

# Recent Technology for Reusing Aged Thermal Power Generating Units

Masaki Kato  
Seiichi Asano  
Shousuke Fukuda

## 1. Introduction

For the continuous operation in another 20 or more years from aged thermal power generating units that have already been operated for 30 years, Fuji Electric has replaced a two-cylinder reheat type turbine with sophisticated single-cylinder reheat type turbine, reused the existing foundation and nearly all the auxiliary machinery as counter-measures of life prolongation of the plant.

By replacing a high-performance single-cylinder reheat type turbine in the limited space of an existing power plant, renewing the insulation of power generating equipment, renewing the high voltage power console and control monitoring equipment, utilizing a digital-electrical governor instead of a mechanical-hydraulic governor, and by adopting an automatic turbine start-up system (ATS) and CRT operation, operability, reliability and maintainability have been improved dramatically.

Because this renewal technology can be applied at low cost to aged thermal power generating units, which are comprised approximately 70 % of the total number of thermal power generating units supplied, this technology is expected to be in high demand as a way to provide new solutions to meet customer needs.

This paper introduces power generating unit renewal technology, which integrates sophisticated technology with mostly reused equipment from an aged thermal power generating unit to solve the issues concerned with that aged unit, and also presents an example application of the renewal technology. Fig. 1 shows the full appearance of a reused power generating unit.

## 2. Serious Issues Concerning Aged Thermal Power Generating Units

With the development of residual life assessment technology, it has become possible to evaluate quantitatively the residual life of equipment, and statistical residual life and accident data have become publicly disclosed. On the other hand, users have the following concerns regarding the continuous operation and ex-

Fig.1 View of reused thermal power generating unit



tension of regular overhaul and maintenance, inspection intervals for aged thermal power generating units, and we frequently hear about these serious below concerns.

- (1) Concern about aging of the entire unit and the possible occurrence of trouble
- (2) Apprehension about damage caused by deterioration of the high-pressure high-temperature steam turbine materials
- (3) Wear, corrosion and erosion occurring throughout the steam turbine
- (4) Concern about the occurrence of accidents due to piping wear, narrowing of the pipe wall thickness, and pipe rupture
- (5) Insulation degradation and life of the generator and electrical equipment
- (6) Incomplete maintenance due to a delay in discontinuing the use of obsolete equipment
- (7) Deterioration in the reliability of control and protection devices
- (8) Incorrect operation due to a delay in improving operability
- (9) Concern about the tendency toward increased vibration with aging
- (10) Loss due to a decrease in efficiency with aging
- (11) Starting power loss due to start-up time delay

### 3. Counter-measures of Life Prolongation for the Power Generating Units

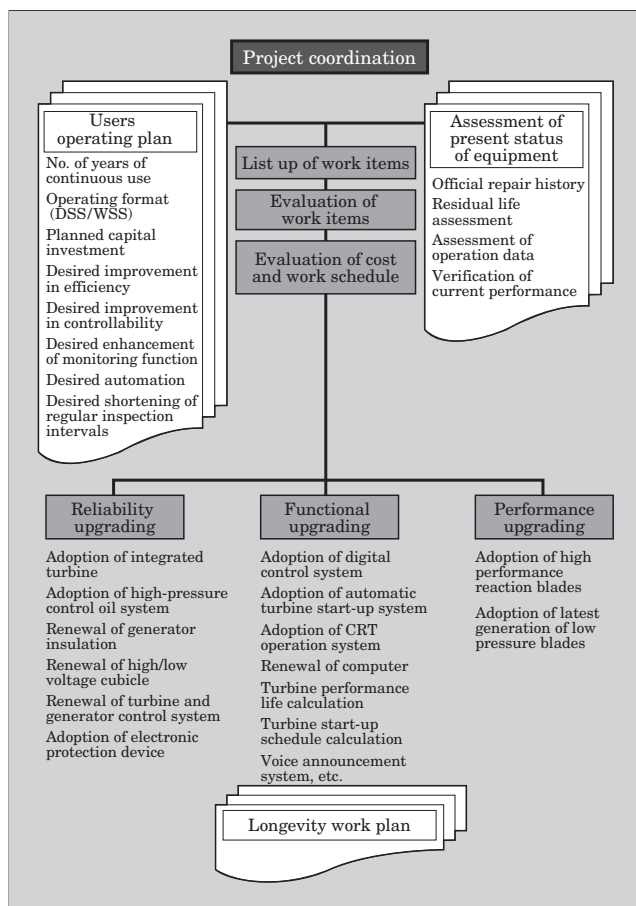
The purpose of the counter-measures of life prolongation, basically repair, replace or renew deficient parts of aging facilities in order to make possible the future long-term continuous operation of the facility and to eliminate user concerns. But it is also important to satisfy user needs by supporting their operating plans and to modernize the plants by applying a wide range of new technologies. Figure 2 shows an outline of the measures for plant longevity that were implemented.

### 4. Application of Sophisticated Steam Turbine Technology

In aged steam turbines that have been in operation for more than 20 years, due to the many years of operation, high temperature creep damage and fatigue damage to the materials can be observed. Such symptoms have typically been treated by replacing the affected parts with new components.

The counter-measures for plant longevity are not simply a return to the counter-measures against plant deterioration which have been practiced thus far,

Fig.2 Outline of work plan to increase plant longevity



rather, these counter-measures employ the latest technology to modify the configuration of a two-cylinder reheat type turbine into a single-cylinder reheat type turbine while continuing to reuse the existing equipment to a large extent, in order to achieve a more compact size, higher efficiency, lower start-up loss, improved operability and much lower maintenance cost in a reused power generating unit.

#### 4.1 Steam turbine specifications

Specifications of this steam turbine are listed below, and Fig. 3 shows a cross-sectional drawing of the steam turbine.

Type: Single-cylinder reheat

Output: 85,000 kW

Main steam pressure and temperature:

13.83 MPa/538°C

Reheat steam pressure and temperature:

3.13 MPa/538°C

Vacuum: 696 mmHg

Number of extraction stages: 5 stages

Rotating speed: 3,600 r/min

#### 4.2 Adoption of single-cylinder reheat steam turbines

In recent years, steam turbine technology as progressed toward larger machine capacities and steam conditions of higher temperature and higher pressure. Turbines, which have conventionally been configured from multiple cylinders, have become much more compact by transitioning from three-cylinder to two-cylinder configurations, and then from two-cylinder to single-cylinder configurations. The steam turbine also achieves a dramatically more compact size by using the existing two-cylinder configuration as a high-medium-low integrated single-cylinder configuration, without any modification to the existing foundation.

Fig.3 Steam turbine cross-section

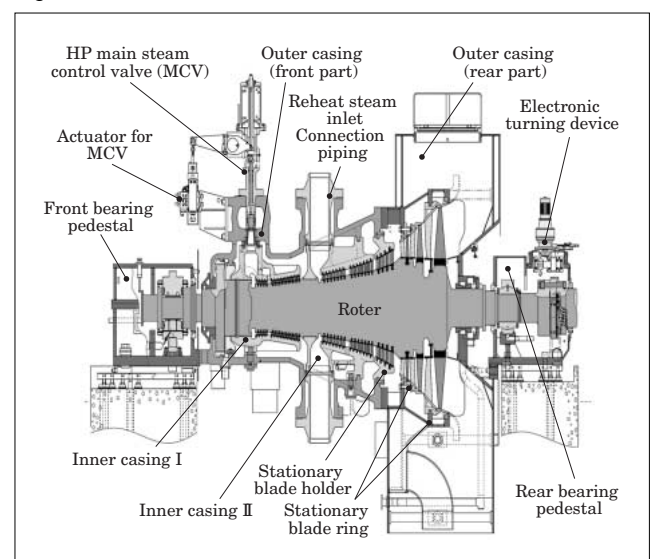


Table 1 Comparison of span and weight for reused and existing steam turbines

Parameter	Single-cylinder type (reused)	Two-cylinder type (existing)
Axial span (mm)	8,300	12,980
Weight (t)	160	210

Fig.4 Comparison of the reused and existing steam turbines

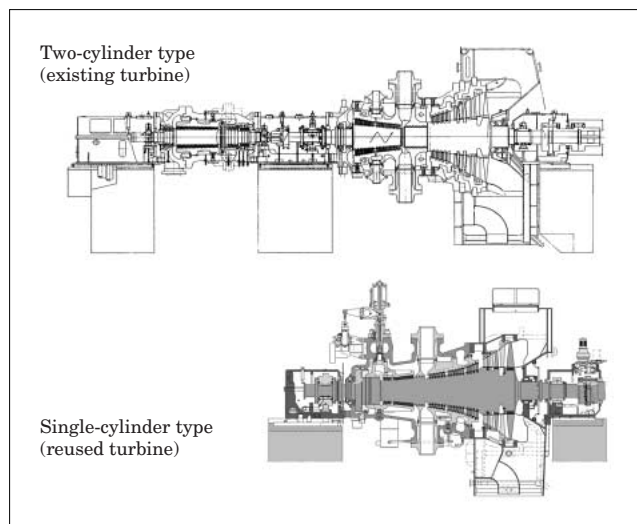


Table 1 and Fig. 4 compare the span and weight of the reused and existing steam turbines.

### 4.3 Characteristics of single-cylinder reheat steam turbines

#### (1) Reuse of the existing foundation and auxiliary equipment

One motivation for unit reuse is that the existing low-pressure steam turbine foundation could be used without any modification. The foundation concrete was assessed for deterioration and the strength of the turbine to be reused was analyzed, and the results showed that it was possible to avoid the cost and labor involved in modifying the foundation. Additionally, the specifications of auxiliary plant equipment such as the heater, de-aerator, condenser and turbine lubricating oil system were reexamined for the purpose of reusing the existing equipment.

#### (2) Adoption of a throttle governing double-shell structure

This plant is an oil-fired thermal power generating plant, and because it was designed for daily start-and-stop (DSS) operation, a throttle governing system was adopted, in which reaction blades were used in all stages, and without a control stage at the steam inlet. As a result of using this throttle governing system, the temperature fluctuation due to changes in the load at the cylinder under the most severe conditions has been reduced, enabling high-speed start-up and a larger range of allowable load changes. As a result, the start-up loss, an ongoing problem for existing plants, has

Fig.5 Steam turbine rotor



been reduced dramatically.

#### (3) Analysis of shaft vibration and preventative measures

Along with the conversion to a single-cylinder configuration, we used a computer to analyze vibration over the length of the entire shaft coupled to the existing generator. The analysis results showed an increase in vibration of the exciter installed at the end of the generator. As a preventative measure, the field balance of the exciter was reconsidered to achieve the same level of vibration as was originally planned. Figure 5 shows the appearance of the steam turbine rotor.

#### (4) Temperature distribution and stress analysis of the entire turbine

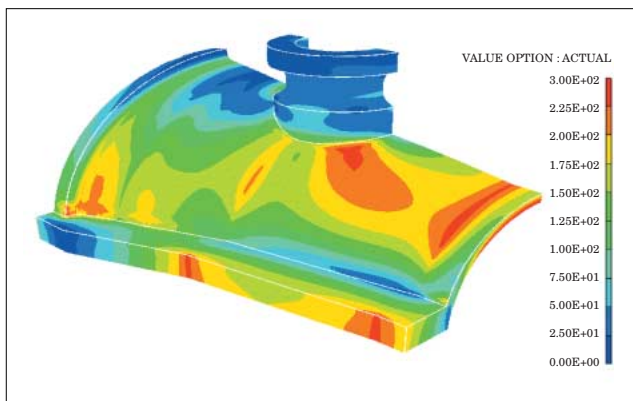
In the structural conversion to a single-cylinder reheat type turbine, the high pressure turbine steam outlet (low temperature reheat part) and medium pressure turbine steam inlet are combined within a single casing, and as a result, the temperature deviation of the casing largely influences such factors as thermal stress, fatigue life and local deformation. Consequently, analysis of this temperature deviation is important.

For this reason, the temperature distribution and stress (finite element method) at the middle of the interior of the reheat steam inlet were analyzed repeatedly and an optimum design (design of the casing and flange shape, wall thickness, etc.) for the single-cylinder reheat type turbine was achieved. Figure 6 shows the results of a temperature distribution analysis performed at the reheat steam inlet.

#### (5) Adoption of a separate-type oil system

The steam turbine was converted from a conventional common oil system (for both lubricating and control oil) to a separate-type oil system. This control oil system achieves higher valve operating force and improved controllability to realize a 14 MPa high pressure oil system, and is a new type of control system, using a plunger-type control oil pump for the operating oil, and using an electro-hydraulic actuator

Fig.6 Temperature analysis of reheat inlet steam part (finite element method)



for the valve operation. Moreover, the low-pressure lubricating oil system has changed from a turbine shaft-driven main oil pump to an AC drive main oil pump and has been designed to allow the continued use of existing lubricating oil system devices.

(6) Adoption of a digital governor and a fully electronic protection system

Labor savings, as typified by automatic start-up and remote automation capabilities, and improved controllability have been realized through the adoption of a digital governor and a fully electronic protection system.

Unlike the conventional protection system, the fully electronic protection system does not require oil pipes or mechanical apparatuses for detection, and thus realizes the advantages of a more compact detection sensor design and greater freedom in the selection of an installation site. Fuji Electric leverages these advantages by adopting this protection system as standard for all types of turbines, including the axial exhaust type turbine and the single-train type combined cycle generating plant.

## 5. Renewal Technology for Power Generating Equipment

The insulation for generator stator coil and others used for a long period of time deteriorates due to electrical stress, thermal stress, mechanical stress and contamination, and comes to the limit of dielectric strength (end point).

Accordingly, from the perspective of preventative maintenance of the equipment, before the insulation comes to the end point and causes a serious accident, it is important to renew that insulations systematically, based on the results of using methods such as non-destructive insulation diagnosis and physicochemical diagnosis to assess the level of degradation of the insulation.

The work plan implemented for plant longevity estimated quantitatively the limit of dielectric strength

of the insulation from the statistically correlation between the generator stator coil breakdown voltage (BDV), calculated from non-destructive diagnosis data, and non-destructive data that had been accumulated over many years, and then assessed the exact timing and scope of the insulation renewal so that the equipment could be reused for another 20 years of continuous operation. This carried out example is described below.

### 5.1 Specifications of the generator

The generator has the following specifications.

Year of manufacture: 1972

Type: Horizontal-mount, cylindrical rotor, fully-enclosed rotating field, internally-cooled

Output: 100,000 kVA

Voltage: 13,800 V

Current: 4,184 A

Power factor: 0.85

Number of phases: 3

Number of poles: 2

Insulation class: B

### 5.2 Rewinding the generator stator

Based on the results of a residual life diagnosis which showed that the BDV value — an important parameter for safe operation — had decreased, we performed the renewal work of rewinding the coil. Since the insulation was class-B, we enhanced the insulating performance by using class-F epoxy resin and vacuum impregnation insulation material, and dramatically reduced the time required for onsite renewal work by upgrading the connecting method of conductor to block connections. Figure 7 shows the generator stator coil during this renewal work.

### 5.3 Renewal of the retaining ring for the generator rotor

As a measure to prevent stress corrosion cracking (SCC) of the retaining ring, we changed the material (18Mn18Cr) of the retaining ring. Additionally, we improved the dropout prevention of the coil end spacer and renewed insulation below the retaining ring to enhance reliability. Figure 8 shows the retaining ring of the generator rotor during this renewal work.

### 5.4 Renewal of the brushless exciter winding

Because cracking and other types of degradation were observed in the field winding lead, we rewound the rotor and stator coils of the exciter in order to improve reliability.

### 5.5 Renewal of the main terminal bushing

The existing main terminal bushing used insulation oil, but because we had previously experienced leakage of this insulation oil and had been repairing cracks in the mounting flange, we decided to change the main terminal bushing to an epoxy-molded type.



Fig.7 Rewinding of generator stator

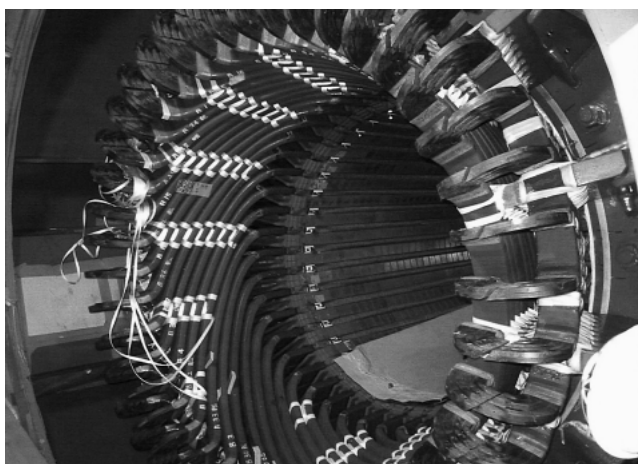
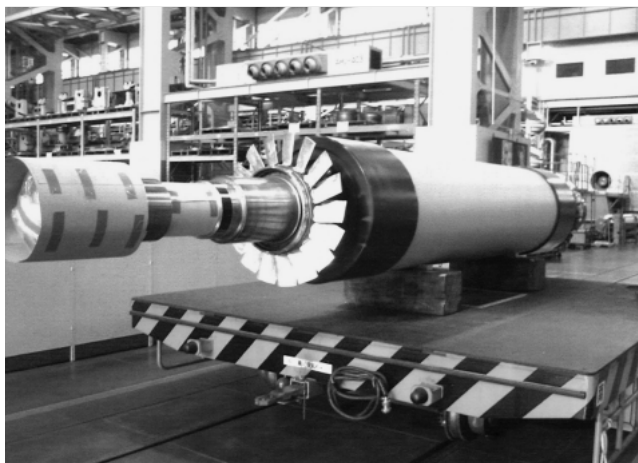


Fig.8 Renewal of retaining ring for generator rotor



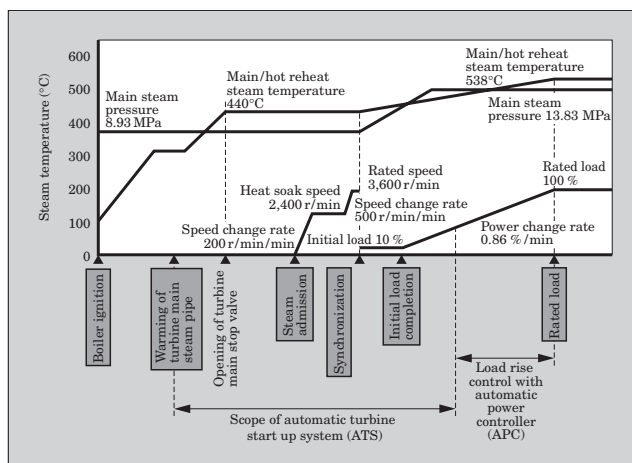
## 5.6 Other improvements

In addition, we improved the insulation to prevent current in the shaft bearing and renewed the generator stator pressurized through-terminal in order to enhance the reliability of all generator equipment.

## 6. Improvement with Electronic Control Equipment Technology

Among a power company's aged thermal power generating plants, the base plant is sometimes used as a load-adjusting plant and is operated to support daily and weekly start-and-stop (DSS and WSS) operation. For this purpose, higher reliability, shorter start-up time, and improved operability are required. In the work plan for plant longevity, in addition to implementing the previous measures for preventing degradation with age, it was also important to strengthen the turbine generator monitoring function, to add equipment and to configure an interface to the existing reused components, in order to satisfy customer needs for shorter start-up time and better operability of the turbine. The sophisticated digital control device and

Fig.9 Scope of automatic turbine start up system (for cold start)



the integration with existing equipment in order to satisfy these needs are described below.

### 6.1 Configuration of automation and monitoring functions

By automating the various operations associated with turbine start-up, which had previously been performed manually, and by strengthening the plant monitoring function, the operator's workload has been reduced and start-up time shortened dramatically.

#### (1) Automatic turbine start-up system

As can be seen in Fig. 9, the scope of the automatic turbine start-up system (ATS) is confined to the range from the warming of the turbine main steam pipe until approximately 25 % of the rated output of the turbine, and thereafter, the load control switches to an automatic power control system (APC).

#### (2) Automation of auxiliary steam pressure control

The auxiliary steam pressure of the existing turbine is used for turbine shaft sealing and ejector driving, but such complicated switching operations required a considerable amount of time. Accordingly, the manual operation and admission conditions for the auxiliary steam are now implemented by an automatic control logic circuit, thereby achieving a drastic reduction in turbine start-up time.

#### (3) Automation of the existing turbine drain valve operation

The existing turbine drain valve is driven by an electric motor that operates automatically according to commands from the ATS.

#### (4) Strengthening the plant monitoring function

CRT operation (see Fig. 10) was introduced in order to realize a comprehensive plant monitoring system and to reduce the number of operations involved. Consequently, the operator's workload decreased. Additionally, a voice announcement system enabled by the unit computer was added and the human-machine interface was improved.

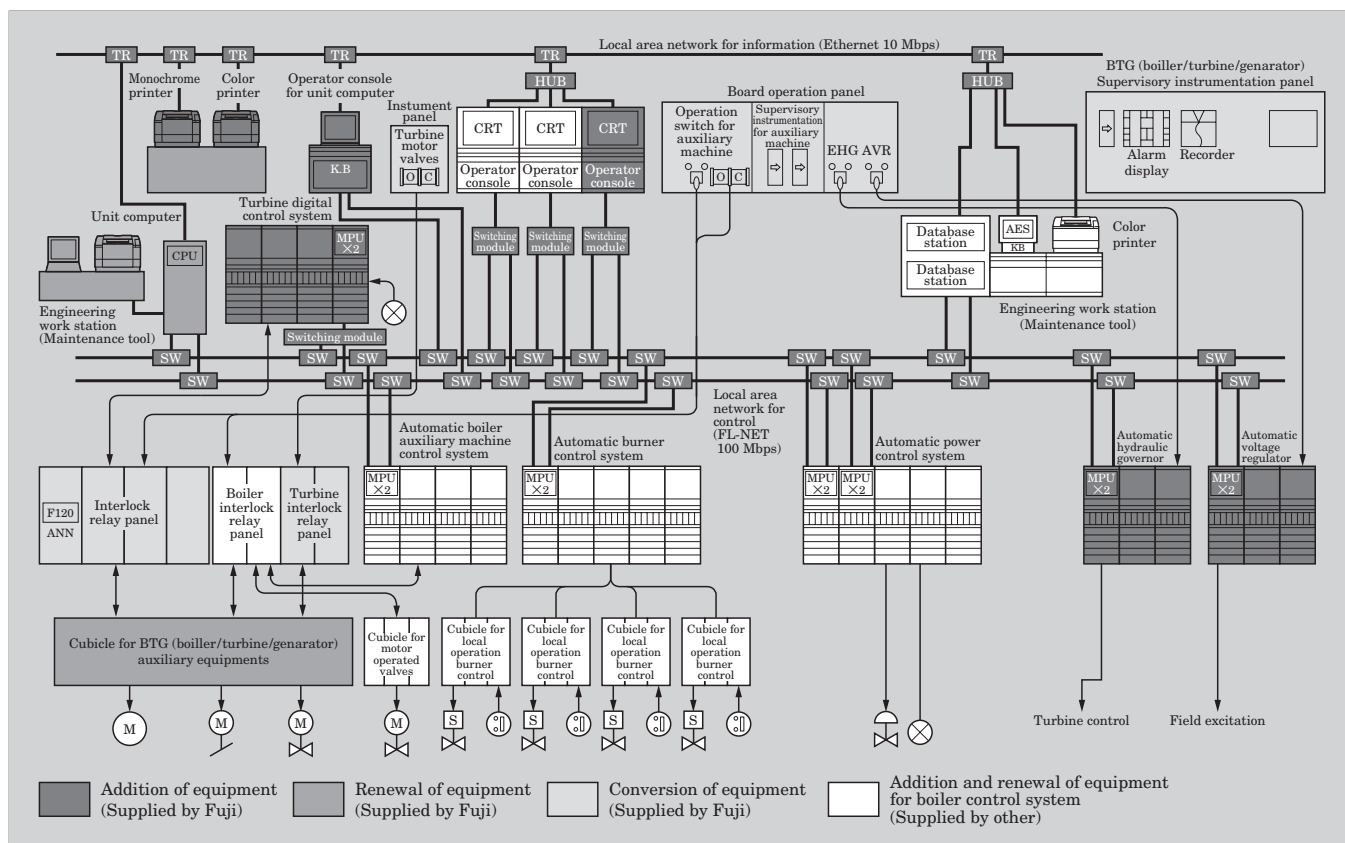
## 6.2 Configuration of the digital control system

Figure 11 shows the automation and monitoring functions that were added and the interface to existing equipment. These added functions are configured with a digital controller. By using a digital controller that is the same model as the boiler controller, the operation monitoring system has been unified and replacement parts can now be shared. Additionally, all the main parts of controllers critical to plant control form a redundant system that instantaneously switches to a standby unit when an active control unit system goes down, so as to continue operation without tripping the plant. These digital controllers and their interface to

Fig.10 Central operation room, after renewal



Fig.11 System configuration, after renewal



existing equipment are described below.

### 6.2.1 Addition of a digital electrical hydraulic governor (D-EHG)

The existing plant used a mechanical hydraulic governor (MHG), but in order to link to the newly designed ATS, APC and other digital control systems, addition of the D-EHG was required.

The D-EHG has the following advantages.

- (a) Linear continuous control
- (b) Easy setting of the speed change rate
- (c) Turbine auto-accelerate and load-increase functions

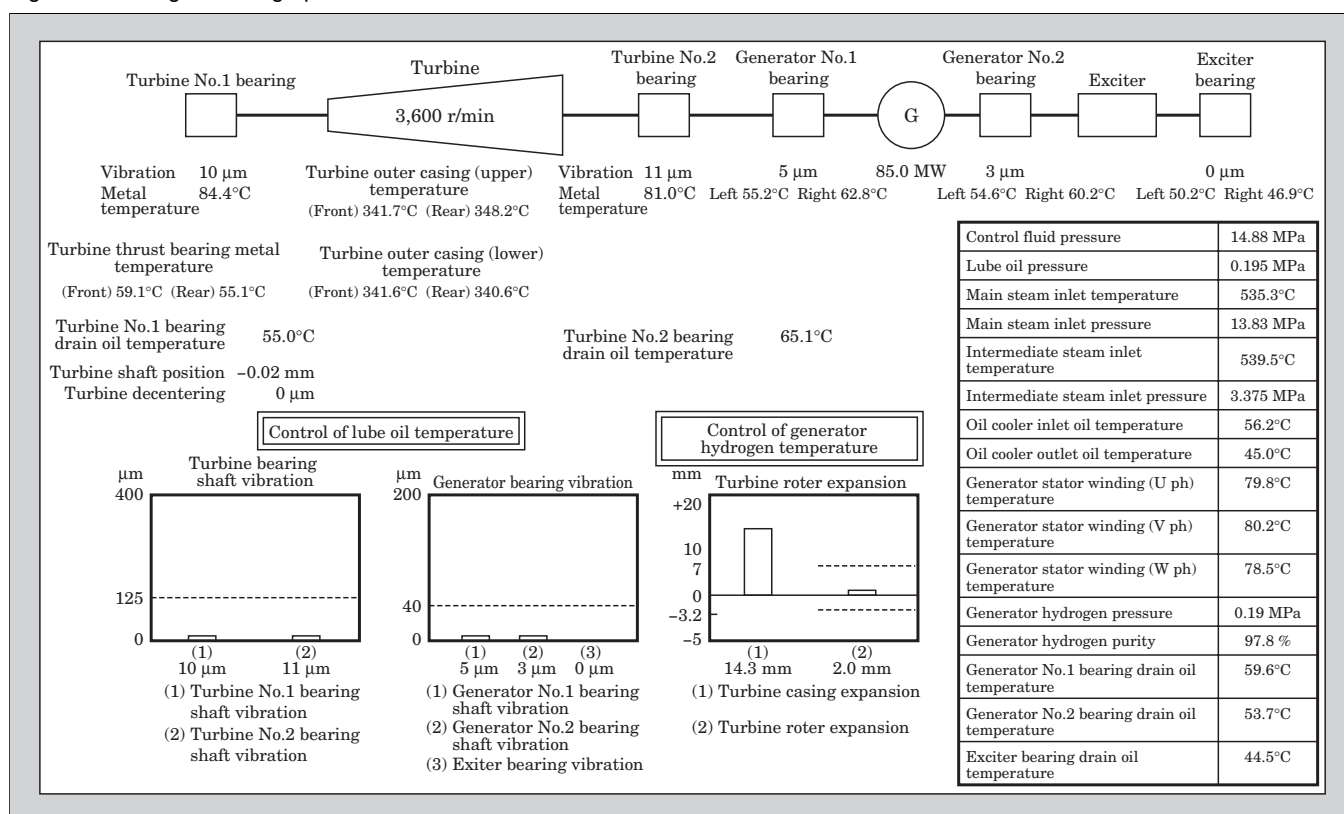
### 6.2.2 Reconsideration and reconfiguration of existing functions

#### (1) Addition of a turbine auxiliary controller

The equipment for renewal includes a unit computer, and the system includes a computer I/O panel that inputs and outputs many field device signals. The body of the unit computer is an independent panel. By equipping the conventional computer I/O panel with a digital programmable controller for controlling turbine auxiliary equipment, a digital control system for both turbine automation functions and computer I/O functions was realized. By installing this turbine digital control system at the site from where the existing computer I/O panel has been removed, all computer-related external cables can be reused.

#### (2) Digitization of the turbine auxiliary closed loop control

Fig.12 Turbine generator graphic



The existing turbine auxiliary closed loop control used an analog programmable controller for each loop, but all these control functions have now been configured with a turbine digital control system. Accordingly, what had been formerly board operations are now concentrated as CRT operations and the operator's workload has decreased. Due to the elimination of the analog programmable controls, maintenance has become more efficient.

### 6.2.3 Introduction of CRT operation

Plant information from the turbine auxiliary controller and other control equipment is transmitted as digital signals to the CRT, and displayed. Figure 12 shows an example display of the CRT graphics.

With the introduction of CRT operation, the distinction between monitoring and operations with the existing board were reconsidered, and board operations were reduced. As an example, the necessary operations for start-up and stopping are implemented from the CRT, and individual auxiliary devices are controlled as a board operation. An auto-mode has been added to the board, and selecting the auto-mode enables board operations to be reduced.

### 6.2.4 Addition of voice announcement system enabled by the unit computer

Linked to the automated operation, a voice announcement system that provides pre-announcements before a command is issued, post-announcements after an operation is completed, and warning announcements in the case of plant trouble has been provided.

These voice announcements are linked to the information of CRT graphics.

### 6.2.5 Improved reliability of data transmissions

A local area network (LAN) conforming to FL-net and connectable to an open loop dataway having high-speed transmission between digital controllers, high reliability, and a simple transmission interface was used. This LAN has a maximum transmission speed of 100 Mbps, is connected to both a digital automatic voltage regulator and a digital controller which had been delivered by the boiler manufacturer, and has a configuration that enables easy sharing of plant information. These communication networks are a mean of improving the reliability of the digital control system. The important control LAN relating to plant control is configured as a redundant system in order to improve reliability.

## 7. Conclusion

This paper introduced Fuji Electric's recently implemented technology for reusing aged thermal power generating units and examples thereof. In order to receive further continued use from these aged thermal power generating units, Fuji Electric intends to continue to supply reuse plans that combine existing units with sophisticated technology to transform those units into modern thermal power units having excellent reliability and operability.



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