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ELECTRIC POWER AND STEAM SUPPLY PLANT FOR THE CHEMICAL INDUSTRY Total Output 64,000 kw 140 t/hr of Steam

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I. INTRODUCTION

In the chemical industry, a lot of steam for chemical processes is generally used in conjunction with electrical power. Therefore, power plants using bleeder turbines, are often employed to supply electrical power and steam from the viewpoint of thermal efficiency. The capacity of these power plants in general becomes larger as the scale of chemical plants is enlarged.

Power plants of this type, which supply both electric power and steam, are required not only as an emergency power source in the case of commercial power line failures but also for sufficient performance and control functions to meet changes in the required electric power and steam quantity. Integrated operation and control upon completion of plant expansion is also essential.

Recently, an electric power and steam supply plant with a power output of 40,000 kw and a steam output of 80 t/hr for factory processes was delivered to the Nishiki Factory of the Kureha Chemical Industry Co., Ltd., and is now in operation.

This plant was added to the previously delivered plant with a power output of 24,000 kw and a steam output of 60 t/hr, which means that the total output is now 64,000 kw and 140 t/hr of steam.

The steam flow and electrical circuitry are shown in *Figs. 1* and *2* respectively. Consideration has been given to providing sufficient adaptability for overhaul, etc., of the boiler, turbine, etc., and at the same time sufficient control reliability during normal operation.

Heavy oil is used for the boiler fuel. Some by-product kerosene and OF gas produced from chemical plant processes is also used for fuel.

This article presents an outline of this new plant.

II. OUTLINE OF EQUIPMENT

The heat flow diagram of the entire plant is shown in *Fig. 1*. The plant is required to supply electric power and steam at both 20 ata and 7 ata for chemical plant use.

In the plant constructed earlier, two turbines were used, a high pressure back-pressure turbine and a low-pressure bleeder condensing turbine, to provide constant electrical power during turbine overhaul and high efficiency under normal operating conditions. In this new plant, however, only one 40,000 kw 2-control bleeder turbine is employed.

The first plant also contained two 70 t/hr boilers to make possible the supply of steam and electric power during boiler overhaul but this new plant contained only one 215 t/hr boiler. Specifications of the main equipment in this plant, the boiler, turbine and generator, are as follows.

1) Boiler equipment

Type:	Outdoor-type pressurized Benson boiler
Fuel:	Heavy oil, OF gas, and kerosene
Capacity:	215 t/hr
Outlet pressure:	123 kg/cm²·g
Outlet temperature:	540°C
Feed water temperature:	206.4°C

2) Turbine

Type:	Reaction type 2-casing 2-control bleeder condensing turbine

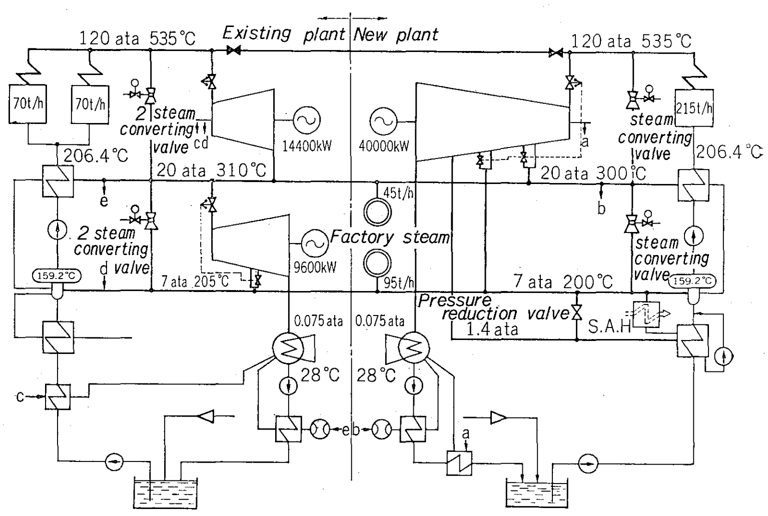


Fig. 1 Steam heat flow diagram

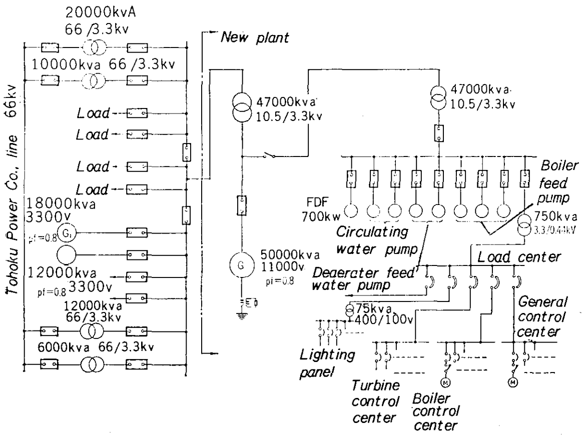


Fig. 2 Electrical skeleton diagram

Output :	40,000 kw (maximum continuous rating)
Speed :	3000 rpm
Steam conditions (at main stop valve) :	119 kg/cm^2•g 535°C
Bleeding pressure	
First bleeder (control) :	19 kg/cm^2•g (20 ata)
Second bleeder (control) :	6 kg/cm^2•g (7 ata)
Third bleeder (non-control) :	0.4 kg/cm^2•g (at rated point)
Condenser vacuum :	0.075 ata (705 mmHg) (at rated point)

3) Generator

Type :	Horizontal shaft cylindrical rotary field-type synchronous generator
Output :	50,000 kva
Voltage :	11,000 v
Power factor :	0.8 (delay)
Speed :	3000 rpm
Frequency :	50 Hz
Cooling system :	Air cooled
Stator winding :	Star
Exciting system :	Brushless
Ground system :	5 amp transformer grounding

Both the existing and the new plants can naturally be operated independently. However, the plant must be operated as one plant in nomal operation to supply both steam and electric power.

Basically, the existing and new equipment are able to be operated independently : the steam generated by the existing boiler is sent to the existing turbine and the steam generated by the new boiler is sent to the new 40,000 kw turbine. However, consideration has also been given to the special conditions required for operation during periodic overhauls, and for this reason it is possible to operate the new turbine by means of the existing boiler or the existing turbine by the new boiler.

Even if the turbine output changes, sufficient steam is supplied constantly for factory processes, and also, if factory steam requirements are altered, the electric power supply remains reliable This is the reason for the application of a bleeder type condensing turbine and the provision of by-pass valves employing steam converting valves from the 120 ata line to the 20 ata line and from the 20 ata line to the 7 ata line.

As described previously, this plant must supply the necessary electric power and steam with controls provided in respect to changes of the 20 ata and 7 ata steam and electric power. However, it is also essential to consider independent changes of the electric power and steam, but generally when the electric power requirements are large, as a result the required steam quantity is also large.

Therefore, turbine specifications must be determined on the basis of investigations into the relationship between the required steam and the required electric power, and the minimum electric power which must be maintained in case the steam quantity occasionally drops to zero. In this plant, inlet steam of 200 t/hr for the 40,000 kw turbine is extracted at a rate of about 140 t/hr as will be described later. The condensate amounts to only 60 t/hr or less.

The new 40,000 kw turbine has three bleeder s: 20 ata and 7 ata control bleeders and a 1.4 ata (at the rated point) non-control bleeder. The steam from 20 ata and 7 ata control bleeders is used for processing steam and heating of the boiler feed water, while the 1.4 ata bleeder is used only for heating of boiler feed water. The 20 ata line steam is normally supplied from the first bleeder of the new 40,000 kw bleeder turbine and exhaust of the existing 14,400 kw back-pressure turbine. If this is insufficient, it can also be supplied from the steam converting valve The 7 ata line steam is simultaneously supplied from the second bleeder of the new 40,000 kw bleeder turbine and the bleeder of the existing 9400 kw bleeder turbine.

In this plant, the generator may be stopped or its load becomes extremely small, while the boiler load remains large in order to supply the steam required for factory processing. Therefore, feed water heating with the third bleeder 1.4 ata line in the lowpressure water heater is also possible by means of a bypass via the reduction valve from the 7 ata line. The 20 ata steam for factory processing has a total required capacity of 45 t/hr, about 25 t/hr of which are from the new plant and about 20 t/hr from the existing plant. The 7 ata steam for factory use has a total required capacity of 95 t/hr, about 40 t/hr from the existing plant and about 55 t/hr from the new plant. Once the factory steam is sent out, none of it returns. Water which has been treated in the chemical water treating equipment is replenished and all water is supplied by means of the 3 line× 100 t/hr chemical water treating system.

Under normal operation only the previously mentioned 20 ata and 7 ata lines in both the existing and new plants are connected, but because of the special conditions arising during overhauls of the boiler, turbine, etc., the 120 ata line of existing and new plants can also be connected.

III. ARRANGEMENT

The arrangement of the newly delivered electric power (40,000 kw) and steam (80 t/hr) plant is shown in *Fig. 3.* It is placed to the right of the 24,000 kw, 60 t/hr plant. Problems arise over the arrangement of the new plant at points where it joined the existing plant. There are two main problems: One of them is the larger width of the turbine room in comparison to the existing plant because the new turbine is bigger, necessitating adjustments of turbine room dimensions. The other is that the new and existing plants are to be connected to form a single plant. Therefore the central control rooms of the existing and new plants must be combined in one room and all control and supervisory instruments must be installed in this single central control room.

Special conditions of this plant are the use of cooling towers. And since electric power must be supplied at 3300 v, the current value becomes very large and a main transformer to step down the 11 kv generator voltage must be installed directly below the 3300 v bus line. This main transformer is located about 100 m from the generator, and the generator and main transformer are connected by means of two 1000 mm² cables for each phase. The main transformer is of the "elephant" type.

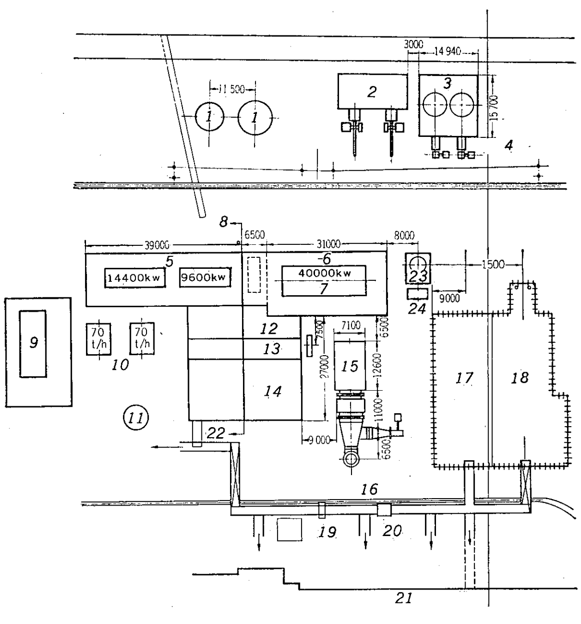


Fig. 3 Plant arrangemement

① Treated water
② Old plantc ooling tower
③ New plant cooling tower
④ Circulating water pump
⑤ Old plat turbine room
⑥ New plant turbine room
⑦ Generator and turbine
⑧ Old plant
⑨ Water treating equipment
⑩ Old plant boiler
⑪ Smoke stack
⑫ Central cotrol room
⑬ Office
⑭ Switch gear
⑮ New plant boiler, 215 t/hr
⑯ 3.3 kv, 6000 amp bus
⑰ Substation for 60 kv
⑱ Substation for 60 kv
⑲ Main transformer
⑳ Breaker for bus tie
㉑ Silicon rectifier equipment and electrolysis room
㉒ Old plant
㉓ Heavy oil service tank
㉔ Oil unit

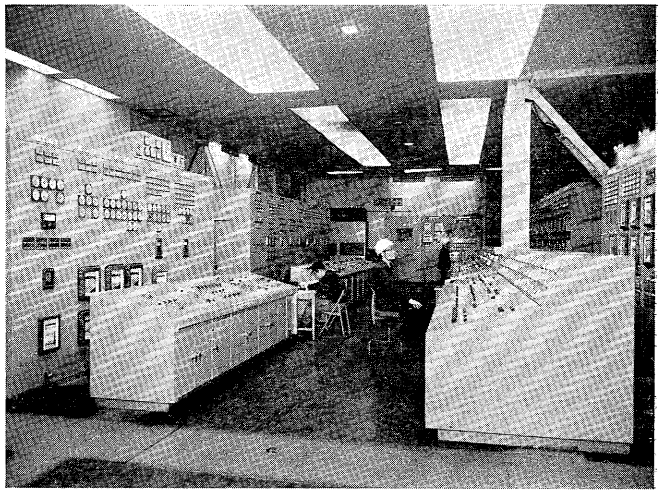


Fig. 4 Central control room

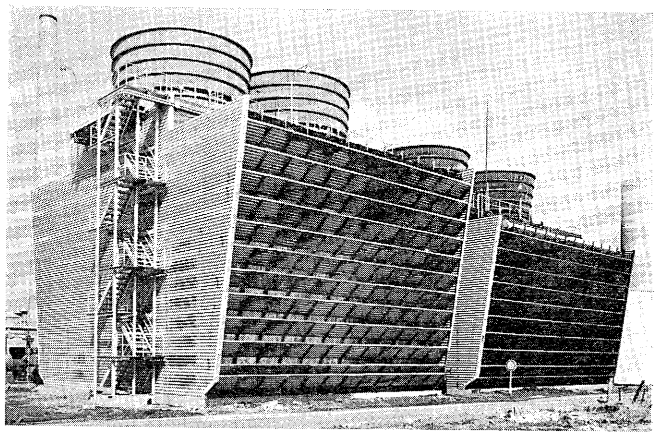


Fig. 5 Cooling tower

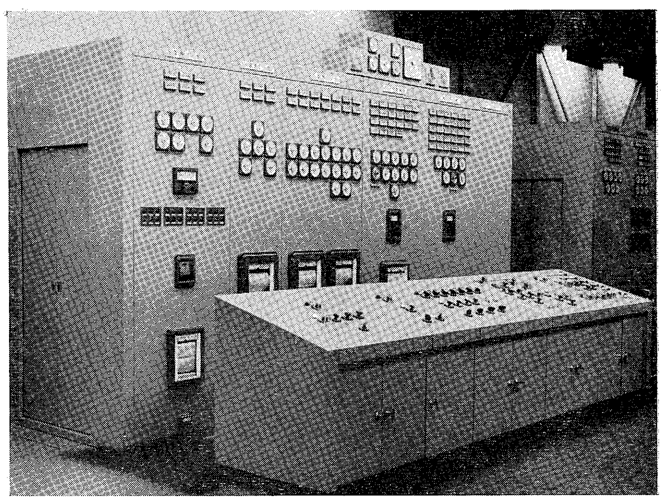


Fig. 6 Contol panel for generator and silicon rectifier

The central control room is enlarged with combination of the existing and new control room and in this control room the existing and new plants are controlled and supervised as a single plant. It contains also control and supervising panels for the silicon rectifier (about 50 Mw) for electrolysis which uses power generated in this power plant. These panels are installed at the generator control panel. In this way, the equipment generating electricity and the equipment which uses the electricity can be controlled and supervised simultaneously at the same place.

The existing turbine room has a width of 13 m and a crane capacity is 25 t, while the new turbine room requires a width of 16 m and a crane capacity of 35 t. The entire room, however, is matched by shifting the increase in the new turbine room width to the boiler side.

The 50,000 kva generator (which will be described later) driven by the 40,000 kw turbine is the largest capacity brushless generator operating in Japan. For employment of the brushless exciting system, there is only one transistor type AVR cubicle with a width of 1400 mm, depth of 700 mm, and height of 2300 mm. This cubicle is located in the central control room and there is no exciting control panel located on the generator side.

This is one of the major advantages of the brushless generator in comparison to other exciting systems. Installation is also extremely simple and the AVR cubicle and generator can be connected only by a single cable of the 100 v, 30 amp class.

IV. TWO-CONTROL BLEEDER CONDENSING TURBINE

Recently, the capacity of thermal generator equipment for both industrial and domestic use as well as joint venture type thermal power plants has gradually increased.

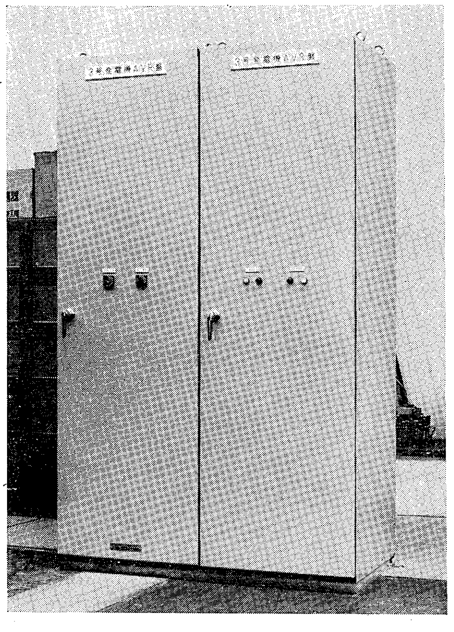


Fig 7 AVR cubicle

In keeping with the increases in capacity, steam at 120 kg/cm^2, 538°C and up-to-date hightest steam condition are employed, requiring higher efficiency. The steam turbine described in this paper is a two-control bleeder condensing turbine with an output of 40,000 kw. In this factory 14,400 kw back-pressure turbine and a 9600 kw one-control bleeder condensing turbine are installed. The exhaust of this back-pressure turbine and first bleeder of the new 40,000 kw turbine are connected and supply steam to a 20 ata line. The bleeder of the 9600 kw bleeder condensing turbine and second bleeder of the new 40,000 kw turbine are connected and supply steam to a 7 ata line (cf. heat flow diagram *Fig. 1*). The features related to the construction and control mechanisms of the new 40,000 kw turbine will be introduced below.

1. Construction Outline

This turbine is used in conjunction with a Benson boiler which has a maximum steam capacity of 215 t/hr and a 1 machine/1 boiler unit system is adopted.

Fig. 8 shows a sectional view of the turbine. An outline of the specifications is given in Section II–2.

As can be seen from the sectional view, this turbine is constructed in two cylinders: a high-pressure casing and a medium-/low-pressure casing.

The high pressure turbine employs an inserted nozzle box type pot casing (barrel type casing); for the high temperature high-pressure conditions this casing is the most appropriate construction. The pot-casing is unique to Fuji Electric and large numbers are now in successful operation. As a detailed description is not considered necessary here, it will be omitted. However, the pot casing turbine possesses a thin wall, light weight, and good stability, and its operating characteristics during starting and load changing are excellent. Unlike turbines used only for power generation, these bleeder turbines are also used for the supply of factory steam and the amount of steam flowing through the turbine is liable to change frequently depending on the factory steam requirements. In such case the pot-casing turbine shows the real worth of its excellent operating characteristics. There are 4 inserted nozzle boxes made of separate castings and installed in the casing. Independent and unrestricted thermal expansion is possible because of the light and thin wall construction. The medium-and low-pressure parts are placed in one casing and they contain bleeding pressure control valves which are controlled by nozzle cut-out governing. Since the pressure and the temperature here is also low, the casing is of the horizontal flange type divided into two parts. The turbine steam inlet flow at rated turbine output is 201.8 t/hr but since most of it is extracted the condensate quantity at the rated

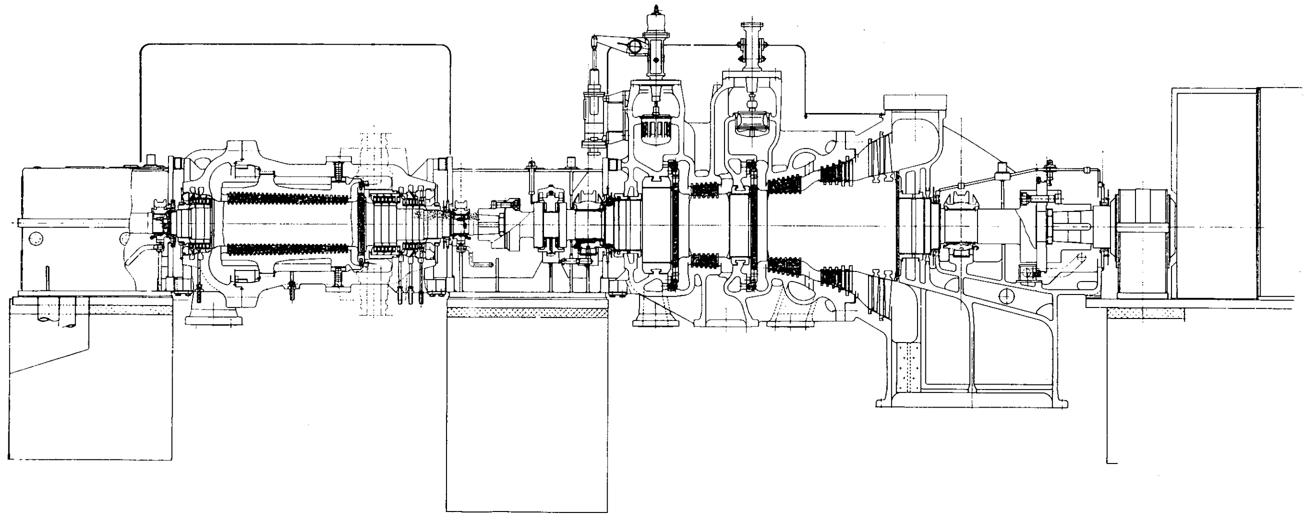


Fig. 8 Turbine sectional view

point of 40,000 kw is only 57.05 t/hr, and the exhaust portion therefore becomes comparatively small.

A newly designed 375 mm moving blade is employed at the final stage of low-pressure parts. The first and second bleeders are extracted ahead of the medium- (20 ata) and low-pressure (7 ata) control valves, and maintain a constant pressure by means of the bleeder pressure control equipment. The third bleeder used only for heating of the boiler feed water is extracted at a point between reaction stages. The high-pressure casing and the low-pressure casing are arranged in opposite directions so as to balance thrust in the axial direction.

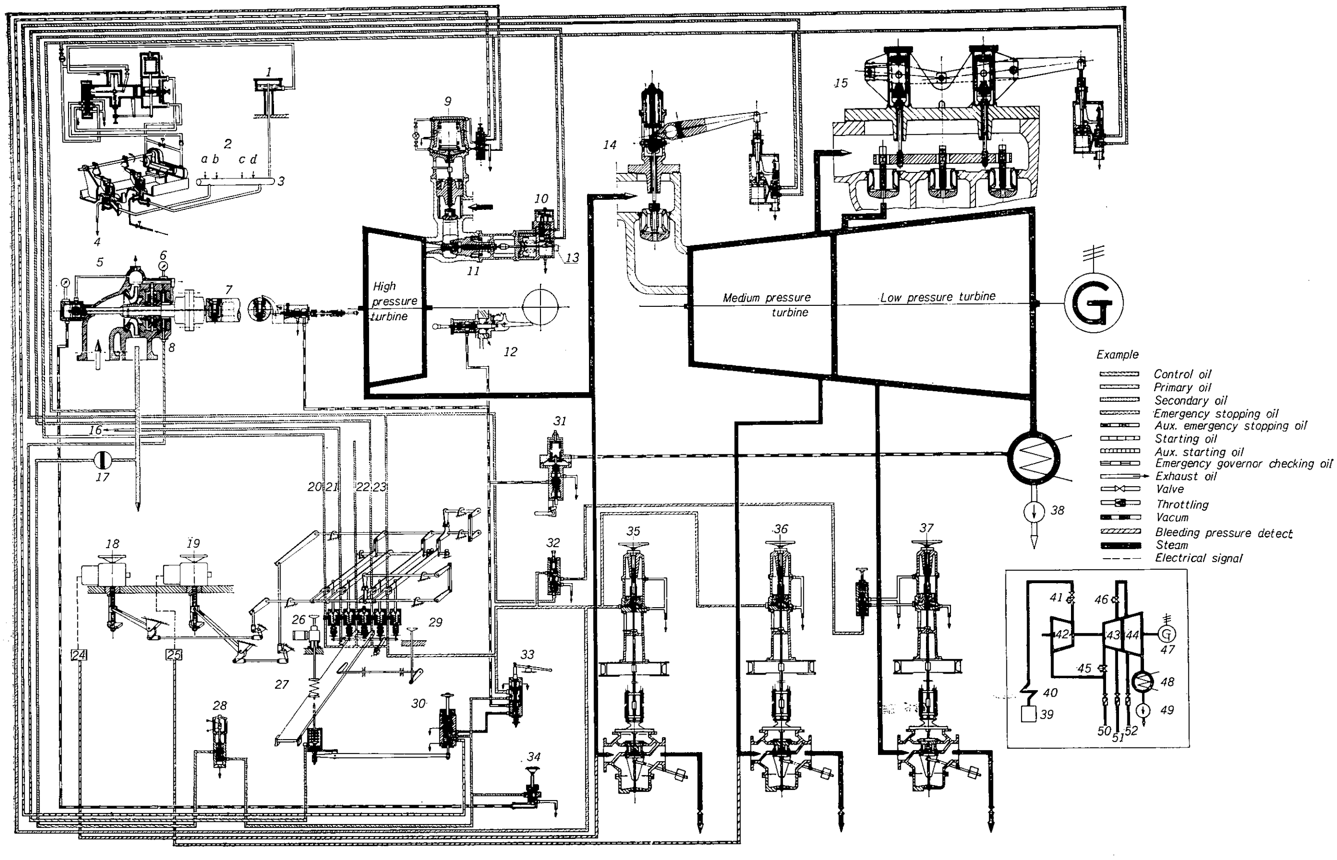
The rear bearing pedestal of the low-pressure turbine forms a single unit with the low-pressure casing and is fixed to the foundation. When the casing expands due to temperature rises, it shifts in the forward direction from this fixed point. Since the high-pressure and low-pressure casings are connected by the casing guides to the front and middle bearing pedestal respectively, the middle bearing pedestal, the high-pressure casing, and the front bearing pedestal slide on the base plate according to thermal expansion of the casing. The shaft is moved forward or back ward from the central thrust bearing located in the middle bearing pedestal.

Therefore, the high-pressure shaft moves in the same direction as the high-pressure casing, while the low-pressure shaft and low-pressure casing move in opposite directions in respect to each other. The expansion difference in each casing is kept to a minimum without any accumulation by means of the thrust bearing arranged between the two casings. The two-control bleeder turbine has three groups of control valves, high, medium-and low-pressure. The high-pressure control valves is connected to the inserted nozzle box by means of a connecting tube. The medium-and low-pressure control valves are installed in a valve chamber which is cast in the casing.

2. Control Equipment

The control equipment of this turbine demands special attention. Two bleeding pressures and the turbine output are controlled separately without influence on one another. In other words, if there is no connection with the external electrical line when the bleeding steam quantity is changed, the speed and the output of the turbine (or when output of the turbine is changed, the bleeding steam quantity) are maintained at exactly the same value as before the change. Naturally, this system is used on the condition that if either one of the two bleeders is changed, it will not influence the other. For this reason, the two sets of bleeding pressure control equipment are connected to the oil pressure system of speed control equipment. In case of parallel operation with the external line, the speed control equipment controls the output, while the bleeding pressure control equipment maintains a constant bleeding pressure when the bleeding steam from the turbine is changed. For example, when the output changes, the high-pressure, medium-pressure, and low-pressure control valves are opened or closed simultaneously by operation of the speed control equipment and the amount of steam through these valves changes only by equal amounts so that the bleeding steam never changes at all.

For example, the low-pressure control valve closes when the pressure in one of the bleeders decreases; when the first bleeding pressure decreases, the medium-pressure control valve closes, but opens when the pressure in the second bleeder drops. In this case the high-pressure control valve opens due to the operation of the bleeder pressure control equipment. From the viewpoint of the entire unit, the total of the changes of output in the high-pressure, medium-pressure, and low-pressure parts is zero; therefore no change is able to form in the generator terminal.



① Standard level water tank
② Automatic gland steam control equipment
  a) High pressure turbine: front part
  b) High pressure turbine: rear part
  c) Low pressure turbine: front part
  d) Low pressure turbine: rear part
③ Gland steam header
④ To condenser
⑤ Main oil pump
⑥ Speed meter
⑦ Emergency governor
⑧ Primary oil impeller
⑨ Emergency stop valve
⑩ Pilot valve
⑪ High pressure control valve
⑫ Thrust protective equipment
⑬ Lift meter
⑭ First bleeding pressure control valve
⑮ Second bleeding pressure control valve
⑯ To high pressure control valve Ⅲ and Ⅳ
⑰ Oil filter
⑱ Motor control device (for first bleeder control)
⑲ Motor control device (for second bleeder control)
⑳ To high pressure control valve I and II
㉑ To high pressure control valve Ⅲ and Ⅳ
㉒ To first bleeding pressure control valve
㉓ To second bleeding pressure control valve
㉔ Controller
㉕ Controller
㉖ Speed setting motor
㉗ Speed governor spring
㉘ Emergency stop solenoid valve
㉙ Overspeed governor checking device
㉚ Starting equipment
㉛ Condenser protective equipment
㉜ Aux. converting valve
㉝ Emergency stop device
㉞ Emergency governor checking equipment
㉟ First bleeder stop valve
㊱ Second bleeder stop and check valve
㊲ Third bleeder stop and check valve
㊳ Condensation pump
㊴ Boiler
㊵ Super heater
㊶ Emergency stop valve and high pressure control valve
㊷ High pressure turbine
㊸ Medium pressure turbine
㊹ Low pressure turbine
㊺ First bleeding pressure control valve
㊻ Second bleeding pressure control valve
㊼ Generator
㊽ Condenser
㊾ Condensation pump
㊿ First bleeder
(51) Second bleeder
(52) Third bleeder

Fig. 9 Schematic diagram of turbine control system

Fig. 9 is a schematic diagram of the turbine control system and *Fig. 10* shows the relation between the speed and bleeding pressure control systems. The principle of turbine control is explained in relation to *Fig. 10*.

The follow piston H_H consisting of spring I_H and sleeve F_H controls the high-pressure control valve; the follow piston H_M consisting of spring I_M and sleeve F_M controls the medium-pressure control valve; and follow piston H_L consisting of spring I_L and sleeve F_L controls the low pressure control valve. Springs I_H, I_M, and I_L are connected to levers K and the force of the springs can be adjusted. These levers are rotated around supporting point h via levers g_1, g_2, and g_3, by displacement of the bleeder control system a_1 and a_2.

When the speed changes (for example, when it increases), the pressure of the control impeller (primary oil pressure) increases in proportion to the square of the speed. Bellows B is compressed upward and raises the three sleeves F_H, F_M, and F_L via lever C. The oil outlet which is formed by the sleeve and follow piston edge is widened in this way, the resistance at the outlet decreases, the oil pressure inside the follow piston (secondary oil pressure) drops, the pilot valves L_H, L_M, and L_L of the servo-motors are pushed downward by the force of springs M_H, M_M, and M_L, the operating oil flows into the lower chamber of the servomotor pistons, and the control valves close. In this case, the effect of the follow piston (secondary oil pressure) and the force of the springs are adjusted, as high-pressure, medium-

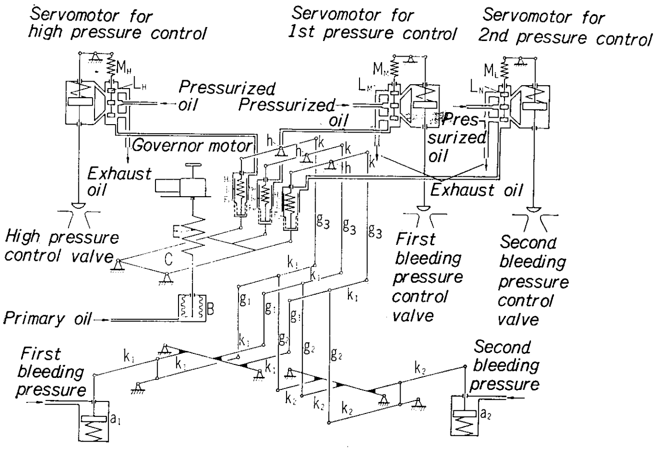


Fig. 10 **Turbine control principle**

pressure and low-pressure control valves change respectively almost equal steam quartity.

When the bleeding pressure changes, for example when the bleeding pressure increases due to a decrease in the steam consumption at the first bleeder, tension is applied to springs I_M and I_L via levers K_1 g, and K, and at the same time, the tension of spring I_H is removed. Depending on changes in this spring tension, the oil pressure inside the follow piston (secondary oil pressure) changes and then the high-pressure control valve closes. Simultaneously, the medium-and low-pressure control valves open. At this time, the decrease in output in the high pressure part is compensated simultaneously by the increase in output in the medium-and low-pressure part due to the lever ratio determined by the design work. Therefore, from an overall point of view, the output always remains constant. When the pressure of the second bleeder changes, the control process is identical to the first case.

These above mentioned actions are shown in Table 1 and the above relationships can be explained by simple equations using the following notation:

G_H: Steam quantity at high-pressure part
G_M: Steam quantity at medium-pressure part
G_L: Steam quantity at low-pressure part
E_1: First bleeder quantity $E_1=G_H-G_M$
E_2: Second bleeder quantity $E_2=G_M-G_L$
N: Turbine output
$K_H K_M K_L$: Proportional constants

$$N=K_H G_H+K_M G_M+K_L G_L$$

(1) When only output changes:

The relation between the output increase (ΔN,) bleeder quantity (no change) ($\Delta E_1=0$, $\Delta E_2=0$), and the increases in steam quantity of the high, medium-and low-pressure part ΔG_H, (ΔG_M, and ΔG_L) is as follows:

$$\Delta G_H=\Delta G_M=\Delta G_L$$

$$\therefore\ \Delta N=K_H\Delta G_H+K_M\Delta G_M+K_L\Delta G_L$$
$$=(K_H+K_M+K_L)\Delta G_H=K\Delta G_H$$

Table 1 Control Process

		High Pressure Control Valve	1st Breeding Pressure Control Valve	2nd Breeding Pressure Control Valve
First Bleeding Pressure	Increase	Closed	Open	Open
	Decrease	Open	Closed	Closed
Second Bleeding Pressure	Increase	Closed	Open	Open
	Decrease	Open	Closed	Closed
Speed	Increase	Closed	Closed	Closed
	Decrease	Open	Open	Open

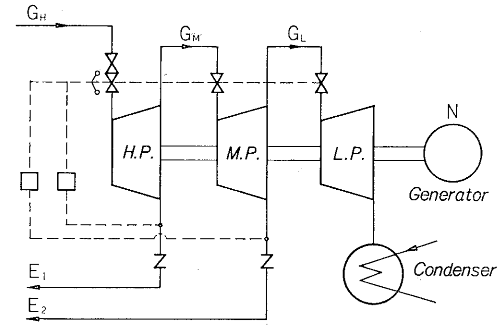


Fig. 11 **Instructions for turbine control**

(2) When only the first bleeder quantity changes:

The relation between the increase in the first bleeder quantity (ΔE_1), the output (no change) ($\Delta N=0$), and the second bleeder quantity (no change) ($\Delta E_2=0$) is as follows:

$$\Delta N=0,\ \Delta E_2=0$$

$$\Delta E_1=\Delta G_H-\Delta G_M,\ \Delta G_M=\Delta G_L$$

$$\Delta N=K_H\Delta G_H-K_M\Delta G_M-K_L\Delta G_L=K_H\Delta G_H$$
$$-(K_M+K_L)\Delta G_M=K_H\Delta G_H-K'\Delta G_M=0$$

(3) When only the second bleeder quantity changes

The relation between the increase in the second bleeder quantity (ΔE_2), the output ($N\Delta=0$), and the first bleeder quantity ($\Delta E_1=0$) is as follows:

$$\Delta N=0,\ \Delta E_1=0,$$

$$\Delta E_2=\Delta G_M-\Delta G_L,\ \Delta G_H=\Delta G_M$$

$$\Delta N=K_H\Delta G_H+K_M\Delta G_M-K_L\Delta G_L$$
$$=(K_H+K_M)\Delta G_H-K_L\Delta G_L$$
$$=K''\Delta G_H-K_L\Delta G_L=0$$

3. Starting and Operating Sequence

The speed control equipment, bleeding pressure control equipment, emergency trip equipment, emergency governor testing equipment, etc., are all compactly collected in one place, and placed on the left side of the front of the turbine.

Therefore, all operation for turbine starting can be performed at the turbine.

On the assumption that all conditions of the auxiliary equipment (the steam, water, and oil line system) are suitable for turbine starting, the sequence of starting operation is described below. The turbine is started with the medium and low-pressure bleeding control valves fully open, and the emergency bleeder stop valve completely shut, i. e., the so-called straight condensing turbine. The bleeding control valves can be completely opened by setting the adjusting handle on the bleeding pressure control equipment at the end position. In this case, the pressure after the emergency bleeder stop valves is kept at the rated value by means of the steam converting valves. The sequence is as follows.

1) Completely open the emergency stop valve and warm up the turbine.

2) Gradually open the high-pressure control valve and increase the speed.

3) Increase the speed to about 94% of the rated value (3000 rpm).

4) The speed control equipment is in operation.

The above four steps can be performed continuously by turning the handles of the starting equipment (load limiter).

5) Increase the speed by means of the governor motor (speed setting system).

6) Attain the rated speed and excite the field of generator, syncronize, and parallel running.

7) Increase the output by the governor motor to about 1/5 load.

8) Turn back the adjusting handle of the second bleeder control equipment from the end position and throttle the low pressure bleeding control valve.

9) Increase the pressure before the low-pressure control valve. When it reaches the set value of the second bleeding pressure, the second bleeding pressure control equipment starts to operate.

10) Open the bleeder emergency stop valve and raise the set value. When the set value exceeds the pressure after the bleeder emergency stop valve, the bleeder emergency stop valve opens. (Even when the bleeder emergency stop valve is open, extraction does not take place by means of the check valve when the bleeding pressure set value is lower than the pressure after the bleeder emergency stop valve.

11) Increase the set pressure value. Open the check valve. Start extraction from the second bleeder.

12) Carry out Steps 8~11 for the first bleeder in the manner of the procedure for the second bleeder.

13) Start the first bleeder. Operate the bleeding pressure control.

14) Increase the output to full load by means of the governor motor.

4. Test Operation Results

Installation of this turbine at the site was completed in March, 1968 ; test operation, governor tests, characteristics tests, heat run test, etc., were performed with good results in each case, and the turbine was put into continuous operation. *Fig. 12* shows an oscillogram of governor tests with 4/4 and 2/4 load dumping.

For 4/4 load dumping, the maximum momentary speed increase remained only at 6.17%, a sufficiently low value indicating excellent performance of the control equipment. The measured results of the percentage of maximum momentary speed increase and percentage of speed variation for dumping of each load are shown in *Table 2*.

Table 2 **Results of Damp Tests**

Load	10,000 kw Non-extraction	10,000 kw Extraction	30,000 kw Extraction	40,000 kw Extraction
Rate of Max. Momentary speed increase	2.66%	2.17%	5.0%	6.17%
Rate of set speed increase	1.44%	3.5%	4.0%	5.34%

V. 50,000 kva BRUSHLESS GENERATOR

Fuji Electric previously delivered a 22,500 kva brushless turbine generator in 1966 for application in the Asahi Chemical Industry Co., Ltd., and now has manufactured nine such generators including those presently under production. All of the generators in operation have received praise from the customers and have exhibited excellent performance from the beginning of operation. The 50,000 kva generator delivered to the Nishiki Factory of the Kureha Chemical Industry Co., Ltd., is no exception to this excellent record. This generator has the largest capacity among brushless types now operating in Japan.

As the brushless exciting system is widely known, the output current of the armature winding of the rotating armature type ac exciter coupled in series with the main generator is rectified by means of the rotating rectifier coupled directly with the main generator and supplied to the generator field. The previously used brushes or slip rings are completely

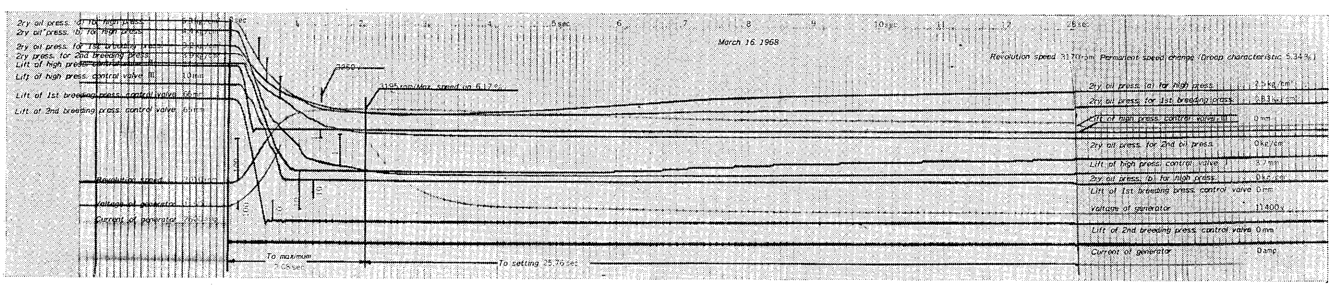


Fig. 12 Oscillogram of governor tests

unnecessary for supplying current to the main generator field winding. This equipment shows its true worth when there are problems at the brush and slip ring of high-speed high-capacity turbo-generators or it is used in adverse atmospheres such as those of chemical plants, etc. Recently in Japan, the use of brushless turbo-generators has been on the increase and they are becoming recognized more and more by users because of the establishment of protective systems to improve the reliability of brushless exciting equipment, etc. The trend is now to use this excitation equipment for larger and larger capacity units. The accomplishment of this brushless excitation equipment for 50,000 kva generators and the results of operation are such that it can be used with even larger capacity equipment.

This generator employs an air cooling system and it is not only the largest air cooled turbo-generator ever manufactured by Fuji Electric but also the largest one in Japan. Since the shaft is rather long for an air cooled generator sufficient consideration must be given to the reduction of loss, and the paths and amount of air passing through so that the temperature rise can be kept even. It it also necessary to pay particular attention to vibrations and noise, and since the load of this generator is mainly the rectifier load, the influence of high harmonic current from the rectifier is also considered in the design. It possesses damper conductors in the magnetic pole parts, and has a sufficient margin for temperature rise and sufficient reliability. An outline will be given of this generator below.

1. Generator

1) Specifications

The specifications of this generator are given in Section II–3). An external view of the generator is given in *Fig. 13.*

2) Cooling system

A sectional view of the generator is shown in *Fig. 14.* Air is ventilated by means of radial fans located at both ends of the rotor winding support

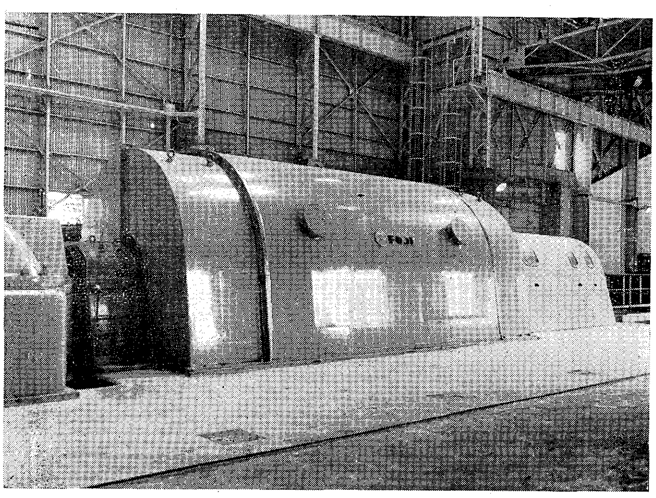


Fig. 13 Brushless 50,000 kva generator

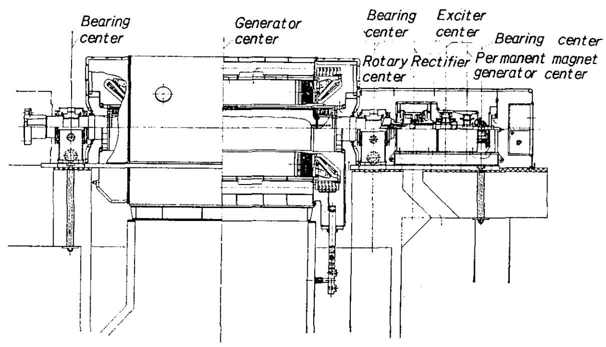


Fig. 14 Generator sectional view

ring. The cooling air blown into the generator by the fan cools all parts of the core and winding and goes out from the back surface of the core via the stator frame and exhaust duct. This hot air is led along an air duct to an air cooler located in the air duct wall. The air cooled in the cooler is then returned to the interior of the generator from both ends of the shield lower surface.

The core of such a large capacity turbo-generator naturally has an appropriate length, so that cooling by the simplex air system, which sends the cooling air from the air gap at both ends of the core is not sufficient for the cooling of the middle parts of stator. Thus, the duplex air system is used in which cooling air in addition to that from the air gap is sent directly to the middle parts of the iron core from the end of the stator frame by means of a pipe which also serves as a reinforcement. In this way, the entire length of the iron core is cooled uniformly.

The exciting equipment is cooled by means of a fan located in the exciting equipment shaft end which draws air from the end of the exciter cover via a filter. This air is then conducted from the casing along a duct in the base of the exciting equipment and is divided into two parts, one of which goes to the rotating rectifier side and the other to the permanent magnet generator side. The cooling air to the permanent magnet generator side also cools the ac exciter and is exhausted together with the cooling air for the rotating rectifier below the foundation.

3) Generator construction

(1) Stator

The stator frame is made of welded steel plates and the stator core is attached to the frame by means of a dovetail key. However, the key is surrounded by insulation material with a low elasticity which allows for a reduction in vibrations transmitted from the core to the stator frame and also prevents any increase of loss in the key. Clamping plate for the tooth section near the winding is made of nonmagnetic steel so that loss can be reduced.

The stator winding consists of one turn coils and employs the so-called "Gitter winding" which is completely transposed in one slot of the core. The same transposition is also used in the end of the coil so that stray loss can be minimized. The insulation is of F resin which has various excelling characteristics.

Fig. 15 shows an actual photograph of the generator stator.

The fan shield is of the same welded steel plate construction as the frame. Since it is adjacent to the end of the stator winding, non-magnetic steel is employed near the coil so that generating of eddy current loss can be prevented. Since the shield is attached to the stator frame and the base plate, vibration proof material is inserted in the attached parts to prevent vibrations from being transmitted to the shield, and the shield itself is designed so that it will not be a source of vibrations.

The bearing pedestal is also of welded steel plate construction and the support surface of the bearing metal has a spherical surface with self-adjusting action so that the shaft is not subjected to any unnecessary stress or contact on one side of the bearing surface due to a warped shaft or installation errors. A multi-layer labyrinth packing is located in the shaft penetrating section of the bearing pedestal and air from the fan is directly conducted to the middle of the labyrinth packing. Oil cannot leak to the exterior. The inner surface of the bearnig is formed of double arc to prevent oil whirls from developing.

(2) Rotor

The rotor shaft consists of single forged nickel-chromium-molybdenum steel. Slots to insert the rotor winding and air holes for cooling air are used previded.

In order to prevent contraction from repeated stoppages, the rotor winding conductor is made of a special high-grade copper containing silver which has good characteristics for creeping. The wedge which clamps the rotor winding is made of a special copper alloy to reduce leakage flux.

The support ring of the rotor winding coil end must have not only considerable material strength to withstand the high centrifugal force of the winding but also be made of non-magnetic steel to reduce the stray loss caused by leakage flux from the stator winding. For these reasons, this generator employs high manganese steels which have been hardened by cold processing. The support ring is installed as follows: one end is attached to the shaft via the support ring holder and the other end is shrink-fitted to the body end via insulation material in order to prevent damping current from flowing in the support ring during unbalanced loads.

Since the load of this generator is essentially that of the rectifier, dovetail slots are made in the center of the pole, a long copper bar is inserted, and a wedge damper sufficiently adapted to the slot is installed in order to cope with harmonic currents developing because of these rectifier loads.

The cooling fans are located in both ends of the support rings and radial type fans are employed as cooling fans in which the nickel-chromium-molybdenum steel fan blades are riveted to a special steel boss.

These fans provide highly efficient cooling.

An actual photograph of the rotor is shown in *Fig. 16*.

2. Exciting Equipment

The exciting equipment consists of a rotary rectifier, an ac exciter, permanent magnet generator, its bearing, and a cooling fan. The rotating part of these components is coaxially installed on the same shaft and is coupled directly to the end of the generator shaft.

Fig. 17 is a schematic diagram of the exciting equipment and AVR. The output current of the permanent magnet generator is rectified by a thyristor and supplied to the field winding of the ac exciter. It is controlled by means of firing angle

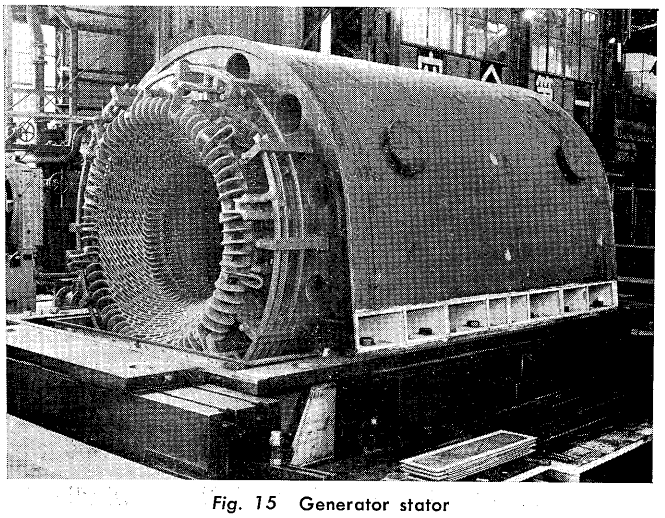


Fig. 15 Generator stator

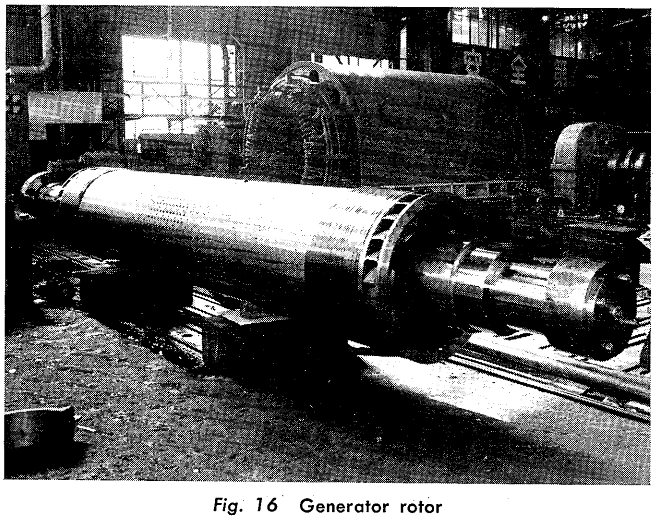


Fig. 16 Generator rotor

control of the thyristor. The exciting power source is a completely independent external source, and even when disturbances develop within the lines, they have no influence so that operational reliability is improved considerably since exciting power is guaranteed. The AVR circuit is a thyristor TRANSIDYN which excels in control precision, stability, and sensitivity as compared with the former magnetic amplifier type. It is supplied with power for control from the permanent magnet generator via an insulation transformer. This is the same system that was used in the 22,500 kva brushless turbo-generator which was supplied to the Asahi Chemical Industry Co., Ltd., where it has proven to possess sufficient reliability, sensitivity, and precision. The specifications of the exciting equipment for this generator are as follows:

1) Ac exciter

Type:	Horizontal shaft rotating armature type synchronous exciter
Output:	145 kva
Voltage:	185 v
Current:	452 amp
Frequency:	200 Hz
Speed:	3000 rpm
Power factor:	0.9 (lag)
Number of poles:	8

2) Rotary rectifier

Type:	3-phase Graetz connection silicon rectifier
Output:	128 kw
Voltage:	240 v
Current:	535 amp

3) Permanent magnet generator

Type:	Horizontal shaft rotating permanent magnet field type generator
Output:	3.5 kva
Voltage:	110 v
Frequency:	50 Hz

4) Automatic voltage regulator

Thyristor TRANSIDYN type AVR

Fig. 18 shows an actual photograph of the rotor of the exciting equipment.

Each component will be explained simply below.

1) Ac exciter

The rated output, voltage, current, and power factor of the ac exciter are determined by the maximum

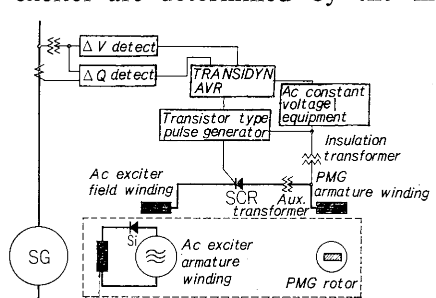


Fig. 17 **Connection diagram of brushless exciting circuit**

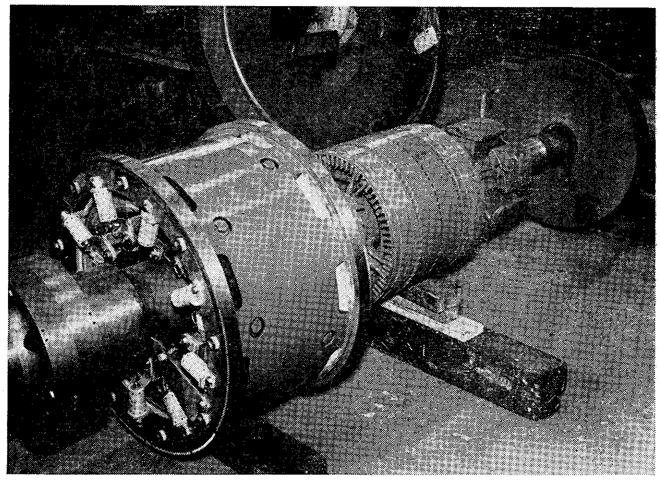


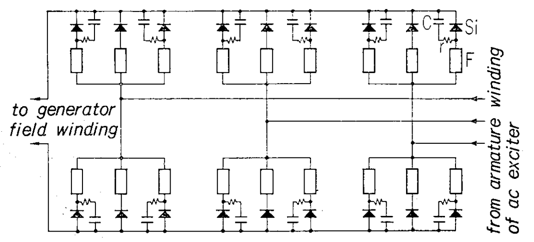
Fig. 18 Rotor of brushless exciting equipment

exciting current of the main generator and the exciting voltage in respect to this as well as the connection system of the rectifier circuit. Since a 3-phase Graetz connection is employed in this equipment, a power factor of 0.9 was selected. The frequency is optional but when the frequency is high, the field time constant decreases and sensitivity goes up. However, when the frequency is higher than required, the exciter becomes too large and is not economical. In this equipment, 8 poles and 200 Hz were chosen and a high sensitivity thyristor TRANSIDYN AVR is employed, so that the sensitivity is sufficient. The max. voltage of the ac exciter is more than 2.1 times voltage corresponding to the rated exciting voltage of the main generator. And voltage responsibility is chosen at 1.4 considering the same formula as with a dc exciter, and therefore a sufficient ceiling exciting effect is achieved.

The stator of the ac exciter is of salient pole construction. The pole core employs a stack of thin steel plates tightly riveted together to reduce the time constant. It is fixed by bolts to the frame which forms a single unit with the permanent magnet generator. In the pole core a damper winding is also installed in addition to a field winding with the required number of turns. The armature core which is made by stacking together silicon steel sheets is directly fixed to the shaft and has cooling holes in the axial direction. It is tightened at both ends by means of end plates. The armature winding is inserted in the slots and fixed by means of wedges. The winding ends are supported firmly so as to withstand centrifugal force from the binding wires.

2) Rotary rectifier

The rotary rectifier consists of a silicon rectifier element and its cooling element, static condenser, resistor, fuse, wiring leads, insulators, a support ring to protect against centrifugal force, and its accessories for the protective equipment. Connections of this equipment are shown in *Fig. 19*. The 3-phase Graetz connection is used since the reverse voltage is high in comparison to the 3-phase half-wave connection



Si : Silicon rectifier element F : Fuse

C, r : Capacitors and resistors to prevent voltage oscillations

Fig. 19 **Protection circuit of rectifier for excitation**

and the rectifier effectiveness is good so that the ac exciter can be kept small.

Silicon rectifier elements are the most important part of the brushless exciting equipment. These elements are the same as the pressure-contact type elements used in the brushless turbo-generator supplied to the Asahi Chemical Industry Co., Ltd. Their characteristics are given in *Table 3*. In West Germany a large number of high capacity brushless turbo-generators are now in operation, including one for 400 Mva. Pressure contact type silicon rectifier elements are used in these generators and they have been shown to possess excellent mechanical and electrical characteristics. They show sufficient reliability for installation in the rotating parts of brushless turbo-generators.

As shown in *Fig. 19*. this rotary rectifier equipment is connected in parallel with 3 elements per arm. Fuses are connected to each element in the series circuit. Therefore, the rotary rectifier equipment has ratings which allow for a continuous flow of over 1440 amp considering the bias of current portions in the parallel circuits. This is more than 3.2 times the main generator rated exciting current of 449 amp so that there is sufficient margin. This rating is also sufficient not only at normal rated operation but at the case of transient current induced in the generator field during short circuits of stator windings, and exciting current for ceiling exciting during disturbances in the line. When an element connected in one of the parallel circuit arms is shorted and cut off from the circuit by the fuse, more than 960 amp can flow continuously in the circuit due to the remaining elements. This is more than 2.1 times the rated excing current and therefore the generator can continue to operate in this condition.

The rating voltage of the rotary rectifier is determined by considering the main generator maximum exciting voltage, the exciting voltage during ceiling exciting, the abnormal voltage during short-circuit of one phase, and the induced voltage at the field during asynchronization etc. High abnormal voltages are induced when the exciting current is reversed : drive as an induction machine during the asyndronous state is a typical example of this. With the usual turbo-generator, the voltage induced in the field winding is rarely more than 4 times the rated exciting voltage during asynchronous operation. In this equipment, rated voltage of the main generator field is 187 v and therefore one series element is sufficient and there is enough margin for abnormal voltages as those mentioned above, naturally under rated operation.

Table 3 **Characteristics of Pressure-Contact Type Silicon Rectifier**

	Unit	Condition	Character Value
Rated Forward Current	amp_{mean}	Ambient temperature at forced draft 50°C	200
Reverse Voltage	V_{dc}	Dc continuous	1000
Peak Reverse Voltage	V_{peak}	50 or 60 Hz half-wave	1500
Inpulse Reverse Voltage	V_{peak}	Reverse voltage less than 5 msec	1800
Max. Ac Voltage of Input	V_{rms}	—	650
Allowable Continuous Temperature at Contact Part	°C	—	150

Fig. 20 shows a sectional view of the rotary rectifier and typical connections. The silicon elements are fixed to the cooling element by means of screws, while the other ends are connected to the wiring leads via flexible leads. A large part of the heat generated in the rectifier elements is transferred to the cooling element and radiated from the cooling element surface to cooling air. The cooling element is made of high purity copper with excellent thermal conductivity. In the surface there are fins and the configuration is such that it increases the heating surface area and also serves as an air fan during rotation. The cooling element is divided into 6 blocks and installed on the support rings insulated by means of glass polyester insulators. Each block contains three silicon rectifier elements and also serves as one portion of the electric circuit.

The static condensers and resistors to prevent voltage oscillations are molded in each epoxy resin unit and possess especially high strength to resist centrifugal force.

The support rings are made of special steel forgings in order to support the above mentioned parts against centrifugal force. Dc side collection rings are fixed at both ends of the each support ring with insulation. The collection rings are made of special steel and also serve as slip rings for measuring field voltage, as will be described later. Fuses are installed inside the above-mentioned collecting rings and connect the collecting rings to silicon rectifier elements.

3) Permanent magnet generator

The permanent magnet generator serves as the power source for both exciting of the ac exciter and the AVR. Therefore, 50 Hz was chosen as the frequency. Fuji Electric's standard thyristor TRANSIDYN employs regular commercial power frequency

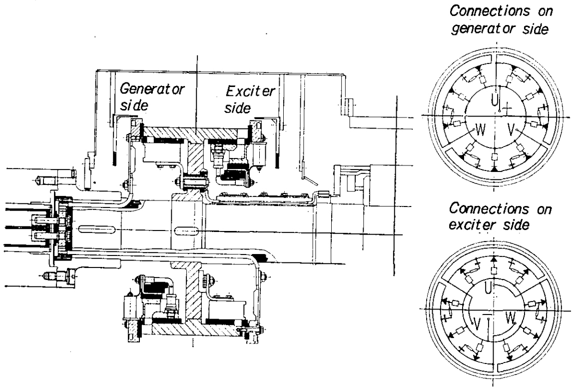


Fig. 20 Sectional view and connections of rectifier

because practical experience with a large number of standard units has shown this to be the most reliable. The rated output of the permanent magnet generator is also determined in consideration of ceiling exciting.

The generator is of the rotating field type using a permanent magnet. Structurally there are 6 poles but magnets are arranged as such that electrically there are only 2 poles.

The stator core is constructed of laminated silicon steel sheets tightened at both ends by end plates. These are fixed to the stator frame which forms a single unit with the ac exciter.

The exciter bearing is of the bracket type and is fixed directly to the exciter stator frame. Radial fans are installed in the exciter shaft ends and are used for cooling the ex- citing equipment.

4) Protective equipment

To protect the exciting equipment, this generator is provided with fuse operation checking equipment, circuits to prevent voltage oscillations (*C–R* circuits) for protection of the silicon rectifier elements, field circuit ground fault checking equipment, field current measuring equipment, and field voltage measuring equipment. Not only is the reliability of the plant increased by this equipment but it is also very convenient for maintenance of equipment.

(1) Circuits to prevent voltage oscillations

Reverse current flows in the silicon rectifier elements for a relatively short time when the direction of current flow changes due to the carrier accumulation effect, and this circulates through the armature winding of the ac exciter. However, the element's reverse voltage stopping characteristics soon recover and this circulating current stops flowing. Therefore, the energy which has accumulated in the armature winding inductance is accumulated in the element leakage capacitance C_s, but since the leakage capacitance is very small, high voltage oscillations occur at that time. Since this voltage is so high and the characteristics of the element are lost for some time, capacitors *C* are connected in parallel in the elements for protection and resistors *R* are also connected for increasing of damping speed of the voltage oscillations and limiting the transient voltage value.

(2) Fuse operation ceecking equipment

Since three silicon rectifier elements are connected in parallel in each arm of this rotary rectifier equipment, rectification would cease and the bridge would be short circuited if only one of these parallel elements was destroyed for some reason. In order to prevent this, a fuse is connected in series with each parallel element. These fuses must be chosen so that they have overcurrent characteristics corresponding to breaking characteristics of the silicon rectifier. The relation between the time-current characteristics of the fuses and these silicon rectifier elements is shown in *Fig. 21*. These fuses have operation indicating devises. Therefore, the operating conditions can be checked at any time during operation by means of stroboscope. These fuses are intended for use under large centrifugal force, so that operation is reliable. Also, since compact size is necessary, the fuses have different characteristics from those used with silicon rectifier elements which are employed in usual static devices.

(3) Grounding checking equipment

Slip rings are located in the exciter shaft ends in order to check for grounding faults in the field circuits. These slip rings are connected to the central point of the ac exciter armature winding as shown in *Fig. 22*. The brush for the slip rings can be raised or lowered with the opera tion lever. The brushes are lowered for daily operation check and can be checked for ground faults.

(4) Field current measuring equipment

The field current measuring equipment measures the armature current of the ac exciter. As shown in *Fig. 23*, there is a pick up coil for measuring the field current between the poles of the ac exciter, i.e., near the air gaps in the quadrature direction. The ac exciter load is in the rectifier circuit and when there is a large inductance on the dc side, the quadrature direction flux pulsates in a cycle six times the armature winding frequency because of the rectifier operation current as shown *Fig. 23* (*b*). Therefore, a voltage is induced in the above mentioned pick-up coil due to this phenomena. Since this voltage is proportional to the ac exciter armature current and therefore also to the main generator field current, the main generator field current can be measured by measuring the induced voltage in the pick-up coil.

The relationship between the voltage induced in the pick-up coil and the generator field current

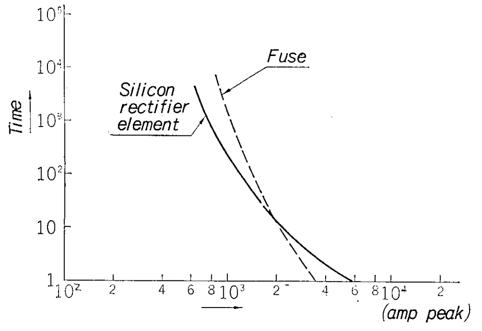


Fig. 21 Characteristics of rectifier elements and fuses

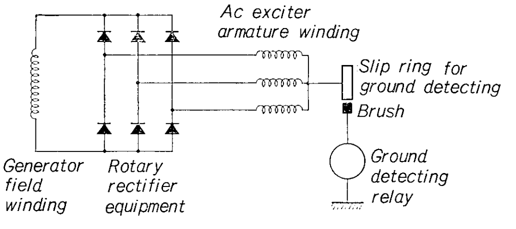


Fig. 22 Detecting circuit for grounding of rotor winding

is checked and calibrated at testing and the current is able to be indicated directly at the meter on the supervising panel.

(5) Field voltage measuring equipment

A voltage measuring brush is attached to the rotatary rectifier frame to measure the field voltage. When measuring the field voltage, the brush contacts the previously mentioned slip ring for field voltage measurement using the operating lever and in this way the voltage can be measured. During normal operation the brush is held upward and does not contact.

3. Tests Performed

The tests conducted in the factory were of two types: Single unit tests and combined tests. Good results were obtained in all cases. For the single unit tests, the equipment was divided into the main generator unit and the exciting equipment. The main generator unit tests consisted of exactly the same test method conducted on ordinary generators with exciting current supplied from a temporary slip ring. In the exciting equipment tests, the output terminal of the permanent magnet generator was taken off and exciting current of the ac exciter was supplied separately from an external source and a temporary slip ring installed in the dc side of the rotary rectifier equipment served as the output terminal. Under these conditions, no-load saturation tests, 3-phase short-circuit tests, heat run tests, insulation resistance tests, insulation withstand tests, etc., were carried out the same as the usual generator tests and the tests were also performed separately on the permanent magnet generator. For the combined tests; voltage setting tests, voltage regulation tests, setting value changing tests, etc., were

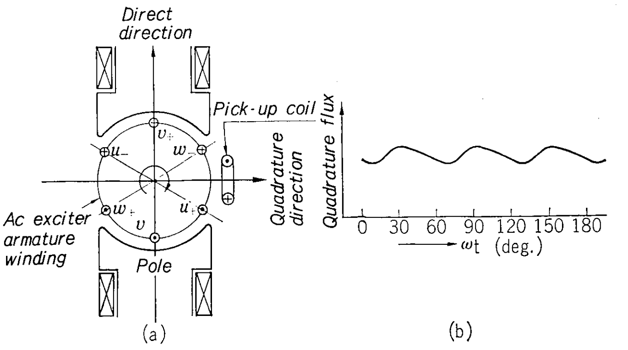


Fig. 23 Measuring circuit for generator field current

carried out in conjunction with an AVR panel and the characteristics were confirmed.

The characteristic curves for the 3-phase short circuit test and the no-load saturation tests of this generator in the combined state are shown in *Fig. 24*.

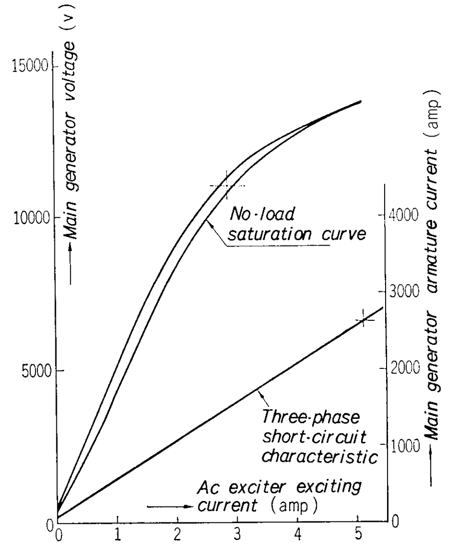


Fig. 24 Three-phase short-circuit characteristic curve

4. Standard Brushless Exciting Equipment

The tendency to use brushless exciting systems with various merits is increasing day by day; some of the most progressive applications include turbo-generators, diesel generators, synchronous motors, etc. Including those now under production, Fuji Electric has up to now manufactured nine turbo-generators employing the brushless exciting system, with a total capacity of 230,000 kva. Under these conditions, Fuji Electric has been working for some time to produce a standard series of exciting equipment for brushless turbo-generators in keeping with consumer demands. This is a good opportunity to introduce a part of this work. This standardized equipment is suitable up to 60 Mva and can be divided into 4 levels according to output. This is shown in *Table 4*.

For less than 10 Mva, the 3-phase half-wave rectifier circuit is used and for the rectifier circuit one parallel and two series silicon rectifier elements are used.

VI. PLANT CONTROL SYSTEM

The steam lines including those in the existing plant were described before with reference to *Fig. 1.* The electric lines are connected to a 60 kv line of the Tohoku Electric Power Co. Therefore various cases must be considered such as connection in parallel with the 60 kv line, parallel only with the existing generator, or operation of the new 50,000 kva generator only, etc.

It is also necessary to consider the use of turbine exhaust as much as possible and not bypassing with the steam converting valves for the process steam in order to obtain the best thermal efficiency under various conditions.

1. 20 Ata Line

First, investigation is made assuming that each generator is connected in parallel with the lines of Tohoku Electric Power Co.

Fig. 25 shows the control system. Under balanced conditions, the 20 ata line pressure changes when there is an increase of process steam in 20 ata. (For other conditions there is no change.)

As long as the setting value relation of the pressure setting device S_1 (S_1') $>$ S_2 (S_2') does not change, steam is supplied from exhaust of turbine T_1 and the bleeder of T_3, and then the 20 ata line pressure is able to remain constant. If the 20 ata line pressure P_1 becomes less than S_2 because steam can not be supplied sufficiently from the exhaust or bleeder, steam converting valves V_{1-1} and V_{2-1} open.

When the capacity of each turbine is 100%, all turbines operate under the same percentage load if load distribution is set at the same percentage by the load distributor.

Next investigations are made under the following operating conditions.

1) When turbine T_1 is tripped, the steam supply from T_1 stops, P_1 drops so that pressure regulator C'_1 sends an open signal and the steam supply from bleeder of T_3 increases. Even if the steam supply from T_3 is at a maximum, and the required steam quantity cannot be attained, $P_1 < S'_1$ and $P_1 < S_2$ (S'_2), and then steam converting valves V_{1-1} and V_{2-1} start to open. If turbine T_3 is tripped, in the same way, the required steam quantity cannot be obtained from T_1 and V_{1-1} and V_{2-1} start to open.

2) When turbine T_1 operates independently (not connected in parallel with other generator or line)

When T_1 operates independently, the load W_1 of T_1 is determined unconditionally, T_1 exhausts steam in accordance with this load and the lacking amount is attained from the bleeder of T_3. When the required steam quantity is not attained from the exhaust or bleeder of T_1 and T_3, the opening of the valves V_{1-1} V_{2-1} is the same as that described above.

3) When turbine T_3 operates independently

When turbine T_3 operates independently, the conditions are slightly different from those of above

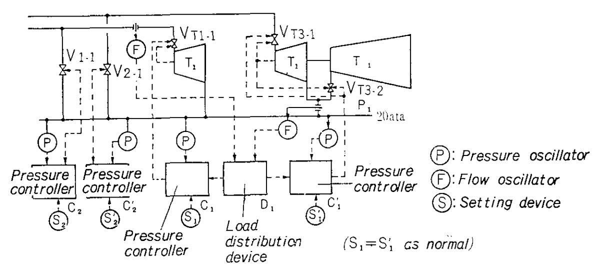


Fig. 25 Schematic diagram for 20 ata line

***Table 4* Standard System**

Application Range			Approx. 10 Mva and Less	Approx. 25 Mva and Less	Approx. 50 Mva and Less	Approx. 60 Mva and Less
Rotary Rectifier Equipment	Type		GRS 6/1-24	GRBS 12/1-24	GRBS12/1-24	GRBS 18/3-20
	Connection		Three-phase half-wave	Three-phase full-wave	Three-phase full-wave	Three-phase full-wave
	Silicon rectifier element	No. of parallel circuits	1	1	1	3
		No. of series circuits	2	2	2	1
Ac Exciter	Type		FG 207/0-6	FG 237/2-6	FG 257/4-8	FG 257/9-8
	Output		50 kva	80 kva	120 kva	160 kva
Permanent Magnet Generator	Type		FM 165/3.6-6/2	FM 165/4-6/2	FM 185/4-6/2	FM 205/4-6/2
	Output		1.5 kva	2 kva	3 kva	3.5 kva
Protective Equipment	Voltage measuring equipment		Included	Included	Included	Included
	Ground fault detection equipment		Included	Included	Included	Included
	Field current measuring equipment		Included	Included	Included	Included
	Stroboscope		—	—	—	Included

(2) because T_3 is the bleeder condensing turbine. If the turbine load is sufficiently large and the process steam change can be followed by a change in the amount of steam to the condenser, there is no change in the steam lines as when T_1 and T_3 are connected in parallel with the 60 kv line. The change in T_3 turbine output due to the bleeding steam or the unconditional determination of T_1 turbine output according to the load is the difference between T_1 and T_3 (other variables, the second bleeder, etc., are considered as constant).

If the process steam changes over a wide range, the T_1 exhaust and T_3 bleeder supply relatively the same amount of steam within the bleeder limits of T_3 and above these limits the portion supplied by the T_1 exhaust increases. If the required amount cannot be attained in spite of this, the opening of V_{1-1} and V_{2-1} is the same as described previously.

4) T_1 and T_3 are operated independently of each other

In this case the outputs of T_1 and T_3 are already determined so that the amount of steam from the exhaust of T_1 is fixed and the lacking amount is supplied from the bleeder of T_3. However, if this bleeder cannot supply the required amount, V_{1-1} and V_{2-1} open.

5) When T_1 and T_3 are operated in parallel but there is not parallel operation with the lines

In this case, the sum of the outputs of T_1 and T_3, W_1+W_3 is determined by the load, but the distribution of the outputs W_1 and W_3 is determined by the turbine governor characteristics. When considering only the increase in the factory process steam from certain balanced conditions, C_1 and C'_1 send out a signal for the increase of exhaust of T_1 and bleeder of T_3. The valve VT_{1-1} opens, the output increases and the exhaust also increases. The valve VT_{3-1} opens, VT_{3-2} closes, the bleeder quantity increases, but the output decreases. (This operation reduces the condensation as much as possible and improves the thermal efficiency.) This relation is shown in *Fig. 26* in respect to the governor characteristics.

The turbine load sum W_1+W_3 is constant. Therefore, when the candensation quantity is a minimum and the steam is still insufficient for process steam, even if VT_{1-1} and VT_{3-1} are open, the turbine speed increases, and the speed governor operates so that VT_{1-1} and VT_{3-1} are returned to their set positions. Therefore, the deficient amount is supplied with V_{1-1} and V_{2-1} open.

(1) If the steam for factory processing increases in *Fig. 26* and the steam is still insufficient when W_1 becomes 100%, VT_{3-1} opens and VT_{3-2} closes until the condensate quantity reaches a minimum. If the steam is still insufficient in spite of this, V_{1-1} and V_{2-1} open.

(2) When W_1+W^3 increase in *Fig. 26*, the load is distributed only according to the governor characteristics. When $W_1=100\%$ and the load increases, the characteristic curve of T_3 rises as in *Fig. 26* and W_3 increases to W''_3.

(3) If any one of the conditions mentioned above in 1) to 5) are switched to another condition during operation, the equipment changes to the new operation conditions without switching the control system or the connections.

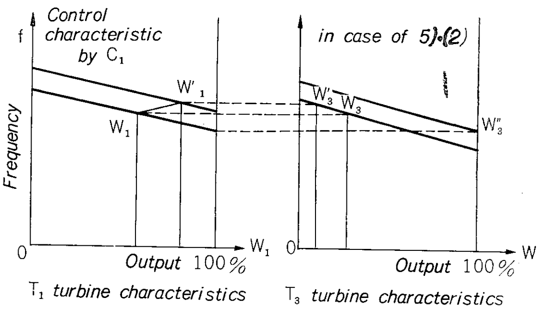


Fig. 26 **Extracting steam and turbine output**

2. 7 Ata Line

The same methods are investigated as with the 20 ata line. The control system is as shown in *Fig. 27*.

If T_2 and T_3 are both connected in parallel with the lines; when the 7 ata steam for the factory increases (and when other conditions do not change), VT_{2-2} and VT_{3-3} close, and VT_{2-1}, VT_{3-1}, and VT_{3-2} open so that the 7 ata line pressure can remain constant.

In this case, as in the 20 ata line,

$$S_3\ (S'_3)>S_4\ (S'_4)$$

The load distribution by the load distributor is also the same as that in the 20 ata line.

The following change of operating conditions during the above operating conditions are investigated.

1) When turbine T_2 (or T_3) is tripped

This is exactly the same as that described under section (1) for the 20 ata line. But, when T_3 is tripped, the situation is different from that in the 20 ata line. When T_3 is tripped and further T_2 is operated independently, T_2 can be operate optionally at any point within the capacity of the 7 ata bleeder of T_2 and the generator output.

2) When turbine T_2 is driven independently

When T_2 is driven independently, the T_2 output W_2 is determined entirely by the load. If the factory process steam requirements increase, VT_{2-1} opens, VT_{2-2} closes, VT_{3-2} opens, VT_{3-3} closes by means of a signal from C_3 and C_3', and the bleeding steam increases without changing W_2 and W_3 (at this time, VT_{3-1} also opens simultaneously).

Extraction takes place in T_2 and T_3 in a range determined according to the equipment capacity and W_2. For steam requirements larger than this, V_{1-2} and V_{2-2} open.

3) When turbine T_3 is operated independently

This case is also exactly the same as that for the 20 ata line mentioned in section 3). Extraction

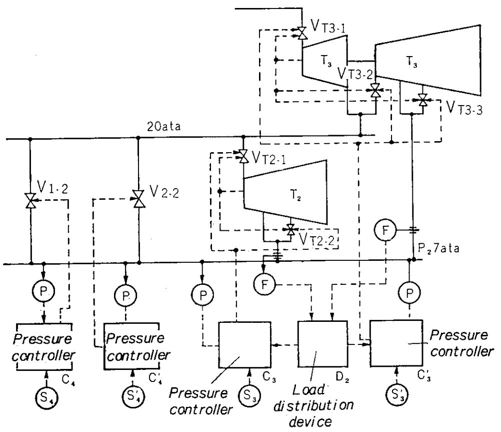


Fig. 27 Schematic diagram of 7 ata line

takes place in T_2 and T_3 up to the permissible bleeder values and limit of W_3, and the insufficient amount is bypassed at V_{1-2} and V_{2-2}.

4) When T_2 and T_3 are both operated independently

This is basically the same as in section 3) above. Since W_2 and W_3 are determined only according to the load, the extraction capacities are limited by both W_2 and W_3.

5) When both T_2 and T_3 are driven in parallel but are not connected in parallel with the line.

Within the bleeder capacity limits of T_2 and T_3, extraction is apportioned according to the portions determined by the load distributor D_2. The outputs W_2 and W_3 are apportioned according to the governor characteristics. After the factory process steam increases and T_2 reaches its extraction limit, only the bleeding quantity of T_3 increases; when T_3 reaches its limit, V_{1-2} and V_{2-2} open. In this condition, when the load increases and W_2+W_3 increase, VT_{2-1} and V_{3-2} open (VT_{3-1} open), and V_{1-2} and V_{2-2} close.

(VT_{2-2} and VT_{3-3} close because of a closing signal from C_3 and C'_3).

3. Turbine Output and Others

The investigations are divided as above into those for the 20 ata line and those for the 7 ata line, and the condition of the 7ata line or other conditions are kept constant during investigation of the 20 ata line. Actually, both cases are connected, but if the operating conditions investigated above are considered in the combined state, there is no problem.

The pressures of 20 ata or 7 ata are considered as variables and it is assumed that W_1, W_2, and W_3 do not change, but if they do increase, all valves (VT_{1-1}, VT_{2-1}, VT_{2-2}, VT_{3-1}, VT_{3-2}, and VT_{3-3}) are moved in the opening direction. Since the operating speed of the speed governor is extremely fast compared to the back pressure and bleeding pressure control, the valves are first opened or closed by means of change in output and because of this these pressures are subsequently corrected when the bleeder pressure (or back pressure) changes.

Up to the present, investigations have been carired out only in relation to increases in the factory process steam but when this steam decreases, the reverse conditions can be applied. If the electrical output is insufficient because the factory steam decreases during independent operation, the operating speed of the speed governor is faster than back or bleeding pressure control and priority is given to the speed governor so that the bleeding pressure (or back pressure) increases and the release valve or safety valve opens.

VII. CONCLUSION

This article has given an outline of the electric power and steam supply plant for the Nishiki Factory of the Kureha Chemical Industry Co., Ltd., with a total output of 64,000 kw and 140 t/hr of steam which employs a 40,000 kw bleeder condensing turbine and a 50,000 kva brushless generator. The capacity of such plants will continue to increase from now on. In order to obtain higher thermal efficiency, a higher steam temperature and pressure must be chosen. Therefore, the bleeder condensing turbine is employed, and plant construction will gradually become more and more complicated.

This introductory report cannot go into sufficient detail but as the plants become more complex, the control systems also become more complex and a high degree of automation will be required.

This 50,000 kva brushless generator is the largest one of its kind ever put into operation in Japan and the basic structure described above can be used for any larger capacity generator. The completion of this generator is considered to be a major step toward the production of large capacity brushless turbo-generators for the future. Since there is a tendency to use more brushless type exciting equipment in turbo-generators located in contaminated atmospheres such as chemical plants, Fuji Electric has completed the standardization of brushless turbo-generators as described briefly in this article, and is fully prepared to supply highly reliable equipment in a short period.

Fuji Electric received considerable help in the planning and manufacturing of this plant from the Kureha Chemical Industry Co., Ltd. We would like to express our sincere thanks to all persons concerned.