the axial flow exhaust type turbine, the shaft coupling for the generator, turning motor and protection device are installed in the front pedestal because the rear pedestal is located in the exhaust hood. Therefore, to simplify the front pedestal as much as possible and to improve the maintenance, all protection devices, such as the over-speed governor and thrust failure protection system have adopted a fully electric configuration (see Fig. 13).

These electric protection devices are also used in Fuji Electric's larger capacity steam turbines, in common with the FET turbines.

5.3 Correspondence to air-cooled condenser

The vacuum obtained by an air-cooled condenser is less than that of a water-cooled condenser.

This higher exhaust pressure severely stresses the low-pressure blades in the steam turbine exhaust part. The development of strengthened low pressure blades has solved this issue (see Fig. 14).

6. Conclusion

The medium-capacity steam turbine FET Series has been expanded so as to be applicable to a wide-ranging market. Due to continuous requests for advanced solutions in response to global environmental needs and de-regulation of the electric power supply industry, the demand for equipment with higher efficiency and lower-cost will increase more and more in the future. Fuji Electric intends to continue to advance technical development in order to accommodate these growing needs.

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