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STEAM POWER PLANT FOR GOI FACTORY OF CHISSO PETRO-CHEMICAL CORP.

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I. PREFACE

The present equipment is a private electric generating plant which operates on process steam and has been delivered to the Goi Factory, Chisso Petrochemical Corp.

The power plant was designed to consist of two boilers and one turbine generator; however, the erection of the No. 2 boiler has been postponed, and the turbine generator is being operated with one boiler. Accordingly, the generator is now being operated on a 5000 kw load which is half of the rated output. Since the government test for the plant was successfully completed at the end of February, we wish to introduce the description of this equipment which follows.

Fig. 1 shows the heat flow diagram. For a back-pressure turbine such as the one used in this plant, it is necessary to determine the condition of the steam at the turbine inlet based on the requirement of the user as to type of process steam to be used and amount of power to be generated. For this plant, quite a high temperature and high pressure process steam is required because of the balance of process steam to the power requirements. However, by limiting the temperature of the steam to a range that permits the use of ferrite steel, a more economical operation is possible. Therefore, it was decided to use process steam with a temperature of 500°C at the turbine, 505°C at the boiler outlet. The pressures adopted were 134 kg/cm^2 g at the turbine and 139 kg/cm^{2}g at the boiler.

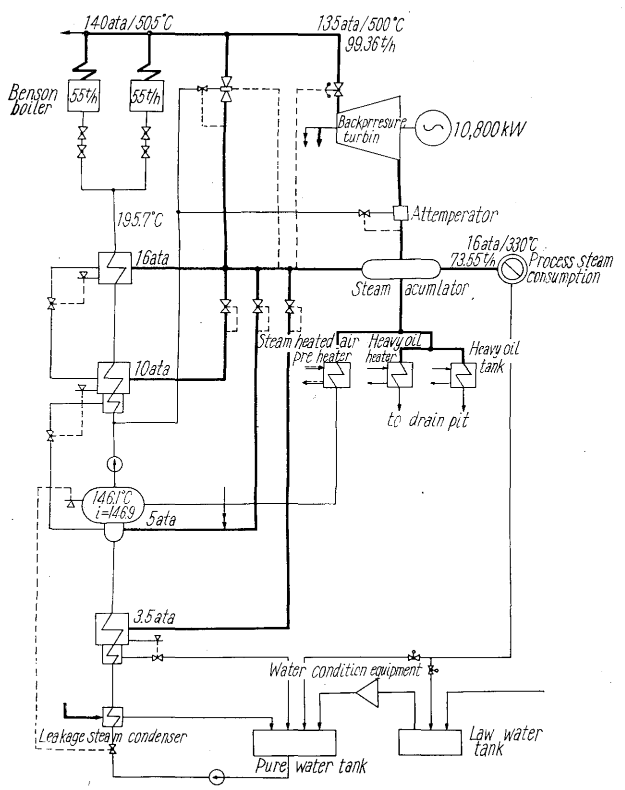


Fig. 1 Heat flow diagram

The boilers, as required by user, were divided into two units in order to provide a supply of process steam even in the case of periodic inspection of one boiler. However, one unit is used for the feed water system in order to reduce installation costs. A Benson boiler (KSK Walter Benson boiler for outdoor use made by Kishaseizo K. K.) was used because of the high pressure process steam requirement. The combustion system used is a pressure firing system which has recently been very popular because of high efficiency and low power losses of its auxiliaries. A meander system of evaporation pipes is used. The view of power plant looking from the boiler is shown in *Fig. 2*.

Fig. 3. shows the view of turbine and generator. The turbine is our peculiar pot type turbine, which has proven to be the most ideal plant for high pressure-high temperature steam when used in conjunction with the Benson boiler. The merits of the pot type turbine, which are explained later, are now being gradually recognized. The one used in this installation is the sixth machine ever supplied.

Fig. 4. shows the central control room. The turbine generator panels are arranged on the left hand side and the feed water purifying panels and soot blower panels are located on the right hand side of the ABC panels which are located in the center switch board. The ABC (automatic boiler control) is equipped with a TELEPERM system by our up-to-date technique. The merit of this system is its ability to

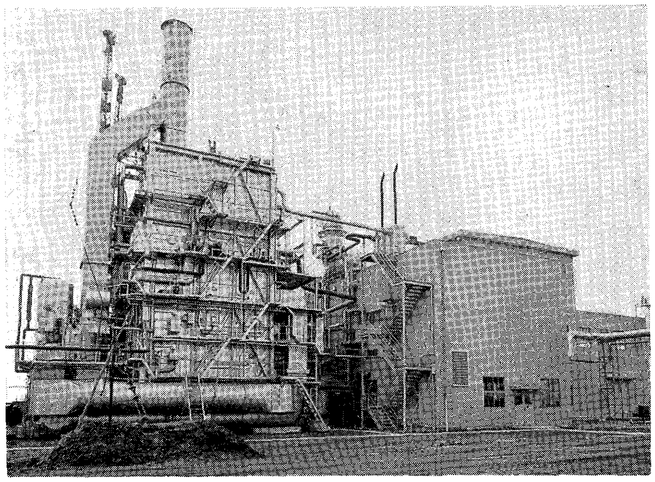


Fig. 2 Power plant's view

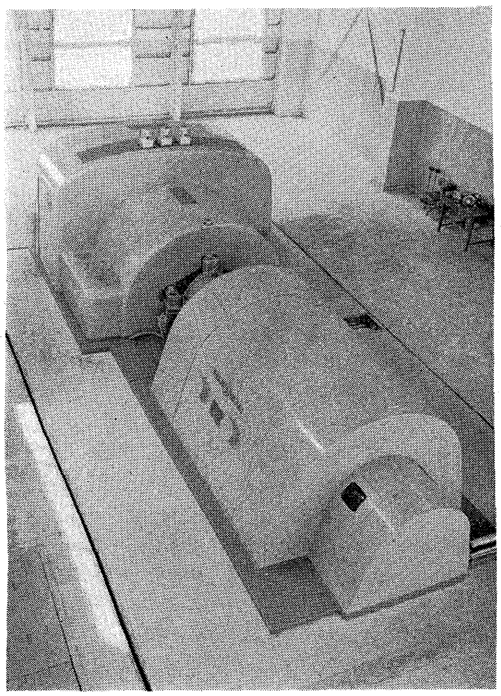


Fig. 3 Turbine and generator

Fig. 4 Central control room

control two units of boilers operated in parallel by use of one master controller. This control provides for the load of each of the two boilers to be raised or lowered uniformly at the same time. However, it has been so designed that, in the case of light load operation, only one unit should be controlled automatically and the other manually.

Further, a steam converting valve has been installed to permit by-passing of the turbine steam or delivering the process steam in the case of turbine stoppage. Explanation of this system is omitted here and shall be referred to in the other literature already issued. This valve is the Fuji-Siemens type, which can simultaneously reduce the pressure and temperature of steam by means of one valve, and is indispensable in operation of a thermal power plant.

II. STEAM PLANT

The specifications of the steam plant are shown in *Table 1*. The boiler is a forced-circulation Benson boiler, operated by independent combustion of heavy oil or combustion of a mixture of heavy oil and fuel gas. An important feature of this boiler is the pressure firing that was adopted because of the high pressure-high temperature supply of process steam required in view of the relation between the process steam flow and the required kwh output of the generator.

We introduce briefly these main items as follows.

1. Flow System

The boiler outer view is shown in *Fig. 2*; its sectional view is shown in *Fig. 5.* and flow diagram in *Fig. 6*.

The feed water, at first, enters from the water distribution cylinder into the inlet header pipe of the bearing tubes and separates into two rows of bearing tubes at the back wall of the furnace. These

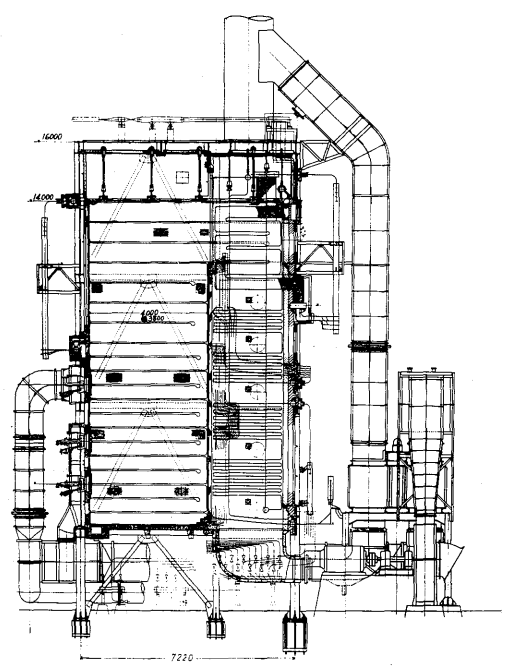
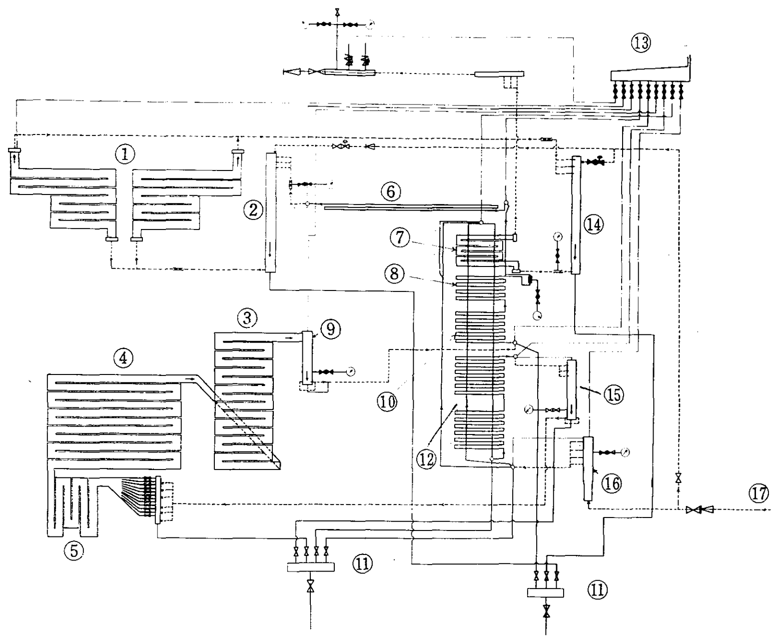


Fig. 5 Sectional view of boiler

Table 1 **Details of Steam-generator**

Boiler	Manufacturer	Kisha seizo K. K.	
	Type	KSK-Walter-Benson boiler	
		KW-55 type outdoor use	
	Unit	2	
	Pressure	Maximum working pressure	153 kg/cm^2
		Nominal pressure (outlet of superheater)	139 kg/cm^2
	Temperature	505°C superheater outlet	
	Evaporation capacity	Maximum continuous	55 t/hr
		Economical	45 t/hr
	Feed water temperature	195°C boiler inlet	
	Fuel	Heavy oil C.	
		Mixed combustion gas	
		Gas volume (max.)	850 Nm^3/hr/unit
		Calorific value (Min.)	1,2980 Kcal/Nm^3
	Ventilation system	Forced draft	
	Efficiency	Maximum loading	91.7%
		Economical loading	92.0%
	Heating surface per unit	Furnace	178 m^2 (Volume 167 m^3)
		Final evaporator	110 m^2
		Superheater I	106 m^2
		〃 II	35 m^2
		〃 III	98 m^2
		Final superheater	122 m^2
		Economizer	272 m^2
		Bearing tube	110 m^2
Air pre-heater	Type	Ljungstrom type (Vertical shaft)	
	Unit	2	
	Heating surface	1510 m^2 (per unit)	
	Air temperature	Inlet 20°C, Outlet 300°C	
		provided with steam system air pre-heater	
Firing equip-ment	Heavy oil burner	Type: pressure atomizing-return type	
		Capacity and quantity:	700 kg/hr×6×2
	Gas burner	Forced air shaft external mixing system	
		Capacity and quantity:	850 Nm^3/hr×1×2
Forced draft fan	Type	Turbo type outdoor use	
	Unit	2	
	Air quantity per unit	1040 m^3/min. (20°C)	
	Static head	475 mm Aq.	
	Motor	150 kw, 1000 rpm, 3000 volts	
Feed water pump	Type	Double casing double volute accelerating type	
	Unit	2	
	Capacity per unit	120 t/hr	
	Outlet pressure	210 kg/cm^2	
	Suction pressure	6.78 kg/cm^2	
	Feed water temperature	146°C	
	Revolution	6930 rpm	
	Motor	1200 kw, 3000 rpm, 3000 volts	
Air separator	Type	KSK-BALCKE tray type	
	Unit	1	
	Capacity purified	100.36 t/hr	
	Feed water temperature	Inlet 115°C, Outlet 146°C	
	Oxygen content at outlet	0.005 cc/l	
	Storage water quantity	28 m^3	
Make-up water treatment equipment	Type and constitution	Clarifier	110 m^3/hr, 1 system
		Gravity type filter	55 m^3/hr, 2 systems
		2-bed 3-tower demineralizing equipment	
		Mixed bed polisher	55 m^3/hr, 2 systems
	Treated water quality	Residual SiO_2 less than 0.02 ppm	
	Operation system	Fully automatic	
Chemical dosing equipment	Dosing chemicals	Ammonia hydrazide	
	Dosing point and control	Dosing after air separator, stroke control by NH_3/pH	
		Dosing at outlet of feed water tank, speed control by NMH_3/pump rpm	
		Dosing after air separator, speed control by N_2H_4/pump rpm.	



① Superheater III
② Attemperator I
③ Combustion chamber evaporator (rear wall)
④ Combustion chamber evaporator (side & front wall)
⑤ Combuston chamber evaporator (furnace bottom)
⑥ Superheater II
⑦ Final superheater
⑧ Superheater I
⑨ Furnace outlet header
⑩ Final evaporator
⑪ Drain header
⑫ Economizer
⑬ Air vent
⑭ Attemperator II
⑮ Collecting pipe header
⑯ Feed water collecting header
⑰ Feed water inlet

Fig. 6 Flow diagram of boiler

bearing tubes have a conventional heating surface and becomes one row at the upper bearing tubes header. This arrangement increases the water velocity and then it enters into inlet pipe header of the fuel economizer which forms a convectional heating surface bearing header (back).

The feed water after passage through the economizer is mixed and distributed in the collecting header pipe and moves to the inlet header pipe in the combustion chamber. This header pipe enters the furnace through the bottom at the rear of the furnace on the left side. The water then enters twelve rows of tubes which are made in plate form. These tubes zig-zag back and forth across the floor of the furnace from front to back. At the rear of the furnace the tubes move to the left wall, turn from the left wall to the front wall and then to the right wall. At the rear of the right wall the flow of tubes is reversed and they are arranged in a zig-zag pattern around these three walls and extend up to nearly half of the furnace height. Then the tubes run down from the rear of the right wall along the wall of the number two flue. From there, they rise along the back wall and go out of the furnace and enter the outlet header pipe in the combustion chamber. This meandering panel system of tubes is known as the " meander system ".

The steam, which has attained a drying degree of 90%, is delivered to the final evaporator to complete evaporation and then enters into the inlet header pipe of No. 2 superheater, after passing the No. 1 superheater. Next the steam passes through the No. 2 superheater, the ceiling of which is composed of parallel pipes, and enters into the No. 2 attemperator to reduce the temperature, and then it is delivered to the No. 3 superheater. The No. 3 superheater occupies half of the furnace—one part of which covers the upper wall of the No. 2 flue. From there it divides into two systems, to the right and to the left, from the front wall with each system forming a panel of twenty parallel pipes. The steam then passes through the No. 3 superheater, enters into No. 2 attemperator to reduce the temperature and then is delivered to the final superheater. The final superheater is divided into eight panels, each consisting of fourteen parallel pipes. The steam, after passage through the final superheater, is delivered to the main steam pipe and then is collected in the steam header pipe.

2. Pressure Firing

The merits of pressure firing are as follows:

1) Because of a totally enclosed construction of the furnace wall, air leakage is completely eradicated, so that boiler efficiency is improved by about 0.2–0.6%.
2) Because there is no need for an air induced fan, the power required for ventilation becomes about 65–75% as compared with balancing ventilation systems. Moreover, the system requires less maintenance since the induced fan, which causes much trouble, is not needed.
3) Because the internal pressure of the furnace is left free, depending upon the load of the boiler, it is not necessary to provide a control device for furnace internal pressure.
4) Safe operation is assured because no damage to the internal pressure of the furnace occurs were starting or during operation.

3. Construction

1) Evaporator

In view of the adoption of the pressure firing system, the water pipe system designed with raising and lowering pipes, which has been used before, was not suitable because of the requirement for the furnace to be gas-tight. Therefore, the meander system described above was adopted.

The furnace wall is so constructed that the internal casing is protected by pipes of 38 mm outer diameter which are arranged in the tangential direction. Because all the evaporation parts are composed of parallel pipes, unbalanced flow in each must be prevented. Moreover, since the present boiler is specified to operate at 35% load, suitable counter measures for unstable flow at a light load must be provided. The arrangement of pipes near burners was accomplished to equalize the thermal load and throttle valves, each designed especially to have a variable orifice, and are installed on the parallel inlet furnace pipes. This orifice was designed to be locked as a fixed orifice after adjustment during the trial running. Unbalanced flow is detected by measurement of pipe wall temperature by an extremely thin thermo-couple fitted on the parallel pipes of the furnace outlet. This arrangement assures safe operation of the No. 1 boiler.

2) Superheater

The superheaters are divided into four groups as described above and are equipped with attemperators at two places to supply water, Thus, the steam temperature at the outlet is made stable by cascade control. The final superheater is designed for heavy oil combustion, and its static characteristic is improved by flat-type construction. Moreover, the temperature rise of steam at the final superheater was designed at 45°C at the maximum load in order to cover the lagging control of steam temperature caused by its heat capacity.

3) Construction of furnace wall

The furnace is constructed of meander system panels with each unit composed of twelve pipes and supported by an iron structure. That is, two portions, the upper and lower of each panel, are mounted upon metal supports. However, in the vertical direction the upper portion is fixed and the lower portion is so arranged as to slide when expansion occurs. In the horizontal direction, the center is fixed and the right and left ends are free to provide for expansion. The side wall is able to expand to the rear. On the front and side walls, fourteen columns are provided on which to mount the metal fasteners. A skin casing (internal casing) is installed behind the pipes to provide heat insulating materials between the pipes and the external casing. Each of the internal and external casings is welded to the iron structure, and to prevent the casing from over heating, the relative expansion difference between the pipes and skin casing is held to a minimum. Because of the high steam temperature (475°C maximum) of superheater III, castable furnace materials and insulating materials are installed on the side with the pipes between the pipe and skin casing. The other sides are quite similar to the construction of the furnace wall of the evaporator. The furnace back wall is equipped with castable furnace materials between the evaporator and bearing tubes to shield flue II. However, as show in the drawing, since it is lifted down from the upper position by the bearing tube, the lowest end uses a metallic expansion joint to shield the gas pressure difference. Further, the sliding surface for the side wall of flue II uses a metallic slide shield to provide perfect protection. Flue II is a brick wall that requires no explanation. The temperature of all the internal casing is maintained much higher than the dew point of flue gases to prevent gas leakage due to corrosion. The test for static head was performed after the welding of the internal casing was completed. The pressure inside the furnace was 75 mmAq with the testing head 150 mm. A pressure drop of 50 mm/10 min. was used as a standard. No trouble was experienced in the test except for some of the inspection hole washers which were quickly repaired.

4) Others

Overheating of the inspection and soot blower holes due to small gas leakage is prevented by blasting a small quantity of sealing air diverted from the forced draft fan during operation. When the inspection holes, burner holes, etc. are opened during operation, a separately installed air compressor induces air of 2 kg/cm^2 pressure into the furnace to seal the furnace gas. This is aspirated air and at the position where the above sealing air is commonly used, three-way cocks are used for changeover.

4. Auxiliaries and Accessories

The feed water pump adopted is a barrel type with the speed between the output and head geared up. Since the well water at the Goi District which was used for the water purifier contained many impurities, pre-conditioning equipment had to be provided. To provide the proper quality of raw water after treatment, the preconditioning equipment was designed with the following design figures as a result of 10 analyses:

total cation 180 ppm as $CaCO_3$

total anion 90 ppm as $CaCO_3$ (inlet of OH tower)

Na% = 58.8%, HCO_3% = 62.5%, SiO_2% = 63.0%

As is clear in the above, because of the proper content of raw water and SiO_2, the water purifier has a very ample capacity as compared with the boiler capacity. As to this capacity, about 50% of about 74 t/hr supplied for process steam was to be recovered as condensate. However, as this condensate occasionally cannot be recovered, the purifier was designed to provide the full requirement of water. The caustic soda used during reproducing is recovered to be used again to reduce operating costs. Since pipes were used for the feed water heater, the chemical dosing equipment used a volatile control system to de-oxygenate by hydrazide under pH control by ammonia. The ammonia was dosed in the low pressure feed water heater inlet to make ratio control for feed water; moreover, it was dosed again into air separator outlet to control the dosing quantity by varying the stroke of the pump according to the pH value (8.0∼9.0) at boiler inlet. The hydrazide was dosed in the air separator outlet to make the ratio control for the feed water.

III. TURBINE

1. Details of Turbine

Fig. 7 shows the view of turbine. Main specifications are as follows:

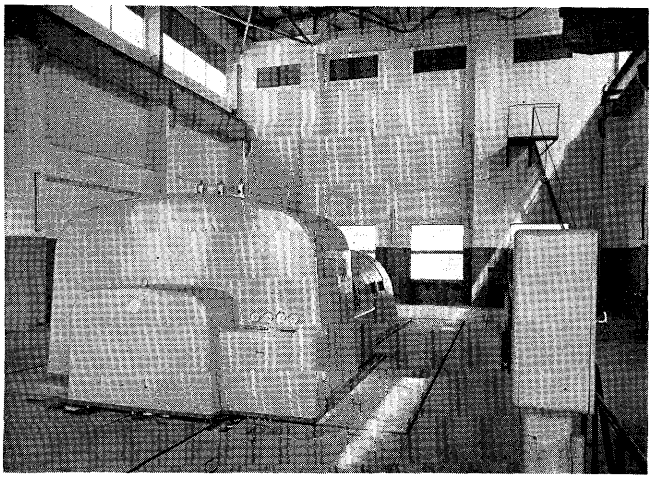


Fig. 7 Turbine

Type:	Fuji-SSW reaction single casing backpressure turbine
Output:	Rated 10,800 kw, Economical 9000 kw
Inlet steam pressure:	134 kg/cm^{2}g
Inlet steam temperature:	500°C
Backpressure:	15 kg/cm^{2}g
Revolutions:	3000 rpm

2. Auxiliaries

Main specifications for auxiliaries are as follows:

Oil cooler:	Surface cooling type, 20 m^2 2 units (one is standby)
Oil tank:	Steel plate welded type, 6 m^3 1 unit
Auxiliary oil pump:	Vertical shaft centrifugal type, 75 m^3/hr, a-c motor driven 1 unit
Emergency bearing oil pump:	Centrifugal type, 22 m^3/hr 2 units (one is d-c motor driven, the other gasoline engine driven)
Leakage steam condenser:	Surface condensing type, 11.2 m^2, cooled by boiler feed water, complete with air exhaust fan, condensing pump.

The a-c and d-c motor driven oil pumps are vertical shaft types and are located in the oil tank to save piping and space.

3. Construction of Steam Turbine

The pot type casing, which is one of the most outstanding features of our turbine, was used with this machine. This machine is the sixth turbine having a pot type casing. Even though the inlet steam pressure for this turbine is as high as 134 atg the thickness of the pot type casing is less than that of other types. Another feature found only in the pot type casing is that its flange, instead of being horizontal, is vertical to the axial direction, and since it is located on the exhaust side of the turbine, only minimum sealing is required against the lower steam pressure.

1) Casing

The casing is made of Mo V cast steel and is constructed to be divided in the forward and backward direction without a horizontal flange as described above. One of the main stop valves is located on both sides of the casing. Steam flows in the valve boxes on both sides of the casing as if to enfold the casing, then flows on, branching upward and downward and is led to the nozzle through the six control valves provided: three for the upper side and three for the lower side.

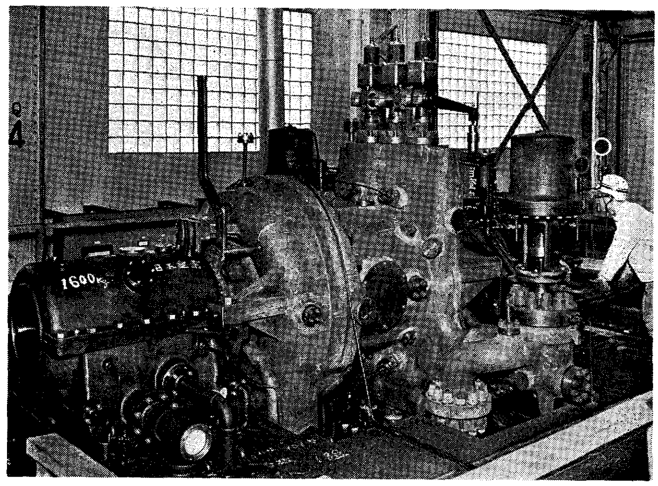


Fig. 8 Pot type casing

2) Stationary blading holder

The stationary blades are fixed upon the stationary blading holder, which is divided into two sections, the upper and lower. However, the blades are tightened by the steam pressure applied upon the outside of the stationary blade holder. This arrangement allows the use of a smaller flange since the bolts attaching the blades to the holder are not required to have enough strength to stand the stress of operation. Therefore, the blade holder, which is nearly symmetrical and has almost the same weight as the rotor, is safe from the effects of thermal expansion and can withstand the temperature variations. The stationary blading holder is made of MoV cast steel.

3) Rotor

The rotor is made of CrMo V steel and is forged in one unit. It is equipped with movable blades consisting of one impulse stage and 40 reaction stages. Since more than 130% of the rated revolution was provided for in establishing the critical speed of the shaft, safety and ease of operation is assured. At the same time, the gap of blade edge is minimized.

4) Blading

The blading consists of one stage for the impulse stage and forty stages for the reaction stage. The nozzle governing is carried out in the impulse stage and the nozzle chamber is divided in six chambers inside the casing. The moving and stationary blades adopted have a rounded head to minimize the drop in efficiency when the turbine is operated at partial loads. This was especially considered since this private power plant would be operated at partial loads for the period immediately after its establishment.

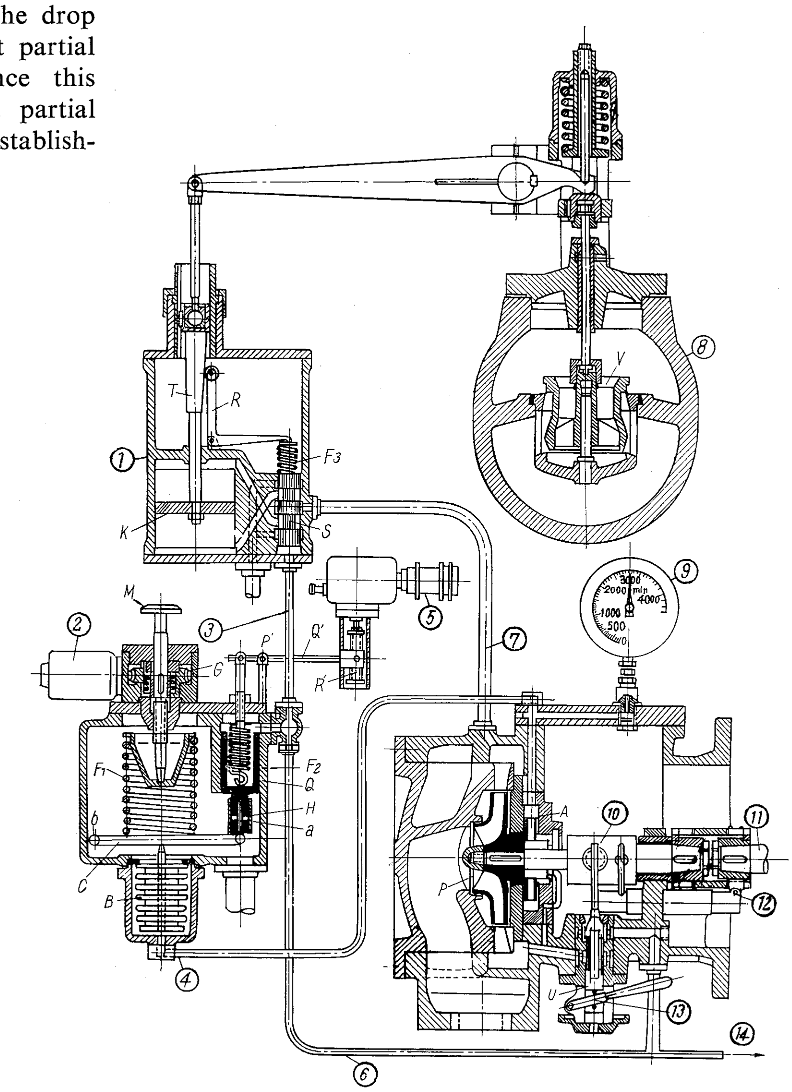
5) Labyrinth

The sealing device of the labyrinth system utilizes a combination of two kinds of packing, one having the usual gap in the radius direction and the other having a gap in the axial direction. The latter compared with the former having the same number of gaps can shorten the length in the axial direction. Therefore, the rotor length can be made smaller and raising the critical speed above 130% of the rated revolution becomes easier.

4. Governing and Protective Device

1) Turbine speed governor (Refer to *Fig. 9*)

Oil hydraulic governors are always used on Fuji-Siemens systems. The system operates as follows. The primary oil pressure control produced by governing impeller *A* maintains a pressure on bellows *B* proportional to the square of the rpm to balance the force of the rpm setting for spring F_1. If the forces become unbalanced because of a change in the oil pressure caused by a change in revolutions, or a change in the force of F_1 caused by changing the number of revolutions on the setting device, pressure relay *H* is actuated. Both pressure relay *H* and piston *Q* are provided with slit *A*, from which a part of the secondary control oil flows out. Since the area of throttle *A* varies by action of *H*, the inside secondary control oil pressure varies to break the balance with the internal spring F_2, so that piston *Q* moves up to a new balanced position, followed by *H*. The secondary control oil pressure acts on pilot valve *S* and operates it according to the pressure, thereby operating the servomotor of the control valve. The movement of the servomotor is fed back to the pilot valve by follow-up lever *R* to give a self-regulating character to the movement of the control valve. By rotating eccentric followup cone *T*, the degree of irregularity can be varied freely even during operation. This turbine has an extremely low moment of inertia for rotors of generator and turbine, and its accelerating time is short. Therefore, piston *Q* is equipped with a damper in order to suppress the speed-up when load interruption occurs. This damper does not obstruct the motion of piston *Q* to provide a slow change of



① Oil servomotor
② Speed control motor
③ 2ry oil circuit
④ Primary oil circuit
⑤ Backpressure control motor
⑥ Tripping oil circuit
⑦ Main oil circuit
⑧ Governor valve
⑨ Tachometer
⑩ Emergency governor
⑪ Turbine shaft
⑫ Thrust bearing emergency device
⑬ Tripping device
⑭ To main stop valve

Fig. 9 **Arrangement of oil-hydraulic governor system** revolution during ordinary operation. However, it obstructs the operation of the pressure relay by piston Q in case of a sudden change of load due to load interruption, etc; thereby, throttle A is suddenly opened, taking off the secondary oil pressure, and the control valve is immediately closed. Thus the speed rise at the time of load interruption is held to a minimum. Since this speed governor does not contain any large parts, it has very little interference from friction, and its governing function is extremely stable and sensitive.

2) Backpressure control device

The servomotor of the backpressure control device is connected with spring F_2 in piston Q through A link mechanism. Thus, by a command from the backpressure control device as the secondary oil pressure is changed, the governor valve is operated to supply the process steam as required. During operation of backpressure control, when the revolution control is set on " OFF ", the load limiting device under the control bellows B actuates and the governor will not respond to the change of cycle in the set work. During backpressure control, when a great rise in number of revolutionso ccurs at load interruption, etc., the governor automatically functions for speed control to suppress the speed rise. In this case, even if the backpressure control is put on " automatic ", it does not matter. That is, when set on " automatic " after the governor suppresses the speed rise, the backpressure control device gradually opens the control valve to raise the turbine speed slowly if the backpressure has been out. However, the speed is regulated so that it never rises to 5% above the rated speed. The Fuji-Siemens steam converting valve (pressure reducing and temperature reducing valve) installed in parallel with the turbine is almost completely opened by the quick-starting device to minimize the change of backpressure; this prevents the backpressure from being lost. (Refer to the site testing item.) When taken out of parallel operation, the turbine is protected from a sudden load from process steam by selective interruption of an electrical load in case of a heavy electrical load. Thus the back pressure control operates very smoothly in cooperation with the excellent steam converting valve.

3) Turbine starting device (Refer to *Fig. 10*)

By turning C_{11}, worm wheel C_9 is activated which in turn releases oil pressure through a cam which is coupled to it. This oil pressure opens valve d. Further turning of C_{11} pushes up control bellows (C_1) and the link holding the control valve in a closed position drops down, and at the same time the control sleeve comes down. Thus, the slit in piston Q is throttled and the secondary oil pressure is produced which gradually opens the control valve and the turbine speed is slowly raised. Accordingly, the main stop valve does not need a manual oper-

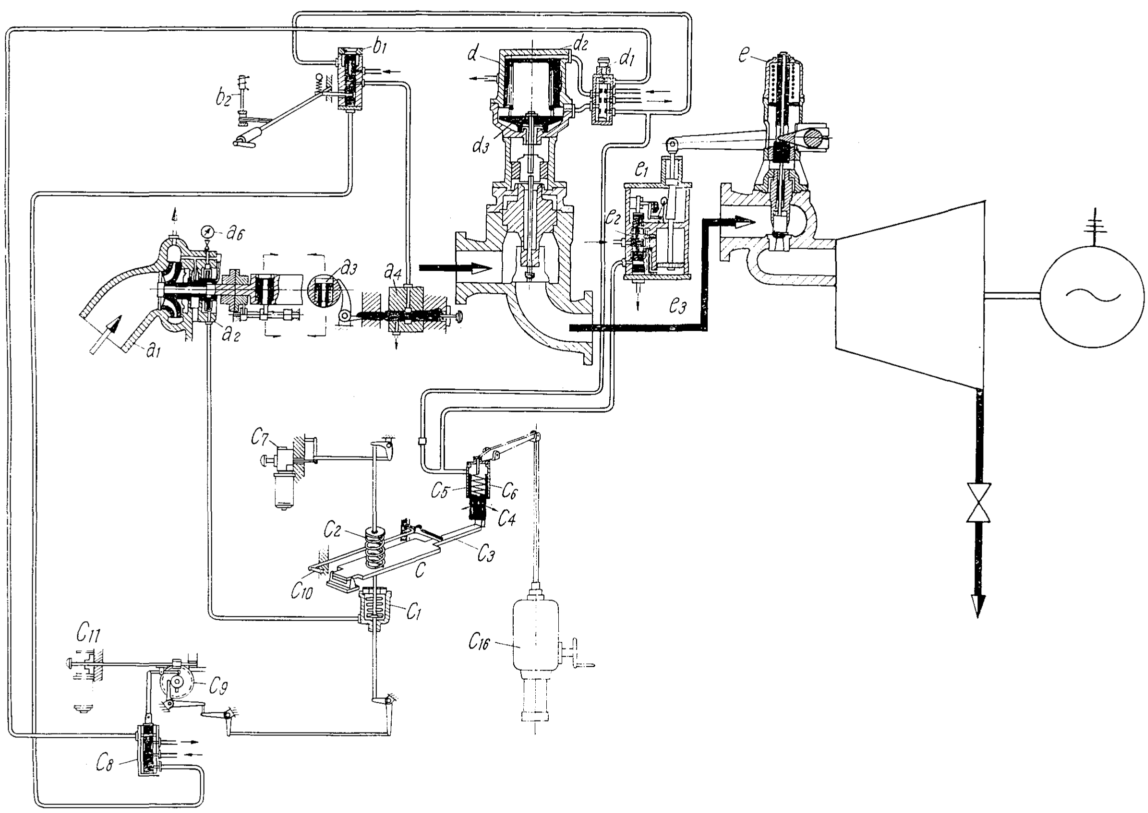


Fig. 10 Governing system and starting device

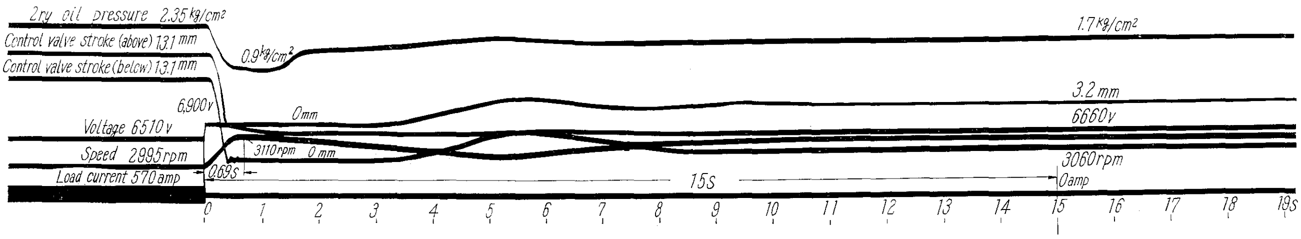


Fig. 11 Oscillogram of governor test

ating handle, with a resulting simplification of the mechanism.

4) Protective device

As a protective devices for the turbine, the following are provided:

Emergency speed governor, thrust bearing protection, emergency stopping device in case of low oil pressure, emergency stopping magnetic changeover valve, emergency stopping pushbuton switch, shaft position indicator, thrust metal decrease indicator, indicator of differential in casing and shaft expansion, vibration recorder, bearing temperature alarming device, automatic starter for auxiliary oil pump and bearing oil pump.

5) Site test (Refer to *Fig. 11*)

The government test was carried out at the end of February and was finished quite successfully. Since one boiler was not completed, the plant, at this time, was approved for 5000 kw, 1/2 of its full load. The rate of acceleration at the time of load interruption was 2.83% on a 2500 kw load, and 3.83% on 5000 kw load. These tests were conducted under automatic operation of the backpressure control. From this data, we assume the acceleration rate on 10,000 kw full load will be 6.5%. The variation of backpressure at the time of load interruption was able to settle to about 1 kg/cm² on 5000 kw by the rapid functioning of the steam converting valve. Vibration was also below 3.5μ.

IV. CONCLUSION

We have introduced the equipment through the above description. This plant is a high quality plant designed especially for use as a private power station. The pressure and heat of the steam is well suited to its capacity. From a technical point of view, up-to-date techniques were applied, such as meander system of pressure firing for boiler, pot type casing, main stop valve, control device for steam turbine, etc. We are sorry that due to a lack of space our description had to be limited to only the most important points. We hope this article will be helpful to anyone who is planning the construction of a new power plant. We wish to express our gratitude to the engineers of Shin-Nippon Chisso Hiryo K.K. and Chisso Petro-Chemical Corp. for their assistance in making this plant possible.