UDC 621. 311. 22 : 621. 165.6-152 : 621. 313. 222-81

54,000 KW INDUSTRIAL THERMAL POWER STATION

By **Noboru Amano**
Electric Power Engineering Dept.

I. PLANT OUTLINE

A 54,000 kw steam bleeder condensation turbine power plant was ordered in June, 1966 by the Takaoka Kyodo Hatsuden Co., Ltd. to be installed at their Takaoka Thermal Power Station. From the time the order was received, plans were completed on schedule and the power station began continuous operation in November, 1967. The following is a time schedule of the project.

Sept. 7, 1966 :	Construction begun
Oct. 1966 :	Piling work
March 1967 :	Foundation work completed
Aug. 8, 1967 :	Intermediate turbine inspection
Sept. 29, 1967 :	Turbine first run
Oct. 24~27, 1967 :	Government test
Oct. 30, 1967 :	Construction completed

The 54,000 kw thermal power station was built as a joint venture by the Japanese Geon Co., Ltd. and Nippon Soda Co., Ltd. to supply reliable and economical electric and steam power for use in a vinyl chloride production "Kombinat". The plant was designed to allow for any future expansion as well as to suit the present vinyl chloride facilities. The design incorporated the latest thermal power generation techniques, a strict adherence to engineering fundamentals, and a satisfactory balance between technological and economical factors. Fuji Electric undertook the construction of the thermal plant (except for the boiler), the plant consulting and the secretarial-work involved in communication between the parties concerned.

1. Features

1) Steam and electric power is supplied to the entire vinyl chloride production "Kombinat".
2) Main fuel (heavy oil) is supplied directly from Port Fushiki through an underground pipeline 6 km in length. There was thus no need for a service tank.
3) Seventy-four tons/hour of high-pressure, high-temperature steam produced at the boiler is supplied to compressors and other sites in the plant.
4) A pot casing (barrel-type casing) is used for the high-pressure turbine.

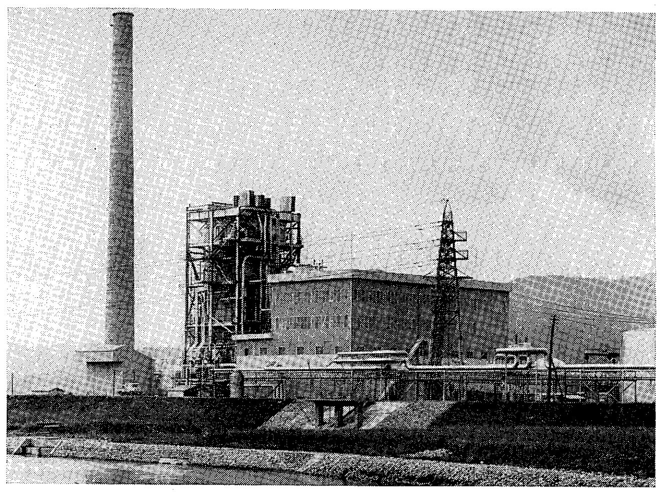


Fig. 1 Exterior of Takaoka Kyodo Power Station

5) A 2-cylinder steam bleeder condensation-type turbine is used.
6) Cooling hydrogen gas pressure for the generator is 2 kg/cm^2.
7) Static self-excitation with a thyristor AVR is employed.
8) Condenser tubes are made of copper-nickel alloy.
9) A simplified APC is employed to economize on power supply.
10) The power plant is controlled by a central control/monitor system using the latest electronic instruments.
11) Fuji Electric's steam converting valves (Dampfumformventil) are positioned to improve capability and reliability.
12) Internal-load operation is possible within the power station.
13) Station is laid out according to an improved plan.
14) Twenty-five meter cored pedestal piles are used in the foundation.
15) The turbine base is of elastic construction.
16) The load test was conducted using a 54 Mw hydraulic resistance system.

2. Plant Design

The design was based on a specified total energy requirement of approximately 50,000 kw for the operation of electrolysis and other equipment, approximately 12,000 kw for compressors, and 85 t/hr of 13 kg/cm² steam power to be used in the vinyl chloride production " kombinat ". Design considerations for this power plant which serves as a source for the entire " Kombinat " were centered around the following items.

1) Stability and economy in the supply of electrical and thermal power to the " Kombinat ".

2) Determination of compressor drive methods and of optimum steam conditions as with steam turbine drive.

3) Determination of systems for taking in and disposing of water used in the plant.

4) Simplified operation and maintenance using minimum number of personnel.

5) Effective arrangement of station components.

6) Reduction in the size of the power station building.

The thermal system was first arranged as shown in *Fig. 2*. Heat balance was obtained, and specifications of primary components such as the boiler, turbine, generator, water supply system, etc. were determined in conformity with this diagram.

The most important things concerning the steam were the limited permissible temperature range to allow for the use of a ferrite steel (other than special austenite steel) in the high-pressure and high-temperature units, and the permissible value of the steam wetness at the turbine final expansion point. Steam pressures (and temperatures) were determined to be 119 kg/cm² (538°C) at the turbine inlet and 125 kg/cm² (541°C) at the boiler heater outlet. A steam bleeder condensation-type turbine

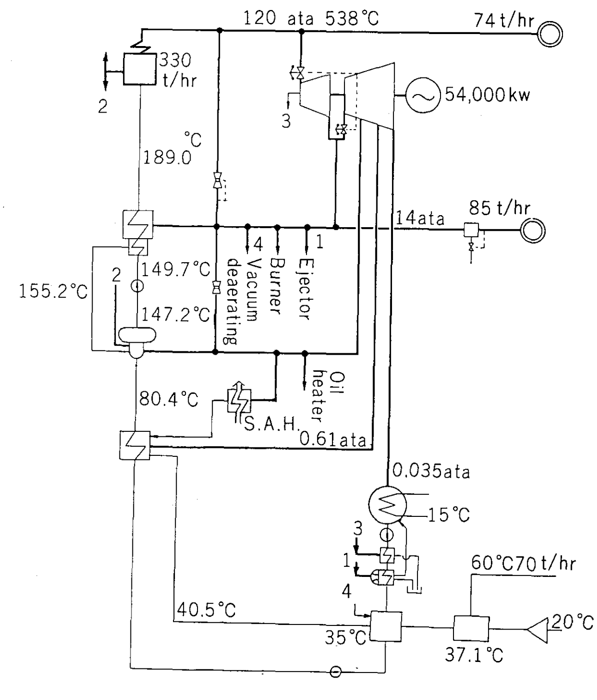


Fig. 2 Heat flow diagram

was employed, which meant more freedom in production planning and operation, while maintaining satisfactory electrical and steam balances within the plant. Since the power station was the first in Japan employing a large capacity steam bleeder condensation-type turbine for domestic use, a 2-cyliner turbine construction was used to guarantee high efficiency under continuous operation without danger of performance diminishing over an extended period of use, and also to allow the equipment to withstand abnormal operation.

The 2-cylinder construction permits an increase in the natural resonant frequency of individual turbine shafts to a value higher than the normal speed of the turbine because of the reduced length of the shafts; and also insures smaller temperature differences within each casing. These features provide higher thermal and physical performance stability compared to single-cylinder construction. The high pressure sections employ a pot casing characterized by an improved durability against high temperatures and pressures. The pot casing flange is arranged on the exhaust side and it is circular in shape to eliminate any steam leaks which often arise in high-temperature and high-pressure turbine because of the flange and its tightening bolts.

The turbine is symmetrical with respect to the rotary axis and has good thermal elasticity construction to enhance operational flexibility.

Two compressors (a 6900 kw 5500 rpm turbo-compressor and a 5340 kw 6800∼5750 rpm screw compressor) are driven by a steam turbine. This drive method suits the installation and operational conditions, and affords greater economy and reliability. In a single-unit arrangement, a drive turbine with a capacity of 5000∼7000 kw and set at a steam pressure of 50∼70 kg/cm² is generally used. These compressors are driven directly by the main 75 t/hr of steam from the boiler. This drive system is superior to steam extracted from the 54,000 kw steam bleeder condensation-type turbine, since in the latter case turbine back pressure would actually be used to drive the compressor turbines and operational relations between the compressors and the boiler or the turbine in the power plant would pose a problem. This method is also not advantageous from the economical and engineering points of view. The direct drive method, on the other hand, is possible because of Fuji Electric's excellent pot turbine (with a back pressure of 4 kg/cm²). This high-pressure and high-temperature turbine has also made it possible to balance the quantity of steam used for driving the compressors and the quantity of steam demand for vinyl chloride production. This Takaoka Kyodo thermal power plant which serves as an energy center for all the generators, as well as high-pressure and medium pressure systems, plays an important role and must possess large operational flexibility. This flexibility is insured by the Fuji Electric steam converting valve (Dampfumformventil) system.

In this plant, steam converting valves are used in the turbine bypass leading to the 13 kg/cm^2 line and in the bypass leading to the deaerator. These valves have a single valve seat, which serves for reducing both pressure and temperature. Features of the valve are: excellent performance with minimum operational noise and vibration, the ability to close the circuit completely, long service life, rapid opening capacity (around 8 seconds at full stroke), etc. These valves are one of the major factors in facilitating operation of the vinyl chloride plant and increasing the reliability of starting and controlling the plant steam supply.

All water for the generator and the vinyl chloride plant is supplied from the Oyabe river which flows past the power station. Water to be used in the condenser and oil cooler is pumped (by a 100% capacity pump) to a rotary screen and two fine-mesh screens in the sedimentation basin for the removal of sand. Chloride is added to the water supply at the inlet position.

From tests on the water of the Oyabe river conducted by the customer, it is not yet ascertained whether the water will change in the future or not, especially in regard to contents of organic matter. As precaution against such changes, reverse flow valve (2×700 mmϕ) has been provided in the condenser cooling water line so that a Taprogecleaning system can be attached when needs arise.

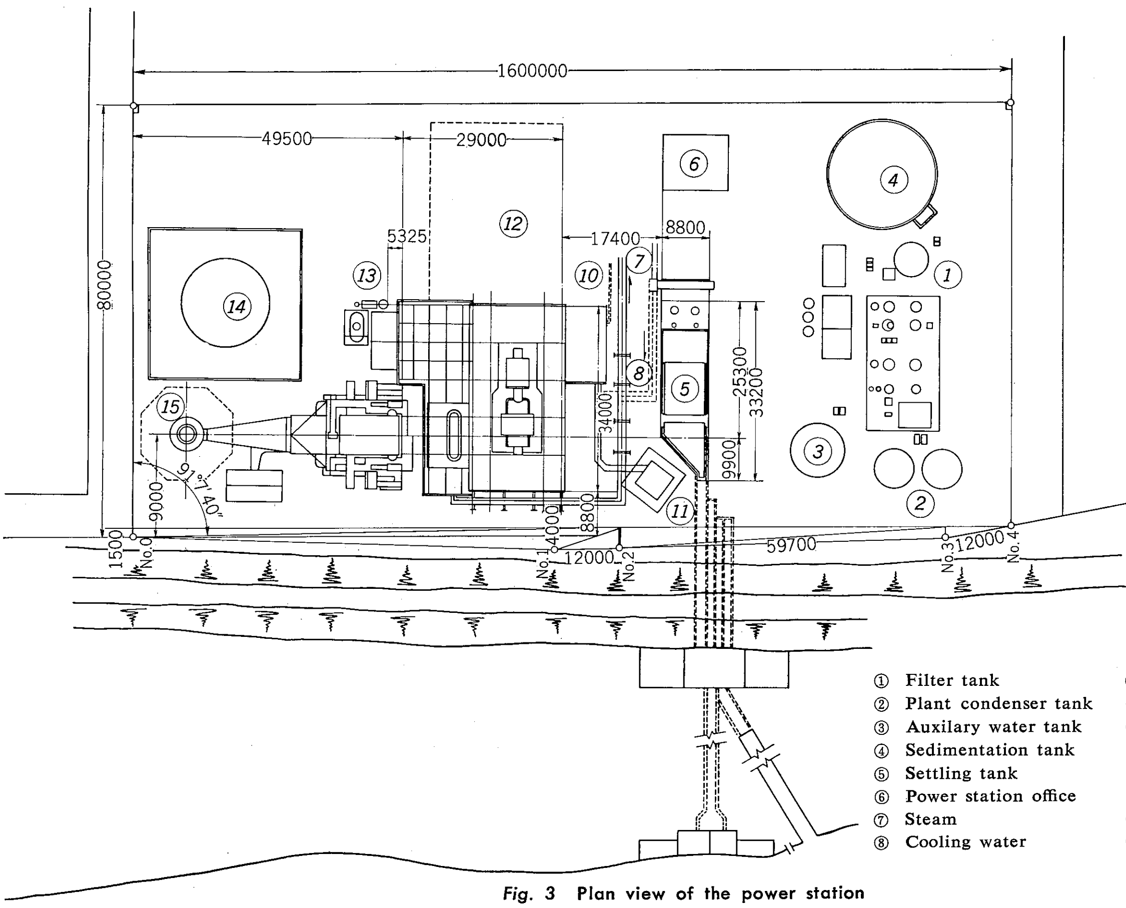
In selecting materials for the condenser cooling tube, stress tests for materials exposed to residual stress and corrosion tests were conducted on various types of materials at a site near the actual water supply. From these tests, a 9/1 copper-nickel alloy proved to be the most satisfactory material.

For the generator hydrogen cooler and other cooling water systems, refined river water is refined again through the clearator system. This method is used for three reasons: no spare was available, some of the equipment requires pure water, and it was the most economical to construct.

No main transformer is provided for power transmission to the vinyl chloride plant, but voltage is maintained at 11.5 kv, while the internal power station load is connected to the generator via a 6000 kva, 11.5/3.45 kv transformer installed in the station. Power loss due to eddy current on the generator rotor caused by harmonics is negligible and there is no possibility of adverse effects to the generator, even when the load from the rectifier is as high as 55% of total consumption.

3. Power Station Arrangement

The power station is located in a 160 m×80 m corner area of the site of the new Takaoka plant of the Japanese Geon Co., Ltd. The overall layout as shown in *Fig. 3* includes sufficient space for another generator unit to be added in the future. The



① Filter tank
② Plant condenser tank
③ Auxilary water tank
④ Sedimentation tank
⑤ Settling tank
⑥ Power station office
⑦ Steam
⑧ Cooling water
⑨ Underground cable
⑩ Iron tower
⑪ Area for construction of future turbines
⑫ New-type purification tank
⑬ Heavy oil tank
⑭ Smoke stack

Fig. 3 Plan view of the power station

power station is positioned for convenience in making connections to outgoing power lines, cooling water intake, steam power line to the vinyl chloride plant, and fuel supply line. Basic layout considerations are as follows.

1) Improvement of operations reliability
2) Simplicity of operation control and monitoring
3) Ease of maintenance and inspection
4) Most effective connections between related equipment groups
5) Good ventilation and access of sunlight
6) Minimum length of piping and electrical cables
7) Reduction in the size of buildings and the site
8) Facilitation of piping and electrical wiring-work
9) Clear separation of the steam system, feed water supply system, cooling water system and electrical wiring

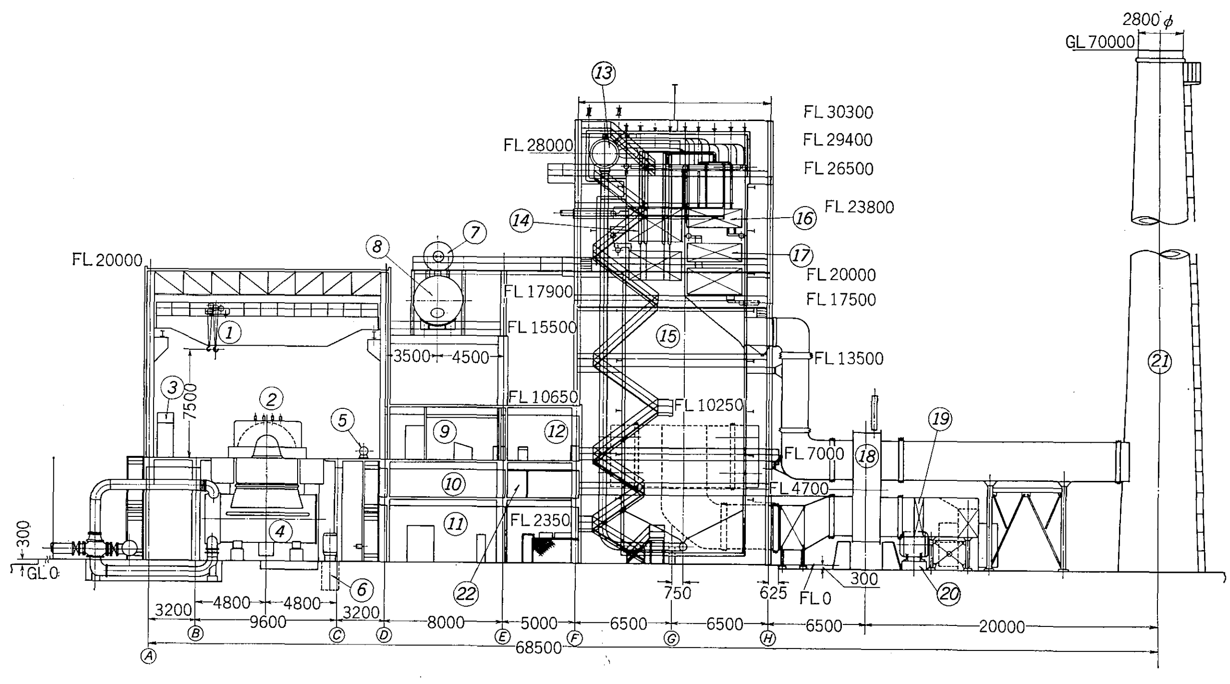
Layout of components in the station building is shown in *Figs. 4* through 6. As can be seen from these figures, rooms of major importance such as the central control room, office room, electrical room, and cable room are accommodated as axial on the main operation floor with the central control room located in the center. The central control room between the turbine and the boiler, and the electrical room containing high and low voltage panels and batteries are on the ground floor while the cable room is between the first and second floor. All the "nerve" lines of the power station are centralized in these room. The main elevation floor is surrounded with heaters, sampling racks, a boiler gallery, and boiler. All valves are controlled collectively in the boiler gallery. This orderly arrangement facilitates operation and maintenance inspection. Piping and pits are arranged so that they do not interfere with each other.

4. Power Station Foundation

Structures

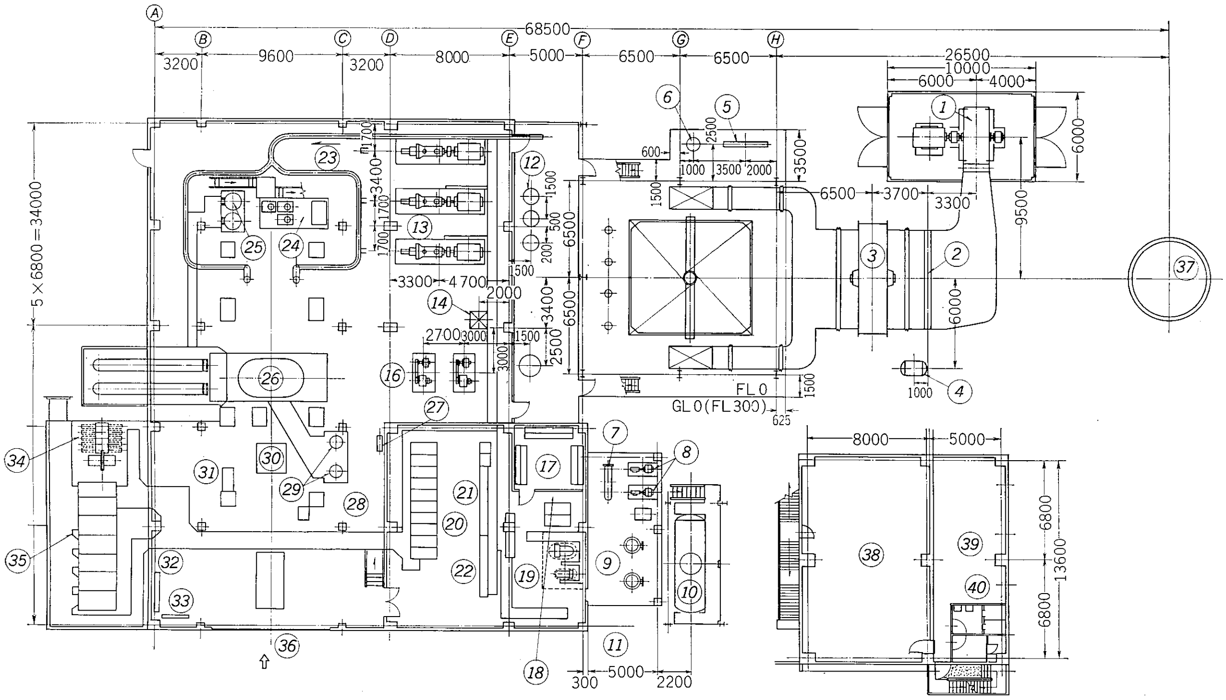
Foundation:	Steel reinforced concrete (RC) supported by cored pedestal piles, and steel reinforced concrete supported by ready-made reinforced concrete piles.
Building:	Ground floor – Reinforced concrete First floor – Reinforced concrete Second floor – Steel frames

Prior to designing the foundations, a bore was taken at the site to examine geological features. The same type of piles, 25 m 430 mmϕ seamless cored pedestal piles, is used in the foundations of the boiler and chimney, the turbine, and the station building. The turbine is supported by 48 of these piles, the building with 66, and the boiler and chimney with 124; making a total of 238 piles. Withstand strength per pile was proven to be 90～120 tons. Comparatively bulky components such as the feed water pump, compressors, etc., are supported by RC piles; lighter components such as the entrance hall (used to assemble the pot turbine cas-



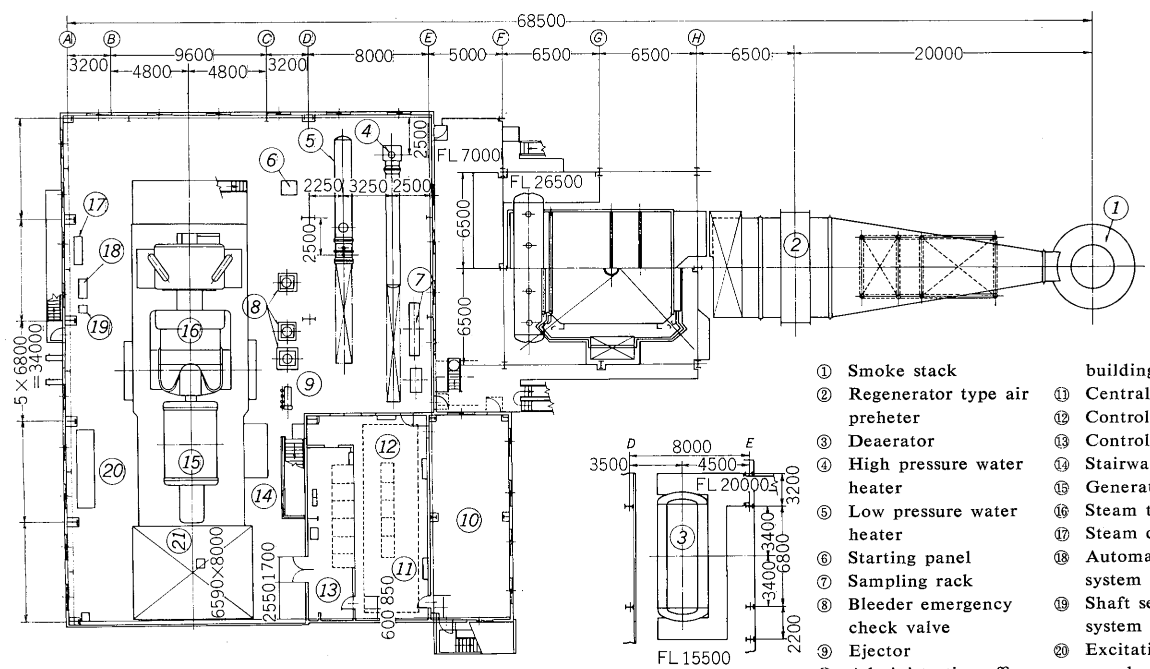
① Over head crane 40/10 tons
② Turbine generator
③ Excitation system panel
④ Condenser
⑤ Ejector
⑥ Condenser pump
⑦ Deaerator
⑧ Storage tank
⑨ Central control room
⑩ Cable control room
⑪ Electrical room
⑫ Administration office for turbine generator building
⑬ Main boiler shaft
⑭ High temperature superheater
⑮ Combustion chamber
⑯ Low temperature super herter
⑰ Fuel economizer
⑱ Regeneration-type air preheater
⑲ Steam-type air preheater
⑳ Forced air blower
㉑ Smoke stack
㉒ Locker room, washroom, lavatory

Fig. 4 Sectional view of the power station



① Forced air blower
② Steam-type air preheater
③ Regenerator-type air preheater
④ SAH drain tank
⑤ Flush pipe
⑥ Flush tank
⑦ Heavy oil heater
⑧ Heavy oil pump
⑨ Straight deaerator, water pump room
⑩ Vacuum deaerator
⑪ Deaerator, water pump room
⑫ Chemical injection system
⑬ Water pump
⑭ Dehumidifier system
⑮ Air tank for control use
⑯ Air compressor for control use
⑰ Battery room
⑱ Load center
⑲ Common control center
⑳ 3 kv metalclad switch gear
㉑ Boiler control center
㉒ Turbine control center
㉓ Main steam route
㉔ Oil tank
㉕ Oil cooler
㉖ Condenser
㉗ Shaft seal steam condenser
㉘ Gas shaft seal supervisory panel
㉙ Condenser pump
㉚ Shaft seal lubrication system
㉛ Gas control system
㉜ H_2 cylinder
㉝ CO_2 cylinder
㉞ 6000 kva transformer
㉟ 11 kv metalclad switchgear
㊱ Entrance
㊲ Smoke stack
㊳ Cable control room
㊴ Locker room
㊵ Wash room
㊶ Shower room
㊷ Lavatory

Fig. 5 Plan view of 1st floor of the power station



① Smoke stack
② Regenerator type air preheter
③ Deaerator
④ High pressure water heater
⑤ Low pressure water heater
⑥ Starting panel
⑦ Sampling rack
⑧ Bleeder emergency check valve
⑨ Ejector
⑩ Administration office for turbine generator building
⑪ Central control room
⑫ Control desk
⑬ Control panel room
⑭ Stairway
⑮ Generator
⑯ Steam turbine
⑰ Steam drain valve
⑱ Automatic shaft seal system
⑲ Shaft seal control system
⑳ Excitation system panel
㉑ Access

Fig. 6 Plan view of 2nd floor of the power station ing), the dehumidifier, compressor reservoir, chemical dosage units, high voltage switchgear cubicle, transformer, condenser cooling pit, etc., are supported by the natural strength of the earth.

Among these components, special consideration was given to the base of the turbine, which will be described in the following section.

5. Turbine Base

The turbine base is of elastic construction, with a natural vertical resonant frequency much lower than the normal turbine and generator speeds (3600 rpm). This has meant considerable saving in the sectional area of columns and beams, and thus in the volume of concrete required. There is more space around the base facilitating the arrangment and maintenance of auxiliary components and piping. These features are impossible in ordinary bulky steel structures.

1) Structures

The turbine base exterior is shown in *Fig. 7*.

The ground floor is provided with piles and a mat as in ordinary bases. This not only gives the base sufficient strength but also prevents uneven sinking which could occur over an extended period of time. This extended durability was obtained by closely considering the elasticity of the piles and the weight of the mat in order to insure appropriate values of the natural resonant frequency and the amplitude of the base vibration. According to the geological survey, forty-eight 430 mm$\phi \times 25$ m cored pedestals were used.

All columns were positioned right below the floor beams to simplify resonance modes in the structure, eliminate unpredictable torsion or compound vibrations, and to the overall strength by supporting equipment weight at appropriate points. The natural

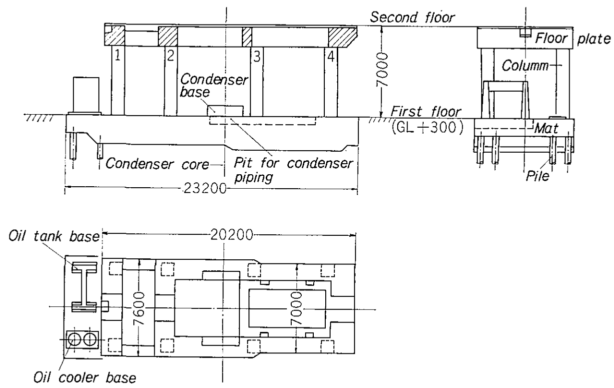


Fig. 7 Turbine foundation

resonant frequency of the Rahmen frames was also taken into consideration.

Overhanging portions and collars from the beams were strictly avoided since their broad area would not only be a good vibration area but also induce vibrations in adjoining portions of the structure.

Table 1 shows the critical speeds of equipment and the natural resonant frequency of the turbine base.

For individual Rahmen frames, the natural resonant frequency was calculated on a simplified structure with the mat assumed stationary. However, checks were made for harmonic and compound vibrations, since these were possible due to the low natural frequency of the base. To obtain an accurate value of the natural resonant frequency, the calculation must include mat weight and pile (ground) elasticity. The base was regarded as a vibratory system with two degrees of freedom consisting of the equipment, floor plates, and some columns, with the collective weight represented by W_1; and the mat, piles, and some columns, with weight col-

Table 1 **Critical Speeds of Equipment and Natural Resonant Frequency of Turbine Base**

			Single Unit			Combined
Critical Equipment Speed			High pressure turbine	4735 rpm		Primary : 2230 rpm Secondary : 4710 rpm
			Low pressure turbine	5149 rpm		
			Generator	2050 rpm 4657 rpm		
Natural Resonant Frequency of Base	Vertical	Inverted U Rahmen frames	No 1	1770 rpm	Inverted U Rahmen frames viewed from the front	Natural resonant frequency of system having 2 degrees of freedom and including the mat and piles. (W_1, k_1, W_2, k_2) Vertical: 1050 rpm 2500 rpm Horizontal: 60 rpm (1 cps) 480 rpm (8 cps)
			No 2	1500 rpm		
			No 3	1840 rpm		
			No 4	1800 rpm		
		Longitudinal Rahmen frames	Primary	325 rpm	1 2 3 4 Longitudinal frames viewed from side	
			Secondary	900 rpm		
			Tertiary	1750 rpm		
	Horizontal		350～400 rpm (5.8～6.7 cps)			

lectively designated as W_2. The elasticity at the top and bottom of the ground floor was K_1 and K_2 respectively. Results obtained from this calculation were in agreement with the actual natural resonant frequency.

Horizontal resonance for both machinery and earthquakes was also considered. Precise calculations gave various strength values including strength in respect to condenser vacuum, generator short-circuits, earthquakes, thermal stress produced during normal operation and laying of concrete, and equipment force.

2) Construction

Laying of concrete was initiated with the mat in November 1966 and the columns and floor plates toward the end of March in 1967. Winter months were avoided for this type of work. Specifications of concrete used are given in *Table 2*.

The 15 cm thick slump is of a stiff consistency to prevent sagging of the concrete and separation of the support bars due to the vibrator. The additive used in the slump is a product of Pozoris and facilitates adequate suppression of concrete hardening and temperature rise, water savings and also laying of the slump.

***Table 2* Ferro-Concrete Specifications**

Specifications \ Base		Column and Floor Plate	Mat
Design Strength		225 kg/cm^2	180 kg/cm^2
Young's Modulus (E)		3.0×10^5 kg/cm^2	2.5×10^5 kg/cm^2
Cement		With a compressive strength of 370 kg/cm^2 4 weeks	
Thin Support Bars		2.5 mm max., with a specific gravity of 2.57	
Thick Support Bars		2.5 mm max., with a specific gravity of 2.67	
Standard Mixture	Slump	15 cm	20 cm
	Cement/water ratio	53%	59%
	Sand content % s/a	34%	41%
	Water volume	163 kg/m^3	184 kg/m^3
	Cement	309 kg/m^3	315 kg/m^3
	Sand	619 kg/m^3	723 kg/m^3
	Gravel	1250 kg/m^3	1080 kg/m^3
	Additive	1545 cc/m^3	1550 cc/m^3
Main Support Beam		SR24 round bars, 25ϕ, 13ϕ SD 30 support bars with special shapes	SR24 round bars, 25ϕ, 22ϕ, 16ϕ

3) Measurements of natural resonant frequency and operating resonance

An unbalanced vibrator was attached to individual inverted-U Rahmen frames to measure maximum and minimum speeds and their phases when the speed was changed in the 0 to 4200 rpm range. Similar measurements were then conducted in an actual operation for each 200~300 rpm speed increase. The results of the former measurements were used as a reference for the latter measurements.

Measurement results shown in *Fig. 8* are measurements of vertical resonance of the floor plate beams near the bearing base and apply to frames No. 2 and No. 4. Frames No. 1 and No. 3 are similar to No. 2 and 4, in that they also show no peak at speeds of less than 2000 rpm, probably due to the weak vibrations applied.

The bearing stand vibrates less than the floor plate beams during operation and still less during starting; it therefore presents no problem.

Fig. 9 shows the vibratory modes of the columns and floor plate beams. Individual inverted-U Rahmen frames have an identical vibratory mode for all speeds in agreement with the longitudinal frames, although there is a slight variation between the two. Vertical vibration amplitudes versus those of the mat near the colum foot were 2.5, 3, 4, and 2 at resonance

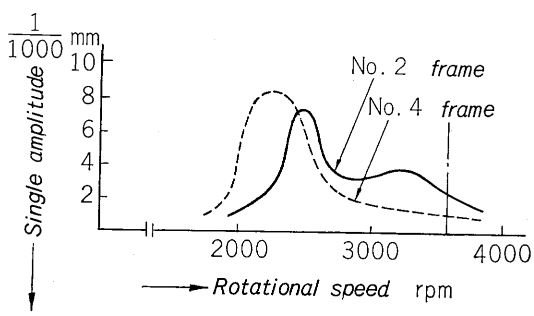


Fig. 8 **Vertical vibration of turbine foundation beam**

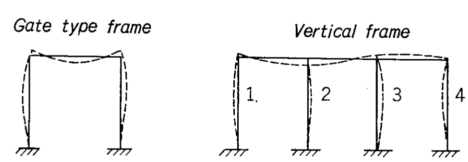


Fig. 9 **Vibration mode of turbine foundation at resonance**

***Table 3* Results of Bearing Vibration Measurements**

Unit: 1/1000 mm

Rahmen No.	1	2		3		4
Bearing No.	1	2	3	4	5	6
Bearing Vibration Amplitude at Full Load	1.8	2.8	1.7	1.6	4.0	3.5
Bearing Vibration Amplitude at No Load	5.0	4.9	2.0	2.5	1.2	0.7
Base Beam Vibration Amplitude at No Load	3.8	3.1		1.9		1.0

for frames No. 1 through 4 respectively, and they were all approximately in phase.

Table 3 shows vibration magnitudes of the bearing and adjoining portions. Machine operation was very quiet with little vibration, partially because of good field balance adjustment.

The operation was quite stable with no defects detected during test operation with respect to starting, resonant point phenomena and under a varying load.

II. TURBINE

This steam bleeder condensation-type turbine with the largest capacity of its kind in Japan boasts the following features.

1) It consists of high and low pressure turbines with the high pressure turbine housed in an inserted nozzle-box type pot casing.

2) The shaft critical speed is determined by elastic shaft speed and higher than normal operation speed.

3) The permissible speed variations during starting and under various loads are determined basically from temperature differences on the wall indicated by a thermometer located on the walls of the emergency stop valve and high pressure chamber.

4) Eighty-five percent of the rated output is obtained even when the zero amount of steam is bled for the plant. When the 3rd steam bleeder is stopped, 100% output is obtained.

5) The turbine can be operated safety under internal loads within the power station over a long period of time, when starting, etc.

6) The turbine base, though made of concrete, is of an elastic construction with a natural resonant frequency lower than the turbine speed.

1. Main Turbine Components

The exterior is shown in *Fig. 10,* and a cross section in *Fig. 11.* The turbine has the following specification.

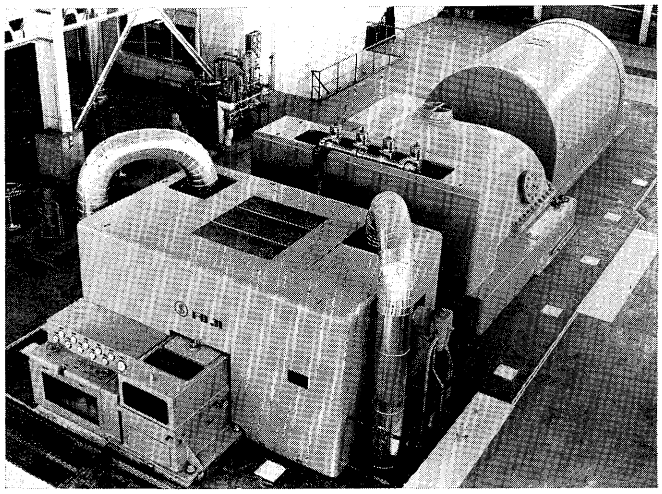


Fig. 10 External view of turbine

Type:	2-cylinder reaction steam bleeder condensation turbine.
Output:	54,000 kw (maximum continuous output at the generator end)
Speed:	3600 rpm (both HP and LP cylinder)
Steam:	Pressure at the inlet of the main stop valve 119 kg/cm²g Temperature at the inlet of the main stop valve is 538°C
Steam bleeding pressure:	(At the turbine exhaust and with the rated output) 1st bleeder (controlled) 13kg/cm²g 2nd bleeder (uncontrolled) 4 kg/cm²g 3rd bleeder (uncontrolled) 0.61 kg/cm² abs
Bleeding quality:	112 t/hr (1st bleeding)
Vacuum:	734 mmHg (0.035 kg/cm² abs) (Under an atmospheric pressure of 760 mmHg, cooling water temperature of 15°C at the inlet, and rated output)
Stages:	HP-cylinder—1 inpulse stage, 24 reaction stages LP-cylinder—1 inpulse stage, 16 reaction stages

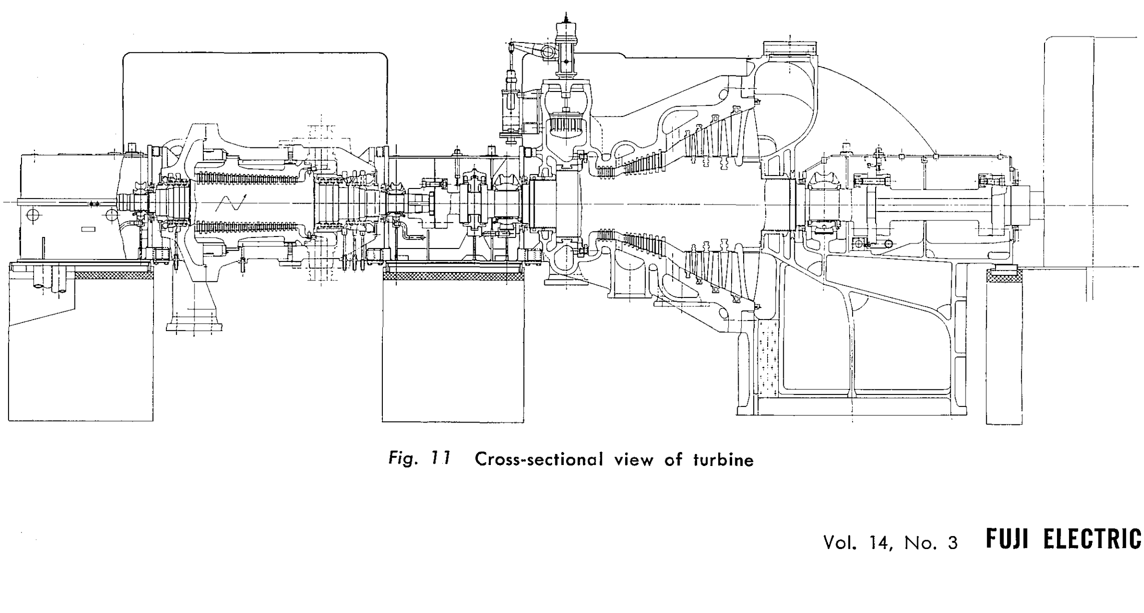


Fig. 11 Cross-sectional view of turbine

As shown in *Fig. 11,* the turbine consists of 2 high and low pressure cylinders. The first controlled bleeder is vented at the connecting pipe between these casings, while the 2nd and 3rd bleeder (uncontrolled) are from the intermediate stage of the low pressure turbine.

The turbine assemble is fixed to the base at the rear of the low pressure turbine; and the remaining portions, including the intermediate bearing base, and the front bearing base with the high pressure turbine attached, are designed so that they can slide along the base to the front when they undergo thermal expansion.

The roters of both the high and low pressure turbines can expand with respect to their casings by means of a thrust bearing in the intermediate bearing base. This thrust bearing is fixed at the steam inlet side and expands in the opposite direction.

1) High pressure turbine

The high pressure turbine employs an inserted-nozzle box type pot casing, a device that Fuji Electric is justly proud of. It features thin walls, and perfectly circularity in horizontal cross sections cut at right angles to the casing shaft with no flanges present. The flange between the front and rear parts of the casing has been made thin because it is not subjected to high steam pressures and therefore need not be very strong.

Since the four nozzle boxes are manufactured individualy and mounted on the casing, walls can be thin and thermal expansion will not be hindered by the casing. (Refer to *Fig. 12*)

The emergency stop valve and control valve are separate units connected to the nozzle boxes with a pipe.

The two-section stator blade holder in the pot casing is subjected to an external pressure in the impluse wheel chamber, and this pressure serves to tighten the holder section joints. Therefore, the horizontal flange can be smaller and the stator blade holder can be of a weight suitable for the rotor. The speed and length of thermal expansion therefore almost completely match those of the rotor.

This turbine construction feature permits considerable flexibility against sudden variations in temperture and rapid response to starting phenomena and load variations.

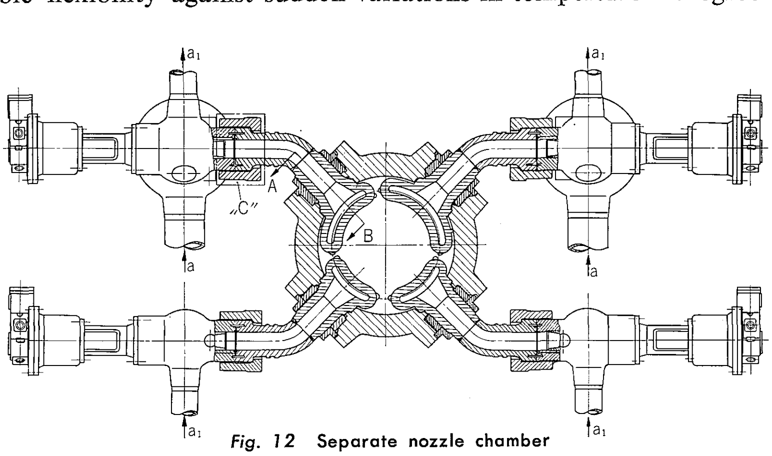


Fig. 12 Separate nozzle chamber

The roter is machined from solid forged steel which allows for a critical speed as high as 130% of the normal operating speed, and thus guarantees the rapid response mentioned above.

2) Low pressure turbine

The low pressure turbine has a horizontal flange, and is manufactured in upper and lower sections each of which can be divided into front and rear parts. The rear bearing base at the rear of the casing is made from the same mold.

The low pressure turbine rotor is made of a single solid forged steel as in the high pressure turbine, and the critical speed is also higher than 130% of the normal operating speed.

The blading consists of one impulse stage for nozzle cut-out governing and 16 reaction stages. The reaction stages can be divided into three groups, and the last four use Fuji Electric standard low pressure blades (maximum 565 mm). These are the same types as those used in the 30 Mw condensation turbine delivered to the Tsukumi Plant of the Onoda Cement Co., where performance has been excellent. All blades are independent with no wire lacings or shroud rings used to bind them together. The individual blades are carefully adjusted so that they do not vibrate in resonance with the turbine rotation. Since the tips of the final row of blades are subjected to corrosive wet steam, the tips are hardened by a special process. The clearance between the stator and rotor blades is made wider to reduce the possibility of water droplets adhering to the blade.

2. Auxiliary Components

1) Condenser

The condenser has the following specifications.

Type:	Surface type condensation
Cooling area:	2230 m^2
Cooling capacity:	5700 m^3/hr
Applicable cooling water:	River water
Cooling water temperature:	15°C
Degree of vacuum:	734 mmHg (0.035 kg/cm^2 abs)

In this turbine, the quantity of condensed water is comparatively small considering the large output capacity. This is because the turbine is of the steam bleeder condensation-type, and the amount of steam bled to heat the supply water is also considerable. However, reliable, satisfactory output is insured with this steam bleeder-type turbine even when the bleeding quantity falls at a minimum. When the bleeding quantity is at minimum, it is still 1.7 times the rated value since two condensing pumps are operated in parallel. There are also two cooling pumps, each with a capacity equal to the 100% quantity consumed.

The condenser is circular, and arranged at right angles to the turbine shaft. The tube base plate and water chamber, made of sheet steel, are partitioned in two sections, one of which operates independently while cooling tubes in the other are being cleaned.

The tubes are made of 9/1 copper-nickel, and attached to the base plate with an expansion pipe.

2) Turning device

The turning device is driven hydraulically. An impulse wheel located between the low pressure turbine shaft and the intermediate shaft in the rear bearing box is driven by oil under pressure (a portion of the oil supplied by the auxiliary oil pump). No independent oil pump is provided, nor is the oil pump capacity increased.

The turning speed is approximately 100 rpm. It serves to agitate air in the casing so that temperature is distributed evenly over the entire casing during cooling to prevent shaft and casing deformities due to irregular temperature distribution.

The turning device is physically independent of the shaft, so that no isolating device need be provided during acceleration. When interrupting the turbine, it is not necessary to stop rotation before starting the turbine device. These features effect both operation and safety.

3. Monitoring Instruments

Instruments for monitoring turbine operation measure the opening angle of the emergency stop and control valves, expansion and expansion differences of the casing, bearing vibrations, and casing wall temperatures.

Thermocouples are installed on the upper and lower portions of the high pressure turbine chamber to monitor the casing wall temperature. They detect temperature differences between these points so that casing deformations can be prevented.

Special wall-temperature thermometer are provided at the high pressure casing chamber and the emergency stop valve box to detect thermal stress caused by instantaneous temperature variations. They measure two temperatures at the same point in the casing wall, one at the surface of the casing and the other at the middle point of the casing wall thickness. The difference between these two temperatures indicates the magnitude of thermal stress at the measured portion, and also reveals whether variations in load and speed during starting and load variation are acceptable to the turbine.

In addition to the casing wall temperature, thermal expansion in high and low pressure casings and differences at various portions, as well as vibrations in individual bearing bases, are recorded in the central control room.

4. Control and Safety Device

A schematic diagram of control and safety devices is shown in *Fig. 13*. In the control operation, speed control is accomplished by individual control valves

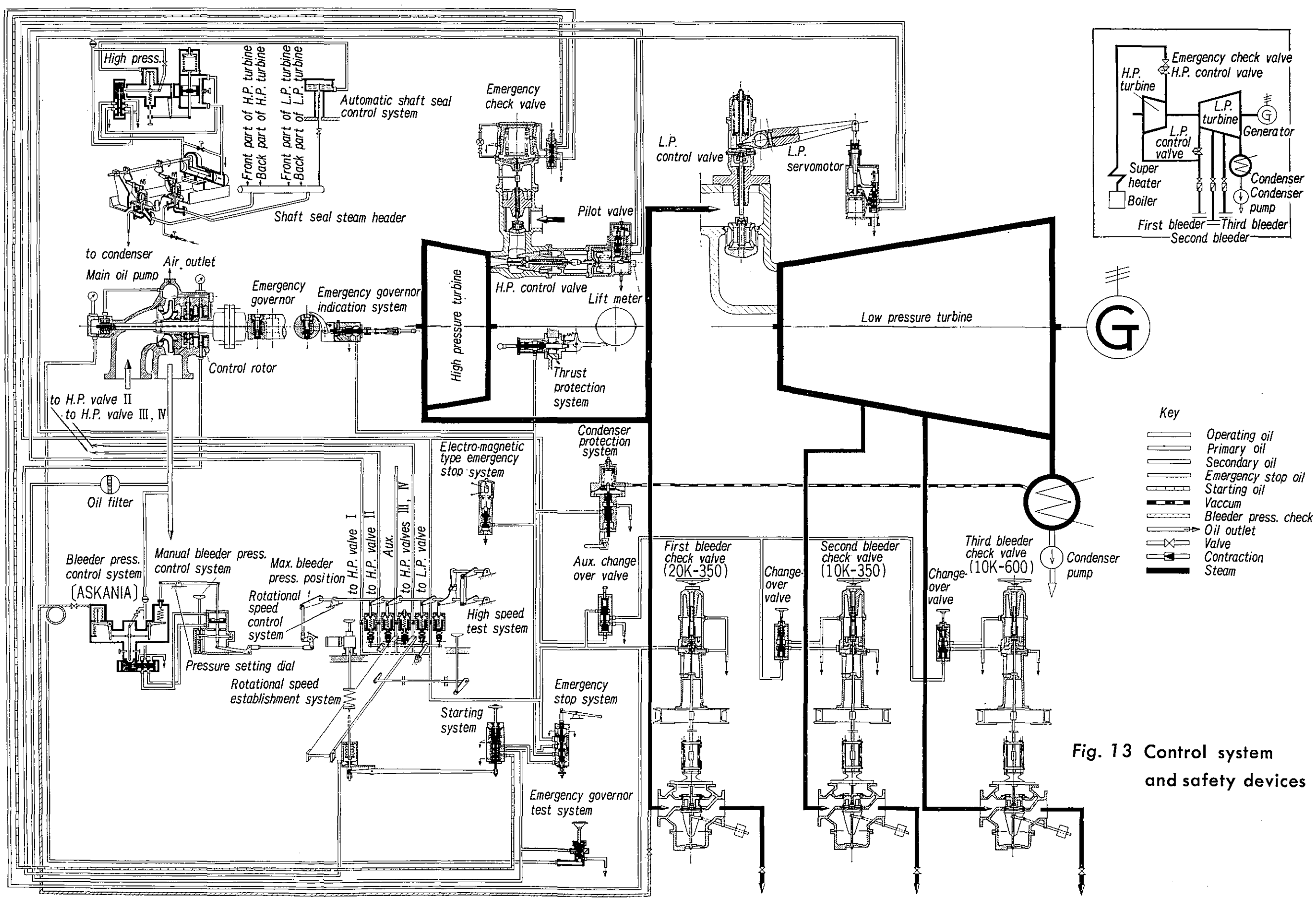


Fig. 13 Control system and safety devices

closed or opened by a servomotor driven by a hydraulic signal i.e. the secondary pressure of the governor impeller. The governor impeller produces a primary pressure proportional to the square of its speed; the primary pressure is inverted in direction and amplified by the speed adjuster before being used as the secondary pressure.

The case where the output varies while the bleeding quantity remains the same can be accomplished by arranging so that the high and low secondary oil pressures change in the same direction, and making their steam quantity equal. When the bleeding quantity changes and the output remains the same, secondary oil pressures change in opposite directions, inversely proportional to the thermal difference between the high and low pressures. An oil-jet type bleeding pressure controller is used to accomplish this.

5. Test Operation

Test operation was completed in October 1967, according to the following schedule. As shown in *Table 3,* the turbine vibrated only slightly.

Results of tests on the governor are shown in *Fig. 14.* These tests were conducted under loads of 4/4 and 2/4, and the figure gives oscillograms made on disconnection dumping of these loads. It can be seen that the rate of instantaneous speed increase is as low as 6.4%, even when all power is disconnected. Various rates of speed increase are listed in *Table 4.*

III. GENERATOR

This generator, with the largest output of any industrial thermal power generator in Japan, has a hydrogen cooling system to cool the rotor field winding. When designing industrial power generators, all loads in the plant including the load within the power station must be calculated so that suitable specifications can be obtained. According to convention this design gives consideration to the problem of harmonic currents produced by load rectifiers. Industrial power generators must be reliable and stable during the time the plant is in operation, since they are the determining factor in plant operation reliability. Power generators must also necessitate a minimum of maintenance. Both of these factors were considered in the design of this power generator.

1. Generator Specifications

Type :	Horizontal shaft, cylindrical, rotary field, hydrogen-cooled type
Output :	67,500 kva
Power factor :	0.8
Voltage :	11,500 v
Current :	3390 amp
Speed :	3600 rpm
Frequency :	60 Hz
Hydrogen pressure :	2 kg/cm^2
Cooling :	Stator winding : indirect hydrogen cooling

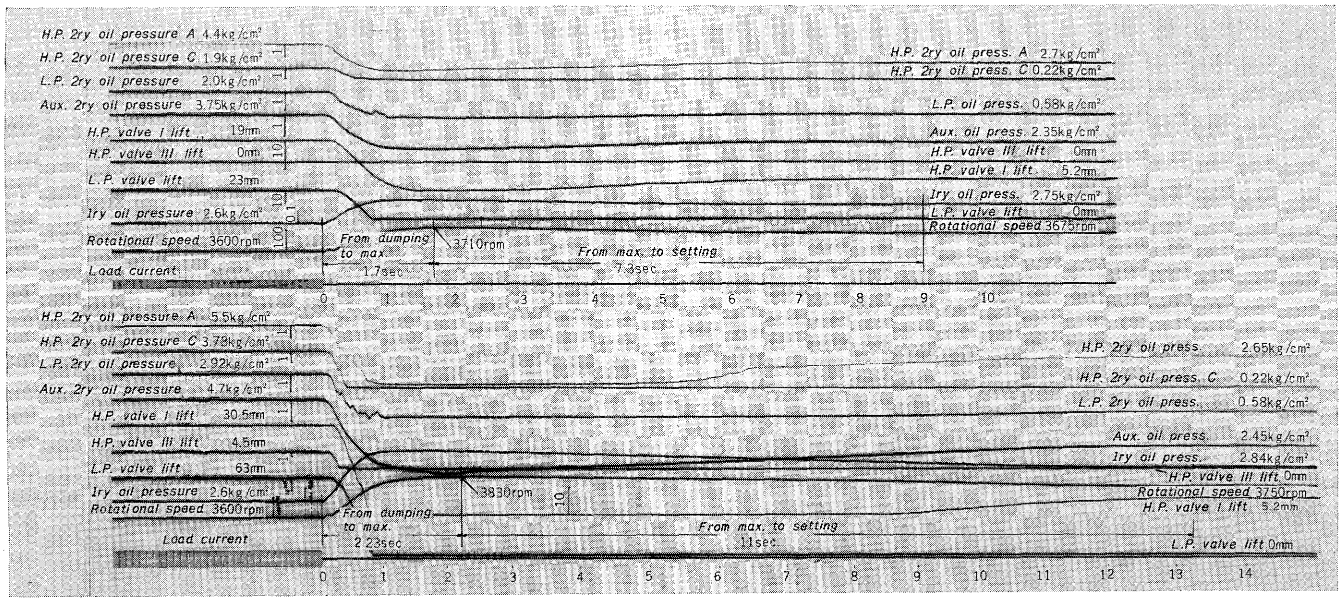


Fig. 14 Oscillogram of load dump test

***Table 4* Results of Dump Tests**

Load	1/4 Not Bled	2/4 Not Bled	2/4 Bled	3/4 Bled	4/4 Bled
Rate of Instantaneous Speed Increase	2.8%	5.0%	3.1%	5.0%	6.4%
Rate of Speed Adjustment	0.83%	1.95%	2.1%	3.3%	4.17%

	Rotor winding: direct hydrogen cooling in the radial direction
Stator winding connection:	Single star connection
Grounding system:	100 amp resistor grounding
Excitation system:	OH static excitation

2. Cooling System

The hydrogen gas cooling system for the generator can be divided roughly into direct and indirect methods, although there are slight variations between these methods, and each method naturally has its characteristic advantages. Thus, some variations are necessary to achieve maximum performance. In this design, the stator is cooled indirectly and the rotor winding is cooled directly in the radial direction.

In the direct radial cooling method, the rotor winding is directly cooled locally so that the cooling efficiency is much higher than with the indirect method. A cut-away view of the rotor cooled by this method is shown in *Fig. 15*. Cold hydrogen gas is introduced in the direction of the shaft middle through a cooling slit located at the bottom of each rotor slot. Holes are arranged at intervals in the conductors in the radial direction. These holes are connecting passages which pass through the retaining pieces and slot insulation to connect the cooling slot and the air gap. Hydrogen gas enters the cooling slot from the shaft end, and flows in the direction of the shaft, during which time it absorbs no heat. It then flows on through the connecting passage into the air gap. While flowing through the connecting passage, it comes into direct contact with the conductors and cools them. For this method, the diameter, number, and distribution of these connecting passages are arranged so that temperatures are uniform in every part of the winding. The hydrogen gas will not be heated before it reaches the connecting passage, and is therefore fresh and cold enough to cool the conductors effectively. In this direct cooling, the rotor winding can be of simple construction with no limitations on the number of coil turns. Excitation current can thus be reduced.

3. Construction

A cross section of the rotor is shown in *Fig. 16*.

1) Cooling gas circulation

Hydrogen gas is circulated by a fan at the winding support rings at each end of the rotor. The circulation circuit is symmetrical with respect to the center of the generator, and is divided into two portions: one on the turbine side and one on the slip ring side. Cooling gas warmed by the heat af the rotor is recooled by two coolers attached to the stator frame in the shaft direction. The stator core is cooled by a multiple system in which gas is driven by a fan through the following three routes.

The first route supplies gas directly to the stator and the rotor gap. Gas flows through the gap to cool the rotor surface and the poles of the stator core, while at the same time a portion of the gas flows into the radial duct in the stator core to cool the stator winding and the core. This gas is then discharged into the heat chamber at the back of the core. The second route cools the ends of the stator winding before entering the cold chamber at the back of the stator core, and flows through the radial duct in the opposite direction of the first route gas. The two gas flows join in the air gap. The third route gas, used to cool the rotor, enters the holes in the support rings at the rotor winding ends, and divides into two routes. One cools the edges of the winding, enters the axial ducts in the rotor to cool the winding indirectly, and then flows into the gap. The other enters the axial slits in the bottom of the rotor winding slots where if flows into the holes in the shaft direction of the winding, cools the winding directly, and is discharged into the air gap. Gas from all three routes meet in the gap, pass through the radial duct, and enter a chamber at the back of the stator core.

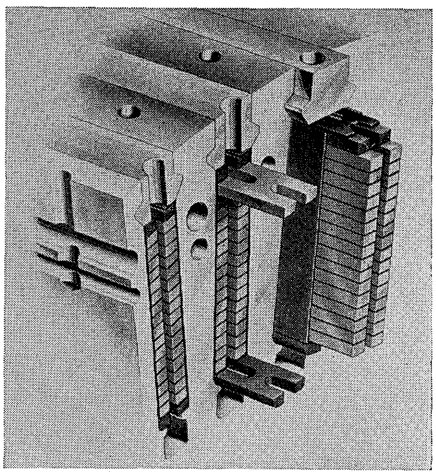


Fig. 15 Rotor coil using direct radial cooling

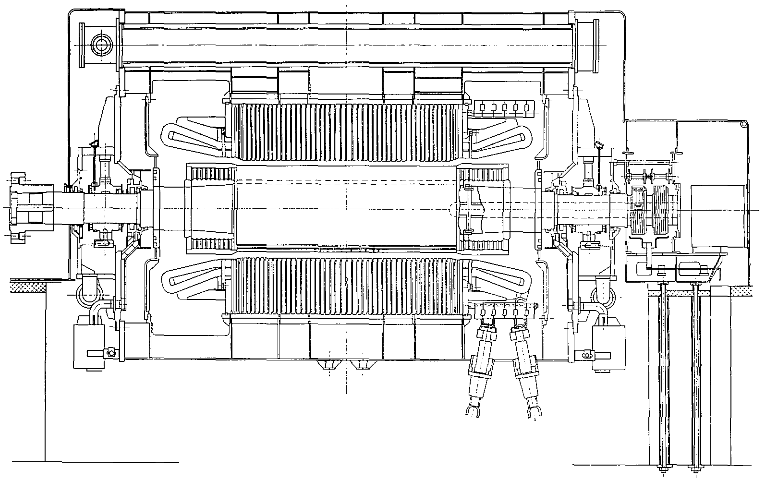


Fig. 16 Sectional view of generator

Heated gas in this chamber is collected in the chamber at the top of the stator frame, where it is cooled by water and recirculated by a fan.

In general, long turbo-generators make it difficult to achieve temperature uniformity throughout the unit, especially in the axial direction. This multiroute cooling system, however, solves this problem. Gas duct width is different at the end and middle of the core so as to provide optimum distribution of the cooling gas and prevent overheating at the center of the core.

2) Stator

In two-pole turbine generators, elliptical deformities in the core will cause vibration which are a multiple of the generator frequency so that a vibration-proof core support is required. In this generator the core is fixed to the stator frame by vibration-proof keys and the stator frame is mounted on the base at four corners so that the central portion where the core is positioned will be free of vibrations.

The stator frame is constructed of welded steel sheets. Explosion-proofing was tested by X ray analysis of the welds, and the frame and bearing brackets were subjected to a water pressure test. Withstand pressure is 10 kg/cm^2. Major components were tested for stress strength over a 15 minute period using a strain gauge.

The core is supported by dovetail vibration-proof keys inside the stator frame. Core elements are tightly and uniformly stacked by thermal compression.

The winding is insulated by F-resin insulation material of long-standing excellence. The winding strands are Roebel transpositioned lattice conductors. Coil wire ends are also transpositioned to reduce stray loss. The winding leads are sealed with epoxy resin at the feed terminal to the generator exterior.

3) Rotor

The rotor shaft is made of nickel-chrome molybdenum forging. Various tests are required to prove that the material is strong, uniform in quality, and has no defects. The shaft was forged under vacuum to prevent hydrogen gas from dissolving in the material. Appropriate forging methods and heat treatment were selected, and the transition temperature was kept low. These factors are important in insuring safe machine operation. To remove the residual stress, material was tempered at maximum temperature and cooled at an appropriate rate. A heat test proved that residual stress was below the permissible value. The finished forging was subjected to a flaw test, tensile test (drill rod and body end test) shock test, transition temperature test and texture test. These tests proved that safety is satisfactory in respect to the toothed portion which receives the largest stress during operation. In addition to these tests, sulfur photography, chemical analysis, and a mirror test for the winding lead holes were also performed. To prevent shrinkage of the winding conductor due to repeated stopping and restarting of the generator, the conductor is made of silvered copper and is supported by retaining pieces made of a special copper alloy applied in the slots. The supporting rings at the sides of the winding are made of hardened non-magnetic wear-resistant steel. The retaining pieces in the slots also serve as a damper winding in addition to the copper damper. This adds to the resistance against the load capacity of the antiphase load.

The slip rings are attached to the outside of the bearing box to facilitate inspection. Holes for the slip rings leads are carefully sealed. Field winding lead bars pass through the outer generator casing, and are connected to the stud conductors arranged in the radial direction which connect the winding leads and slip rings. The lead bar holes are airtight, and stud conductors are sealed in respect to the shaft with heat resistant rubber packings. Gas will not leak in this double airtight construction unless both seals fail at the same time, making reliability extra high.

The slip rings turn at a peripheral speed of 90 m/sec or greater. A brush material to withstand this high speed was carefully selected by various tests.

Rotor insulators must be resistant to centrifugal force produced by high-speed rotation. During assembly from the time when the winding is installed in the core to the time when the dynamic balance is taken, the winding is subjected to a number of compression tests using pressures greater than the maximum operational centrifugal force and heating at an appropriate temperature for settling.

4) Bearing

The bearing bracket is made of welded steel sheets, reinforced with ribs for adequate strength and elasticity. Horizontal seams are bolted under heat, so that the sheets form a solid unit. Seams are made airtight with a non-drying liquid packing injected under pressure. Bearing metal and shaft seal rings are used in the bearing bracket to isolate it from shaft current, and a hydraulic starting device is provided. The interior forms a twin-arc configuration known in German as a " Tragspiegel " (lit " support mirror "), which prevents agitation of bearing oil.

5) Shaft seal

This seal ring, in the gap in the bearing bracket where the rotor passes through the stator, keeps gas inside the generator. Construction is as shown in *Fig. 17*. The seal ring has a narrow cavity containing oil at a pressure 1 kg/cm^2 higher than the gas pressure to prevent the gas from leaking from the generator interior. The seal ring has a counter-pressure groove in the surface opposite that exposed to the gas. This groove prevents the ring from being damaged by heat produced in the ring and equipment contact surface when the ring is forced against the surface by pressurized hydrogen during operation.

6) Shaft seal oil supply and gas supply

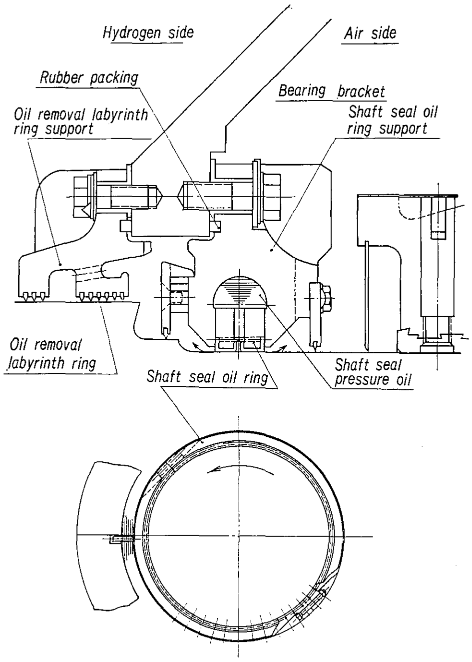


Fig. 17 Shaft seal

The shaft seal oil supply system operates under a vacuum. Oil is supplied by an alternating current pump (normal operation), a direct current pump (emergency operation), and includes a portion from the turbine oil system. Oil pressure is automatically set in accordance with the pressure of the gas in the generator.

The cooling gas supply system consists of a carbon dioxide substitution system used to supply and discharge hydrogen gas, a hydrogen gas supply system, a replenishing system, a gas purity indicator to monitor the purity of the gas in the equipment during substitution and operation, and a gas dryer. Measuring instruments and valves are centralized on a single graphic panel, to facilitate operation.

The shaft seal oil supply, the gas supply, and respective alarms are installed in a room beneath the generator room. The exterior is shown in *Fig. 18*.

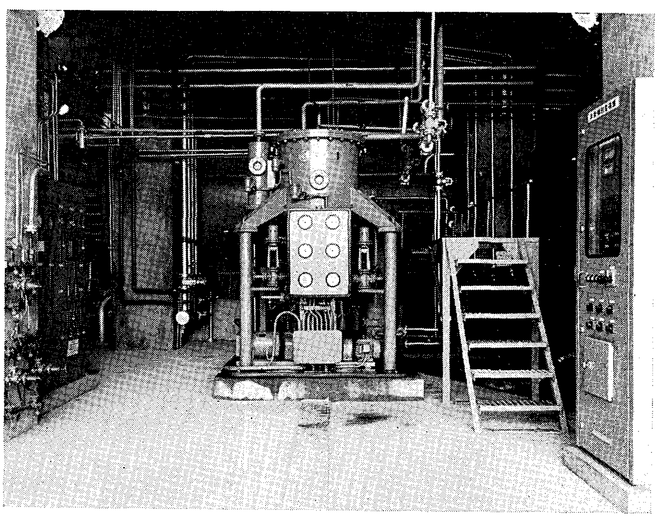


Fig. 18 Gas and shaft seal oil supply and alarm devices

4. Excitation and AVR

1) Excitation

The OH type static exciter, employed in this generator, has been used for a long time in water turbine generator and turbo-generators, and its superior performance is well known. It features outstanding exciting quick response, with small installation space, and minimum maintenance. Performance details have been published often in various Fuji manuals, and they will not be repeated here. The exterior is shown in *Fig. 19*.

2) AVR

The generator voltage and reactive current are ragulatad by changing the value of dc current in the winding controlling the main saturable reactor.

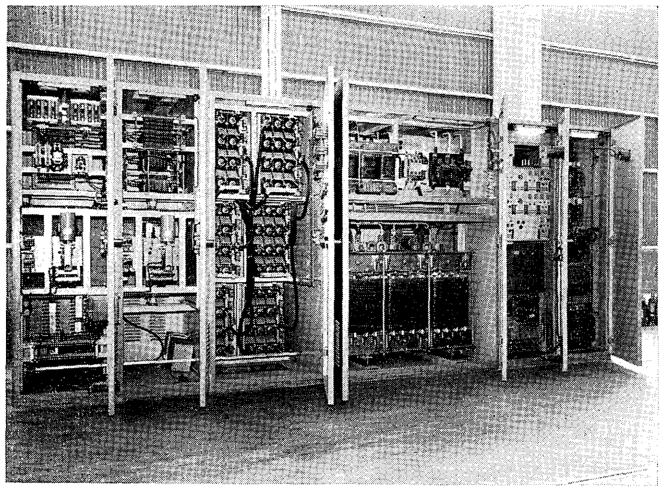


Fig. 19 OH-type static excitation equipment cubicle

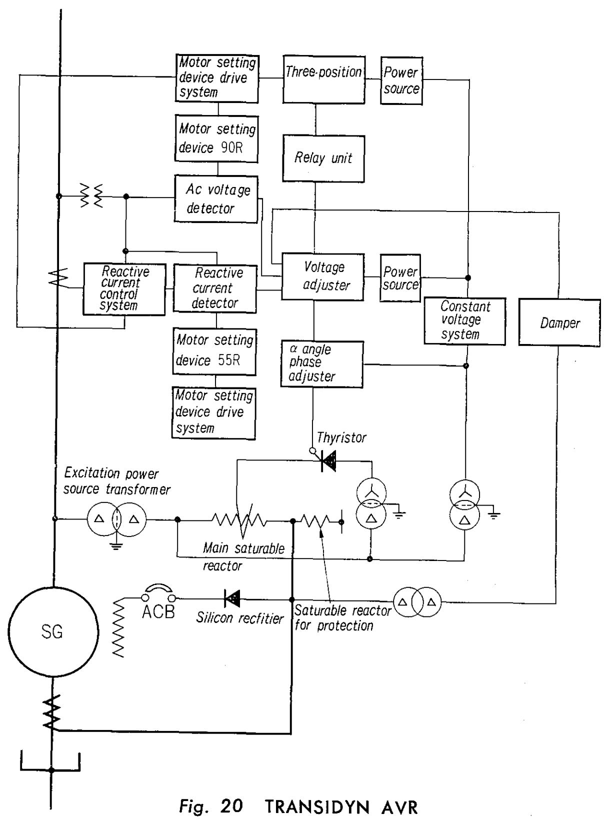


Fig. 20 TRANSIDYN AVR

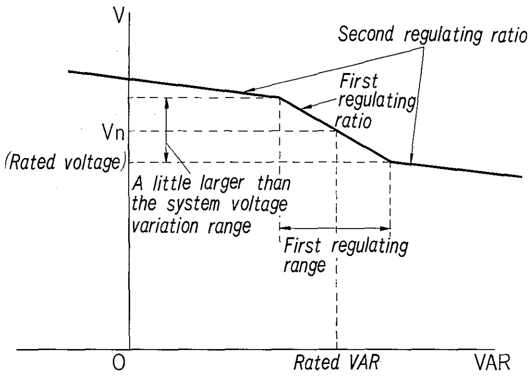


Fig. 21 Voltage drooping characteristics

A thyristor TRANSIDYN AVR as shown schematically in *Fig. 20* is used to improve control response, stability and accuracy.

The generator voltage and reactive current are detected by an ac voltage detector and reactive current detector respectively. These readings are compared with the values set on the reference value devices 90 R and 55 R, and the resultant differences are fed to the voltage adjustor to be integrated and amplified. The output is then fed to the α angle adjuster. The phase angle adjuster feeds gate pulses in phase with the input and synchronized with the source voltage to the thyristors and in this way the saturable reactor is controlled.

The generator operates under constant voltage when used independently. It employs a VAR constant, power factor constant system for parallel operation. In general, it is difficult to change AVR characteristics to suit operation modes (independent or parallel). This generator uses no switching, only a reactive current detector with characteristics as shown in *Fig. 21*.

Detector voltage :

$$VD = IsR \sin\theta$$

Setting voltage :

$$Vs = KIsR$$

Defference :

$$Vs - VD = IsR(K - \sin\theta)$$

When the difference is zero, $\sin\theta = k$, and constant power factor control is achieved. The first regulation rate, second regulation rate, and changing points between the first and second rates (shown in *Fig. 21*) are served by individual dials. Adjustment of these dials will provide compensation for voltage regulation and generator reactive power regulation. These adjustments can be made within ranges of 0∼40% for the first regulating rate, and 0∼10% for the second regulating rate. The adjustment range for the first regulating range is 0∼±30%.

Reactive lead or lag currents, developed beyond the permissible value due to large line voltage variations or incorrect usage of the 90 R will result in damage from coil overheating or generator instability. A reactive current limiter is installed to prevent such abnormalities in the reactive current. The limiter controls the reference value setter to maintain reactive current within the permissible range.

The AVR is stabilized by feedback from the junction of the main saturable reactor to the power current transformer via the isolation transformer and damper.

5. Test Results

1) Vibration

The generator unit gave the following for vibration tests (single amplitude).

(1) Bearing, turbine side

The vibration were 5.0μ in the horizontal direction, 2.6μ in the vertical direction, and 4.4μ in the axial direction.

(2) Bearing, opposite side

The vibration were 2.8μ in the horizontal direction, 2.5μ in the vertical direction, and 2.4μ in the axial direction.

(3) Stator frame

Average of 2.7μ.

Generator vibration were very small for a unit of this size. These low values are due to excellent balance adjustments, the superior manufacturing and engineering techniques of the rotor, as well as the four-corner stator support method.

2) Excitation characteristics

(1) Indicial response test

Indicial response was tested on the closed excitation loop with the voltage changed over approx-

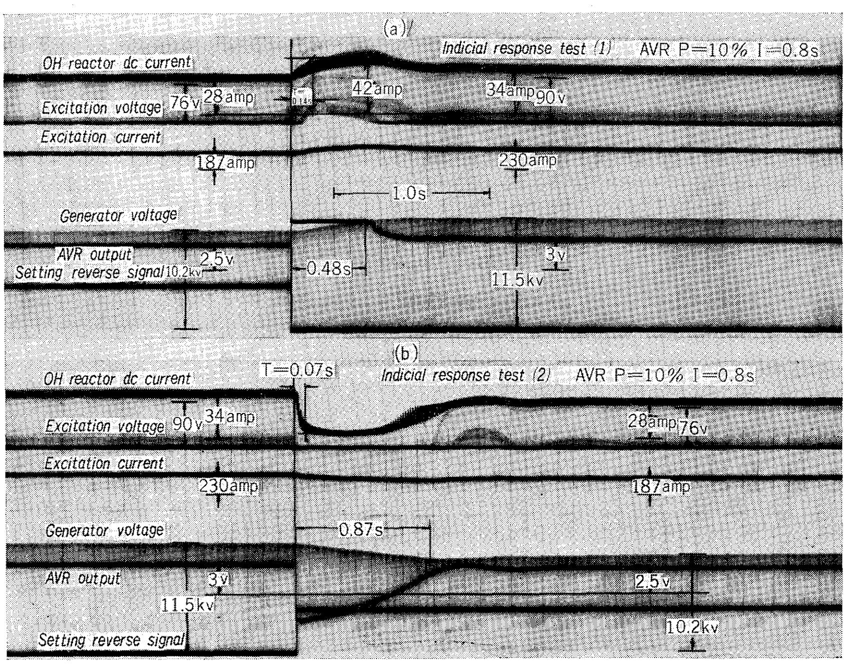


Fig. 22 Indicial response

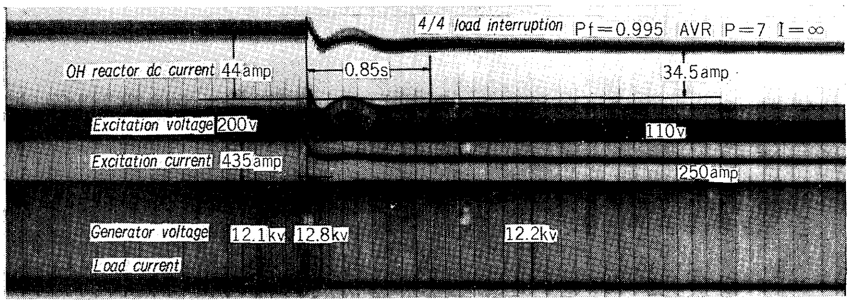


Fig. 23 4/4 load interruption

imately 10% of the set value. The variations observed are shown in the oscillograms in *Fig. 2*. The damper was not used in this test.

(2) Load interruption test

A 1/4∼4/4 load interruption was tested using a water rheostat. An oscillogram of the 4/4 load interruption is shown in *Fig. 23*. The damper was used with the voltage regulator set at P=7% and I=∞. For the interruption of a 4/4 load, voltage increase in the generator was as low as 5.7% maximum, (1.6% for 1/4, 1.7% for 2/4, and 5.1% for 3/4). Setting time was 0.3 sec, and setting time of the magnetizing voltage was 0.85 sec. All of these values prove the excellence of the equipment.

IV. MEASUREMENT AND CONTROL EQUIPMENT

1. Ground Instrumentation Plan

Thermal power station instrumentation must be capable of maintaining constant temperature and steam pressure for the turbine. The following factors are also important.

1) Steam power for chemical process must be maintained (instruments must be highly reliable)

2) Personnel must be a minimum. (instruments must be efficient)

3) Central instrument panel size must be minimum (instruments must be small)

To fulfill these factors, this equipment uses S-series electronic instruments, which are small and reliable; as local controllers P-type controllers, whose high reliability has been guaranteed over a long period of use, are used. S-series electronic controller are used in the important control systems.

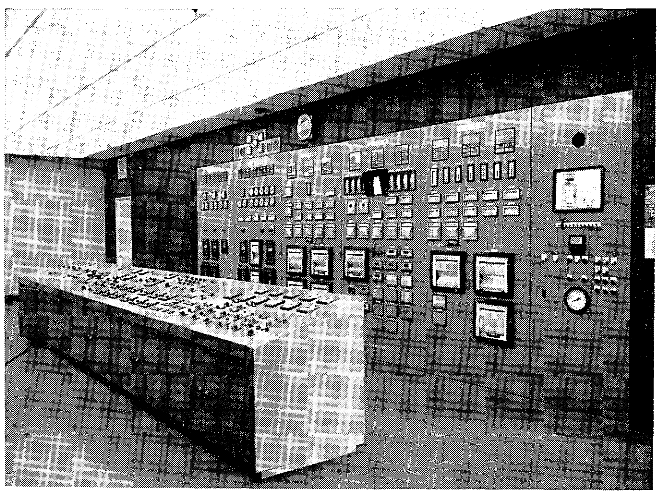


Fig. 24 Instrument panel

Table 5 Measuring Points

Measured Item \ Boiler and Turbine	Boiler	Turbine	Total
Thermometer	44	20 *1	64
Pressure Gauge	45	11	56
Flow Meter	12	4	16
Level Gauge	8	1	9
Gas Analyzer	1	0	1
Control Valves	27 (7) *2	2	29 (7)
Alarms	53	29	82

*1. Including 6 measuring points in the turbine wall.
*2. Damper and vane devices.
- 6 measuring points, turbine vibration, expansion differerence.
- Supply water *pH*, O_2, and μv/cm are supplied by the boiler manufacturer.

An overall view of the instrument panel is shown in *Fig. 24*. In this figure, units are, from right to left, the soot blow panel, boiler panel, turbine panel, and generator panel. The number of measuring points are listed in *Table 5*.

2. Boiler Instrumentation

A schematic of the boiler instrumentation is shown in *Fig. 25*, and a schematic of the boiler controls in *Fig. 26*. Features are as follows:

1) Steam pressure control device

Because this device maintains constant steam pressure at the inlet of the turbine, the steam pressure detector is located near the turbine. The pressure is detected by detector (E-PTH) and measured, differences are calculated (PID operation) by the main controller, and the difference is supplied to the fuel controller as a correction signal. This is a cascade control system.

2) Fuel control devices

Heavy oil and off-gas (gas produced in the refining of petroleum) are used as fuel. Automatic fuel control is applied only to the heavy oil; off-gas is manually controlled at the control center. Steam

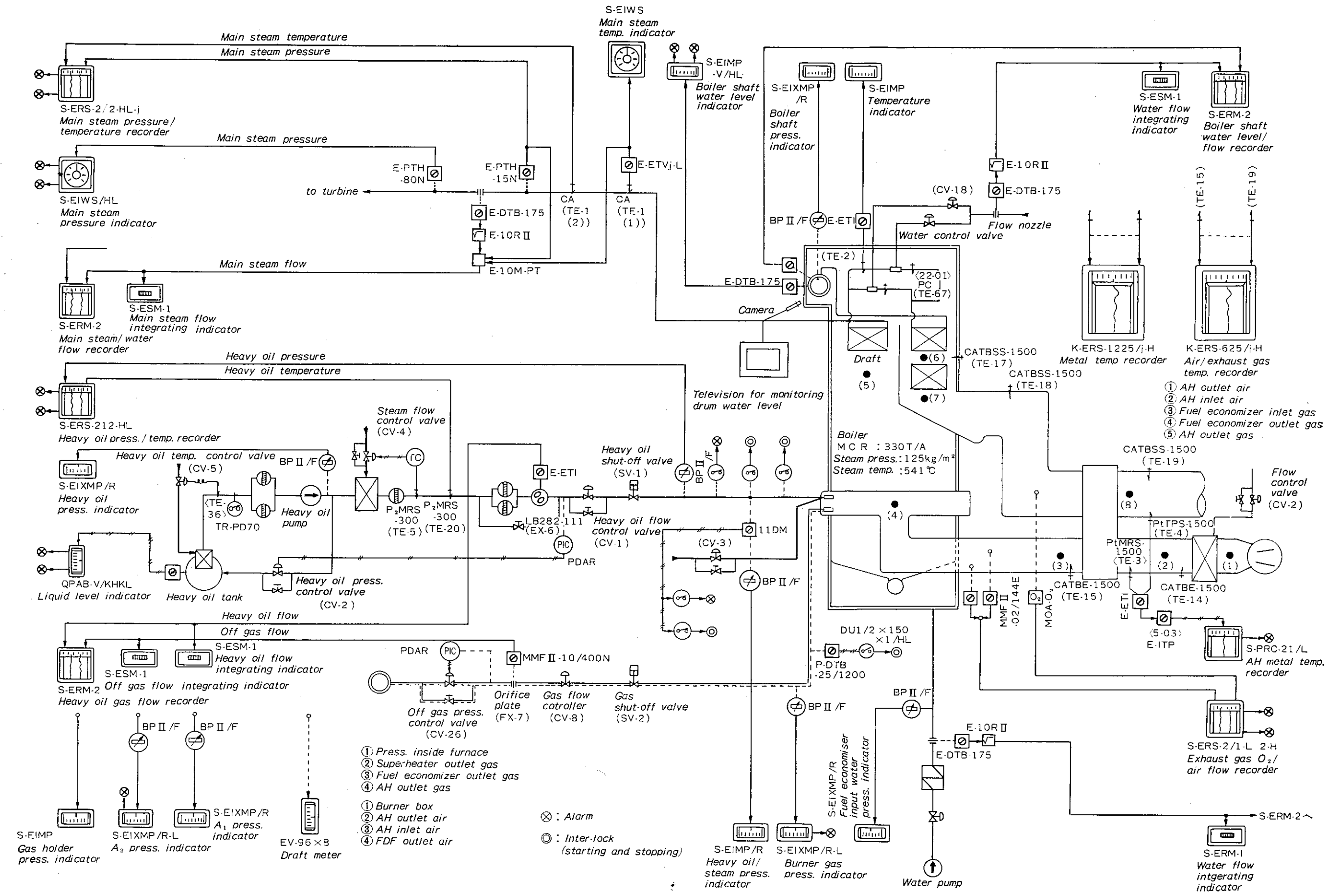


Fig. 25 **Instrumentation diagram for boiler**

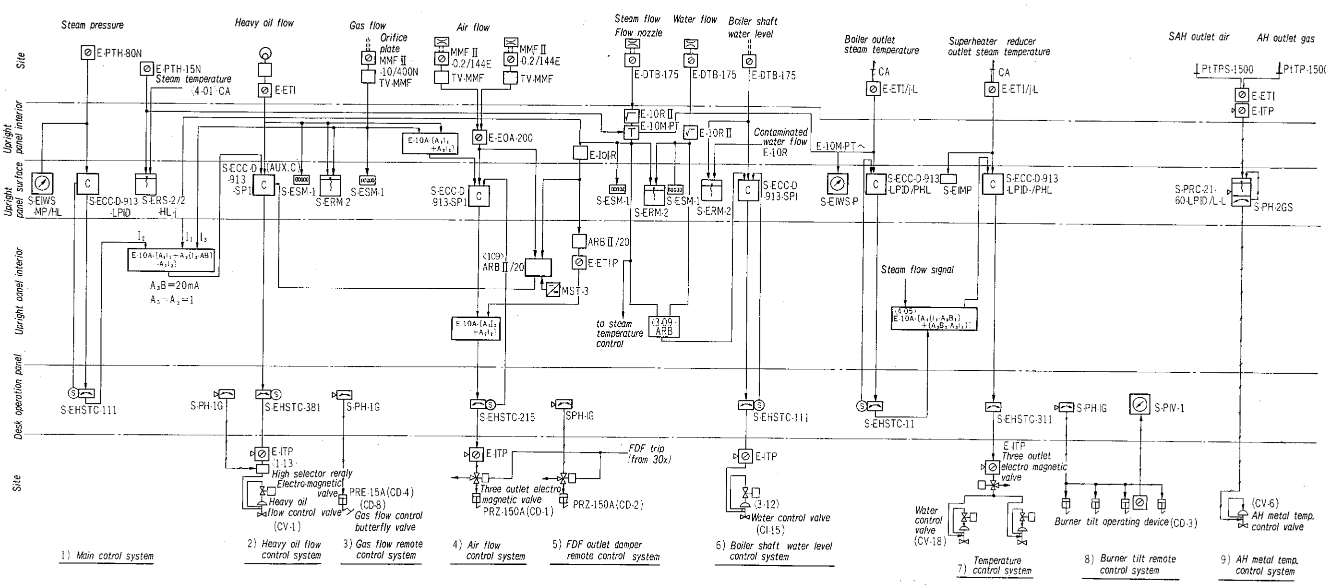


Fig. 26 **Instrumentation diagram for boiler ABC**

flow signals (feed forward signals) are added to the output signal of the main controller to improve boiler response. The volume of off-gas is converted to a corresponding volume of steam, since the off-gas volume is constant in this case, and it is subtracted from the steam volume. This signal is therefore used to set the volume of heavy oil to be supplied to the boiler.

(1) Minimum pressure maintenance system

When steam flow decreases suddenly, the heavy oil flow adjustment valve is normally closed fully by the heavy oil flow controller D action, lowering burner combustion or in the extreme case extinguishing it. To prevent this, a minimum pressure maintenance valve is used. In this equipment, a high selector relay is used as shown

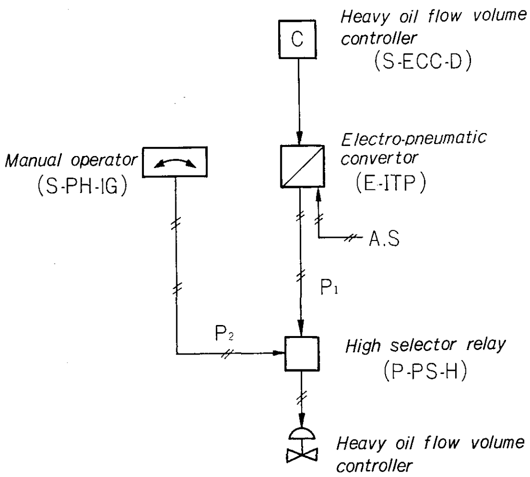


Fig. 27 **Instrumentation diagram for boiler at lowest pressure maintained by high selector relay**

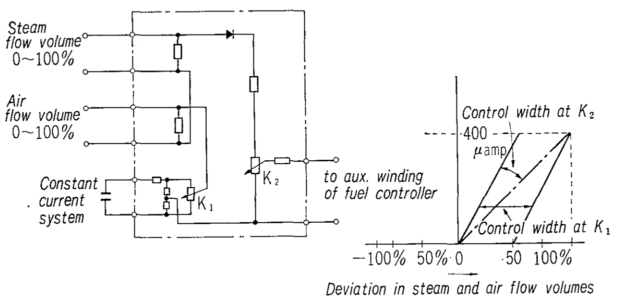


Fig. 28 **Circuit and characteristics of fuel cut-back relay**

in *Fig. 27*.

In this figure, when the controller output is P_1, and the manual selector output is P_2, the high selector output will be P_1, if $P_1 \geqq P_2$ and it will be P_2 if $P_1 < P_2$. Signal pressure to the control valve will not fall below P_2, and valve kept open at this value (P_2). P_2 will differ with the number of burners, and is manually controlled from the control center.

(2) Fuel reduction system for emergencies

This is known as a fuel cut back relay, and reduction is accomplished electrically. Characteristics are shown in *Fig. 28*.

This system functions to reduce control valve opening to stabilize combustion in such cases as when the fuel-to-air volume ratio falls to fuel≧air due to FDF trip, etc. It will not affect the fuel control system when heavy oil<air volume. It has a dead band to avoid disturbances in the air flow controller which might occur with normal steam volume variations since the air flow control system response is usually not very rapid. The dead band and sensitivity can easily be adjusted or set with slide rheostat K_1 and K_2.

Operation will be explained in reference to *Fig. 26*. Steam volume (proportional to the heavy oil volume) and air flow are compared at the auxiliary resistor box ⟨109⟩ ARB II/20, and when the resultant difference falls beyond the dead band limits, a signal is transmitted to the auxiliary input winding of the heavy oil flow controller to reduce the heavy oil volume in proportion to the deviation. The input winding is an original Fuji Electric product for use in S-series instruments.

3) Air flow controller

There are two air ducts, and two flow meters to measure overall air flow. The overall air flow is adjusted by the FDF damper, i.e., by the air flow adjuster to a value appropriately larger than that required for the fuel volume. Combustion of sulfur in the heavy oil burner presents various problems, especially corrosion at low temperatures. To prevent this, an additive can be mixed with the heavy oil or heavy oil with a lower sulfur content can be used. However, an effective combustion under a suppressed O_2 content has been recently perfected. In this combustion method, a boiler with a structure suitable for low O_2 combustion, must be used with an appropriate controller. This control system must have quick response and the ability to stabilize combustion. These requirements are attained by the use of differential steam volume signal ; the signal is applied to the control system when the steam volume increases. However, to avoid unstable combustion it is not applied when the steam volume decreases.

4) Boiler drum water level control device

Water level in the boiler is regulated by three elements : water level itself, steam volume, and supply water volume. As can be seen from *Fig. 26*, the auxiliary input winding of the controller is used effectively in this system.

The high-temperature, high-pressure boiler water level is important enough to require two water level gauges in the boiler, and an industrial television monitor system is employed for direct observation.

5) Steam temperature controller

Steam temperature is held constant in two ways : one method is by automatically adjusting the volume of water supplied at high loads. Another is by automatically adjusting the angle of burner jets when the load is comparatively low.

(1) Water volume control method

This system uses the method used in the Benson boiler. A detailed schematic is shown in *Fig. 26*. Characteristics and another schematic are shown in *Fig. 29*.

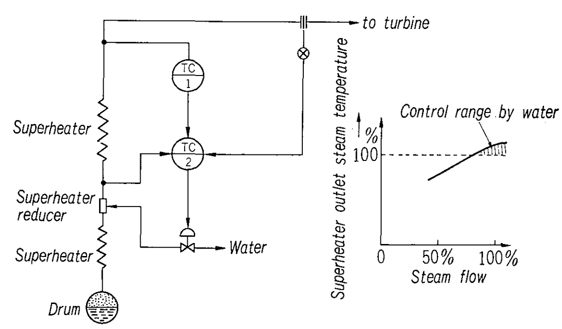


Fig. 29 **Instrument diagram of steam temperature control and superheater characteristics**

This system is based on the fact that heat absorbed in the superheater steam varies with the steam volume. In general, the heating effect increases as the volume of the steam increases (this will differ as the ratio between the direct heating and radiation heating when combined). The desired steam temperature can be obtained by controlling the steam temperature at the outlet of the desuperheater in accordance with the steam volume (accomplished by TC–2). However, in practice, this is not feasible due to various disturbances in the end superheater.

To prevent such disturbances, the cascade signal of steam temperature controller (TC–1) is used to modify the input characteristics of the steam temperature controller (TC–2) at the outlet of the desuperheater, i.e, the relation between the steam volume and steam temperature at the heater reducer outlet is corrected.

As can be seen from the heater characteristics curve in *Fig. 29,* no water is supplied under low loads, (In general, this occurs at 50∼80% of the total steam volume). An controller with simple PID characteristics permits a considerable overshoot of steam temperature due to its integrating functions. To prevent this, an output proportional mechanism (Type: PHL used in S–ECC–N/PHL and SV–EICC/PHL) is added to the controller. This mechanism serves to change PID to P when the controller output falls either blow or above the set value. Output proportional partial P characteristics are shown in *Fig. 30.*

6) Other control device

Controllers for heavy oil pressure, temperature, and other various levels are of high reliability for on-the-spot control. Description of these controllers is omitted here due to limited space.

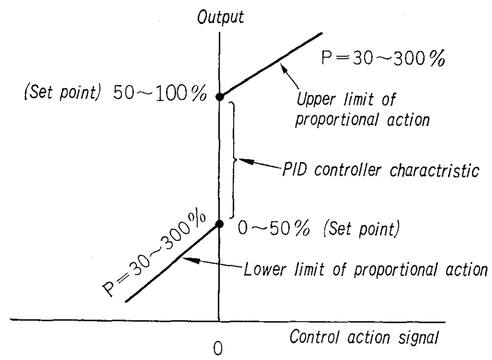


Fig. 30 Partial P action characteristics

3. Turbine and Steam Converter Valve Instrumentation

As shown in *Fig. 31,* the turbine instrumentation consists mainly of monitoring meters, and various controls accomplished by oil pressure. For these controllers, refer to the "TURBINE" section except for special controller and steam converter valves, described in the following.

1) Steam turbine wall temperature measuring device

During turbine operation, the casing must be maintained within the permissible temperature variation range. Permissible values are measured on the walls of the high-pressure emergency stop valve and high-pressure vane chamber. These measuring points are located at the midpoint and inner wall of the high-pressure emergency stop valve, at the midpoint and inner wall of the front portion of the high-pressure vane

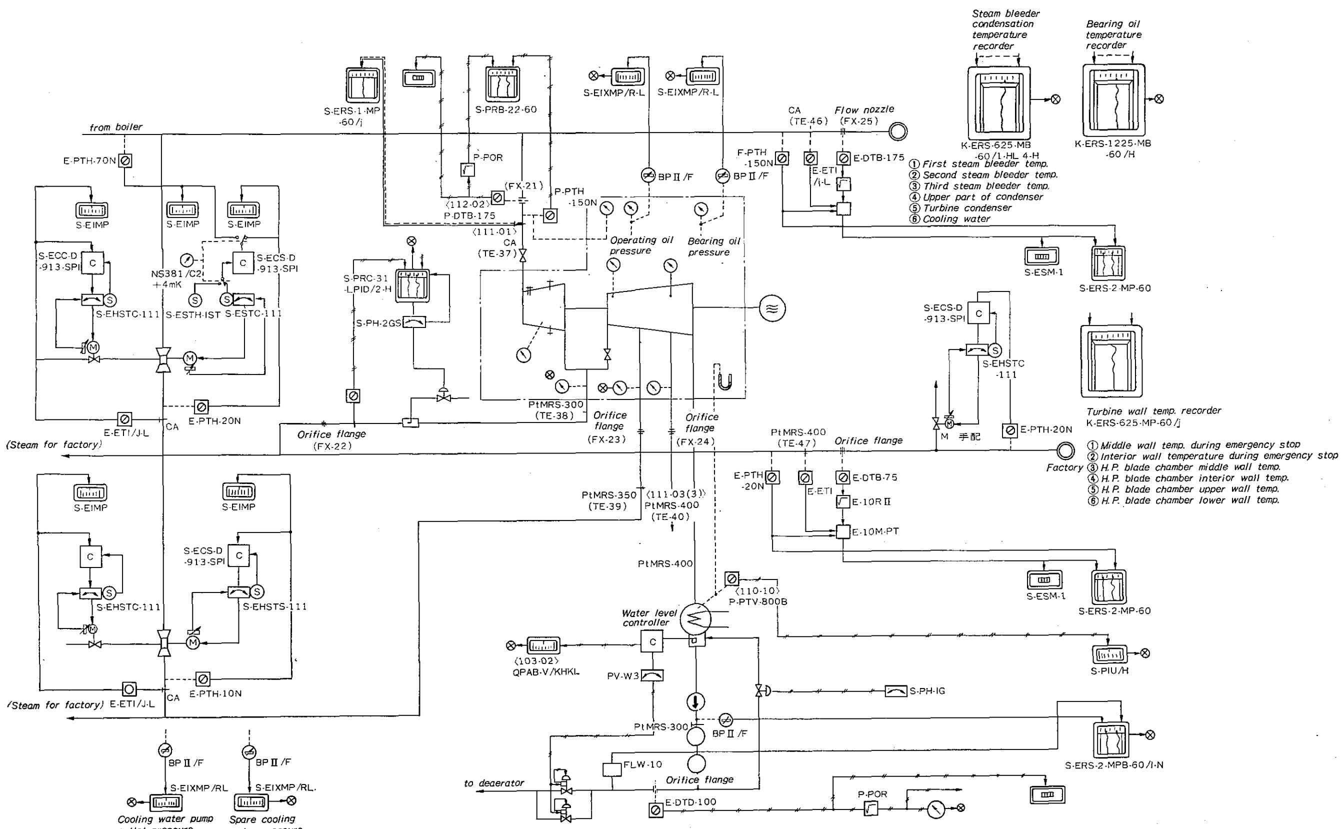


Fig. 31 Instrumentation diagram of turbine and steam converter valve

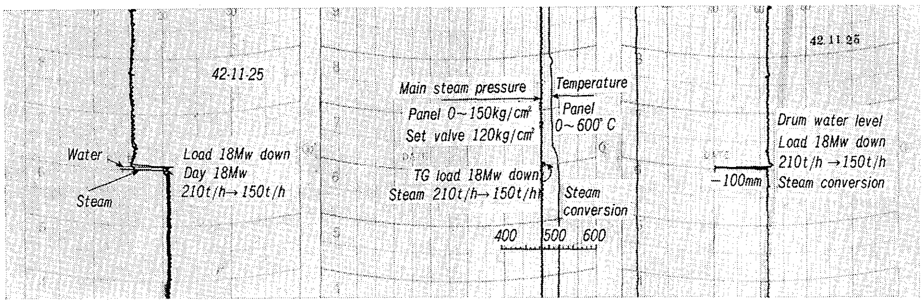


Fig. 32 Recording characteristics of control results

chamber wall, and at the top and bottom of the main wall of the high-pressure vane chamber wall. These temperatures are measured by high-performance thermocouples specially designed for wall temperature measurements. Other special monitoring meters, such as a vibrometer and ductilometer, are provided.

2) Steam converter valve controller

The structure and features of the steam converter valve have been described previously. Only the control system will be described here.

〈High Pressure Converter Valve Control Device〉

The steam converter valve is used primarily to reduce the steam temperature and pressure to provide steam for medium pressure lines during turbine trip. The control method is determined from plant operating conditions.

In this method, the steam converter valve is controlled by means of front pressure in the turbine inlet (the set pressure is higher than the steam pressure in the boiler ABC so that the converter valve is kept closed during normal operation). It opens when the steam pressure increases abnormally, to correct the pressure. In this way there is less chance that the safety valve will operate and service life is extended.

During the turbine trip, the steam converter valve is opened quickly by the trip signal to maintain steam volume in the medium line. This high-speed device attains an opening speed of 8∼10 sec. from complete closing to complete opening of the steam converter valve. Steam pressure variations in the medium line can be minimized by opening the valve at a speed coordinated with the turbine load variation rate. A timer is equipped in the high-speed drive circuit to adjust opening speed.

After turbine interruption, the steam converter valve is switched to operate under a back pressure system to maintain medium pressure line steam pressure constant during subsequent operation.

4. Automatic Control

Adjusting meter PID values are determined from various characteristic tests given in *Table 6*. Performance characteristics based on these values are shown in *Fig. 32*. Steam pressure variation is as low as $+2\ kg/cm^2$ over 20% variation of the boiler maximum load. Although water level in the boiler is low (100 mm), overall performance is satisfactory. The steam temperature varied slightly due to manual control, but this variation was not large enough to affect turbine performance.

Table 6 **Controller Setting Points**

Controller	P (%)	I	D (min)
Main Steam Pressure Controller	30	2 min	0.5
Heavy Oil Flow Controller	100	30 sec	—
Air Flow Controller	100	45 sec	—
Boiler Water Level Controller	50	45 sec	—
Main Steam Temperature Controller	70	3 min	0.8
Main Steam Temperature Controller	100	1 min	0.12

V. CONCLUSION

As a rule industrial thermal power plants were constructed mainly for independent industries. The present tendency, however, is toward the development of larger capacity thermal power plants to be used for improvement of mutual benefit and efficiency by groups of two or more industries. In realizing these groupings, various problems will be involved such as engineering technology, profit, future prospects, proper timing, and system considerations. The Takaoka Kyodo Thermal Power Station presented here will serve as a model for designing of power plants in " Kombinat ".