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22,000 kW THERMAL POWER PLANT FOR HYOGO OIL REFINERY OF IDEMITSU KOSAN, LTD.

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I. INTRODUCTION

Fuji Electric supplied the steam turbine, generator and plant electrical equipment for the 22,000 kW steam supplying combined thermal power plant newly constructed in the Hyogo Oil Refinery of Idemitsu Kosan, Ltd. The main features of this equipment will be introduced here.

II. OUTLINE OF THE EQUIPMENT

The main feature of this equipment is that the turbine and the generator are outdoors. The turbine and generator units are usually indoors but in this system they are completely contained in one outdoor case. Operation, inspection and maintenance during bad weather have been considered and the turbine starting-panel is also included in the case. At the ground floor of the turbine room there are no walls, and air can be blown through turbine room, so explosive gas dosen't stay in turbine room. These type plants for 3,200 kW 3,500 kW and 27,400 kW have already been installed in the Chiba Refinery of Idemitsu Kosan, Ltd. as well as a 3,400 kW plant in the Tokuyama Refinery of the same company and two plants for 5,750 kW and 16,000 kW in the Idemitsu Petrochemical Co. All of these plants have proven highly satisfactory.

The specifications of the main equipment are as follows.

1. Steam Turbine

Type: reaction-type, 2-cylinder, extraction condensing turbine
Output: 22,000 kW
Inlet steam conditions: 125 kg/cm²·g, 537°C
Extraction pressure: 23 kg/cm²·g
Condenser vacuum: 0.075 kg/cm²·abs
Speed: 3,600 rpm
Cooling water: sea water, 26 °C

2. Generator

Type: horizontal-shaft, cylindrical, rotating 3-phase AC synchronous generator
Output: 25,900 kVA
Power factor: 0.85 (log)

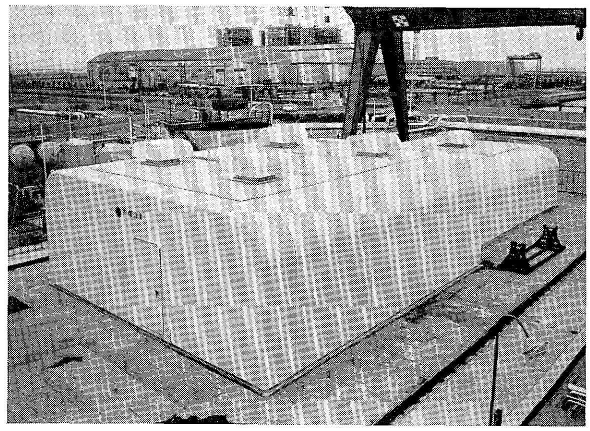

Fig. 1 Outerview of outdoor turbine and generator

Voltage: 11,000 V
Frequency: 60 Hz
No. of poles: 2 poles
Speed: 3,600 rpm
Insulation: Class B
Exciting system: brushless exciter
Cooling system: enclosed air circulation using air cooler

III. STEAM TURBINE

There has been a trend in private turbines recently towards high temperatures and pressures and large sizes in accordance with economic requirements and there are many cases where steam is obtained for equipment which requires heat.

This plant was also planned with the aim of supplying electric power and process steam both economically and stably by using high temperature and pressure steam conditions. Below, the features and a general outline of the turbine and its control equipment are given.

1. Turbine Unit

As can be seen from the sectional view in *Fig. 2*, this turbine consists of two cylinders divided into high pressure sections. The high pressure section employs a pot-type casing with an inserted nozzle. The pot-type casing is of special Fuji Electric construction, and it have been planned for flexibility against internal temperature changes caused by rapid

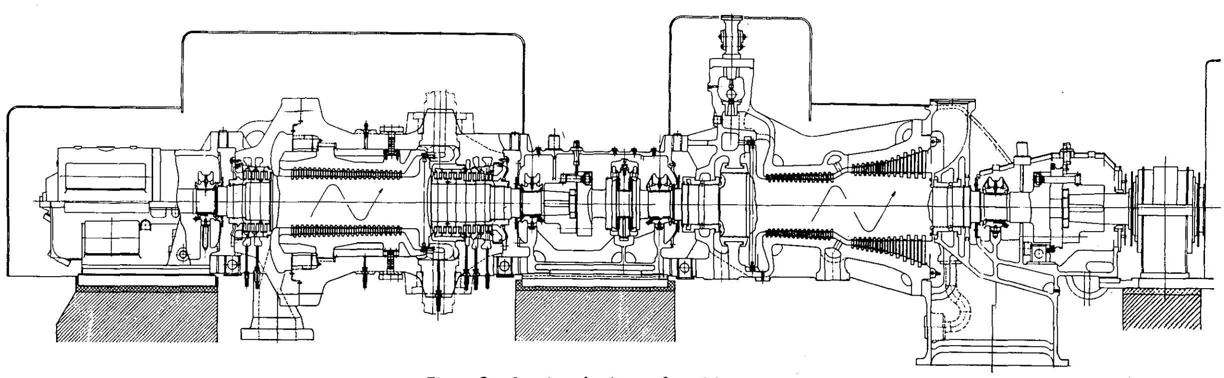

Fig. 2 Sectional view of turbine

variations in the load and the amount of process steam, It is ideal as the high pressure section of a high temperature/high pressure steam turbine. This type of construction has already been introduced several times in this review and will not be given here. The low pressure part is of the horizontal, double-casing construction. The steam, after leaving the pot-type casing, is mostly extracted for use as process steam.

The blades are a rounded-head profile reaction type series which are safe in respect to strength and vibrations and also have a high efficiency during both the rated load and partial load. Twin-type moving blades are used in the high pressure impulse section where the stress conditions are severe but all the other blades are of the indepened construction. A riveted shroud ring is not used.

The rotor is a central shaft formed from a single casting with the high pressure section, and there is never any disk shrinking pressure. The critical speed of the rotor is higher than the normal speed of this rigid shaft so that stablility is insured and there is no need to worry about resonance during starting and stopping.

2. Control

In industrial power plants using extraction condensing turbines, the turbine capacity after steam extraction can be planned to be very small because of the relation between the factory steam requirements and the power requirements. In such a case, it is almost impossible to use the former method for controlling extraction condensing turbines without any changes.

In other words, when the steam required in the factory is supplied at constant pressure and the power is supplied simultaneously, a back pressure turbine is generally used, but when the power generated by a back pressure turbine is not sufficient to fulfil the plant power requirements, a condensing turbine is connected subsequent to the back pressure turbine and it becomes a single shaft extraction condensing turbine. The power and steam requirements of the plant must be fulfilled in this way.

In this case, because of the balance between the plant power and steam after the turbine extraction section, the capacity of the low pressure turbine can be planned very small. When planning to provide for the factory load which changes in accordance with the power generated in the low pressure sections, sometimes an extraction turbene is used and at other times a back pressure turbine is used. In this case, it is desirable that control be such that the turbine does not transmit power back to the external system during parallel operation with an large system and the output automatically follows the plant power load. To meet these requirements in the mechanical hydraulic type operation control used in former extraction condensing turbines, the low pressure control valve was operated with a large stroke in accordance with very small changes in the turbine speed and the amount of extraction. Many problems arise with this system such as the considerable wear involved and speed control becomes unstable when the low pressure control valve is open.

Fig. 3 shows a static diagram for this extraction condensing turbine and *Fig. 4* shows a diagram of steam flow vs. power. As can be seen from these figures, the low pressure section input is only 20 t/h, about 10% of the 205 t/h input of the high pressure section. When an extraction tonnage of from 20 t/h to 205 t/h is insured, there are very severe conditions for control so that the amount of commercial power can be kept as small as possible and there is no reverse power transmission (*Fig. 4*). In order to fulfil all these conditions, a type of electrical/hydraulic system employing an automatic power control device APC, a extraction pressure control device PCT and cut-off devices for them, as well as a PCB bypass control device are employed. The following control systems are used so that stable operation is insured

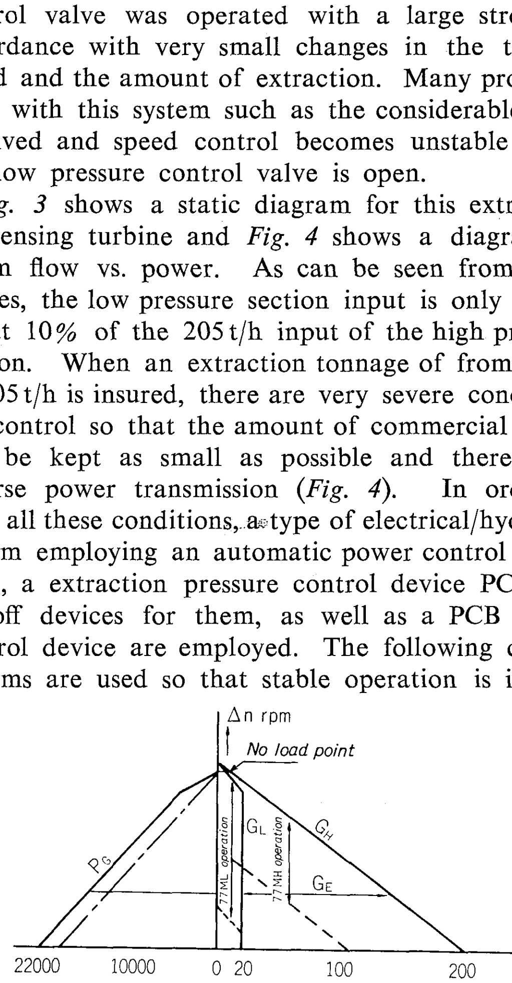

Fig. 3 Static diagram of extraction condensing turbine

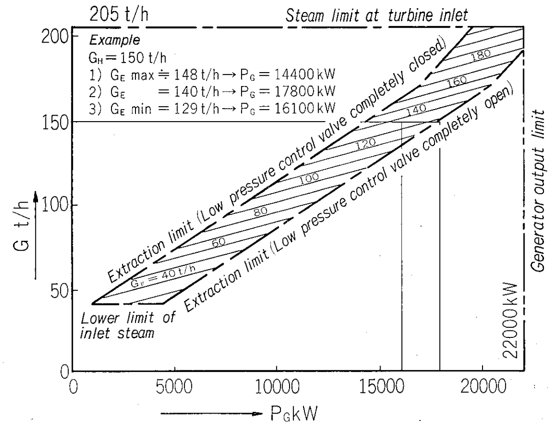

Fig. 4 **Diagram of steam flow vs. power**

for the entire plant.

Fig. 5 is a schematic diagram of the turbine control system. The following explanation is made in accordance with this diagram as well as *Figs. 3* and *4*. Under normal conditions, the steam from the boiler superheater enters the high pressure section of the turbine via the turbine inlet high pressure control valve V_H. The majority of the system from this section is supplied to the plant via the extraction line and the remainder enters the low pressure section of the turbine through the low pressure control valve V_L. It is expanded to the pressure of the condenser and then enters the condenser. The output generated by the low and high pressure sections of the turbine is converted to electrical power P_G by the generator, and is transmitted to the plant load P_L. The small amount of commercial electrical power P_R from the large system is also taken by the plant load P_L.

In *Fig. 3*, the amount of steam for the high pressure section is G_H, while that for the low pressure section is G_L. G_H-G_L is G_E, the amount of extraction. The terminal generator output P_G for this amount is shown on the left side of the figure.

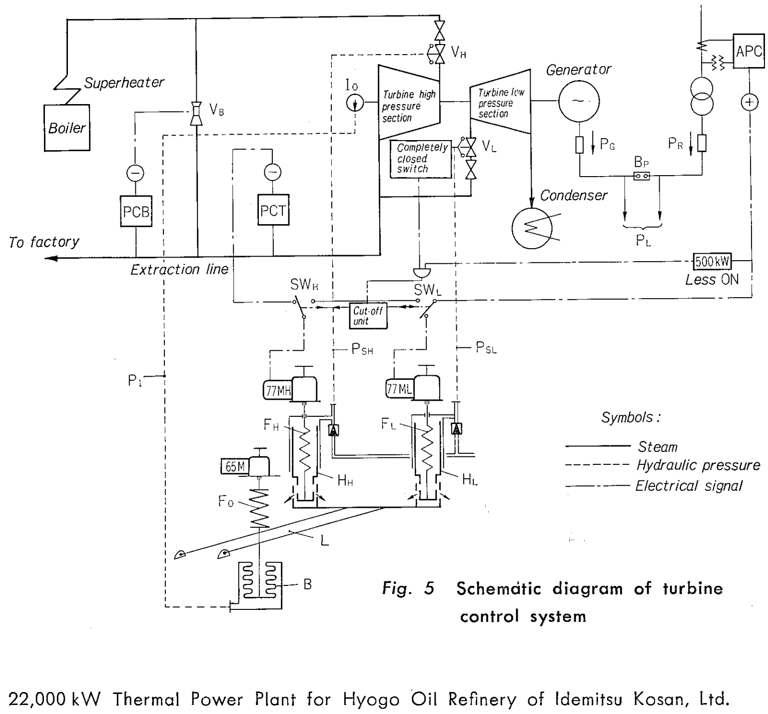

Fig. 5 **Schematic diagram of turbine control system**

The extraction line pressure is maintained mainly by the extraction control device PCT (hereafter referred to as a PCT). The extraction line pressure in cases where it is impossible to maintain the pressure for the extraction amount G_E operates the bypass valve V_B by means of the bypass control device PCB (hereafter referred to as PCB) which is provided as a back-up device. The set pressure value of this bypass control PCB is less than the set value of the extraction control PCT. When the extraction line pressure is less than the PCT set value, the bypass valve is opened by the PCB and the pressure is maintained at the PCB set pressure.

The amount of power purchased is controlled to a constant value by operation of the low pressure and high pressure control valves by means of the automatic powers control device APC (hereafter referred to as APC).

The following is a detailed explanation of output control and extraction pressure control for the various operating conditions of the turbine.

1) Independent operation

Output control during independent operation is performed so that the turbine speed is kept constant. When there is an unbalance between the load P_L and the generator output P_G, for example when $P_L<P_G$, the speed is increased and the primary oil pressure P_1 which is generated by the governor impeller I_0 is increased in proportion to the square of the speed. With this increase of P_1, the governor bellows B moves the lever L upwards against the speed setting spring F_0, the high and low pressure follow-up pistons H_H and H_L are raised, and the tension on the tension coil springs F_H and F_L in the pistons is weakened. By decreasing the spring tension, the secondary oil pressure P_S, which is generated in respect to the spring tension, is decreased, the high and low pressure control valves are turned and the turbine speed returns to its original value. In this way, the generator terminal output P_G is decreased and it is balanced with load P_L. When $P_L>P_G$, the two are balanced by exactly the reverse of the above process. In this case, the extraction control device PCT and the automatic output control APC in order to make the maximum turbine output possible extends the extended coil springs F_H and F_L of the high and low pressure follow-up pistons to their maximum positions by means of the 77 MH and 77 ML motors and holds them there. They are then set in a position where it is possible to open the low and high pressure control valves completely (the G_H and G_L lines in *Fig. 3*). Naturally at this time, there is no operation whatsoever of the PCT and APC.

The amount of steam extracted from the turbine G_E is determined by the turbine load but by manually opening the low pressure control valve V_L, the amount of steam extracted can by adjusted at constant output only within the low pressure adjustment range.

Amounts of steam extracted outside the adjustment range are controlled as indicated below.

(1) Turbine output for load $P_L>$ required extraction amount

It is necessary to reduce the load in keeping with the amount of extraction.

(2) Turbine output for load $P_L<$ required extraction amount

Because the extraction pressure is small, the part lacking in the required amount of extraction is supplied by the bypass valve V_B in the PCB.

2) Paralell operation

When this system is operated in parallel with an large system, the turbine speed is determined by the frequency of the large system. Speed control is not performed, the tension coil spring F_H of the high pressure follow-up piston is operated by the extraction control PCT via the 77 MH motor and the extraction pressure is controlled by opening or closing the high pressure control valve V_H. The automatic power control APC which knows the commercial power from the large system operates the tension coil spring F_L of the low pressure follow-up piston via the 77 ML motor and this controls the commercial power to a constant value by opening and closing the low pressure control valve.

Since the output adjustment of the low pressure section of the turbine is small, the low pressure control valve is completely closed and when the power required by the plant P_L is smaller than the turbine generator terminal output P_G, a signal that the low pressure valve is completely closed is sent to switches SWH and SWL and the switches are changed from the position shown in the diagram to the opposite side. When this occurs, the turbine extraction pressure control PCT is cut off and the APC signal switches from the 77ML to the 77MH for operation of the extended coil spring of the high pressure follow-up piston. The high pressure control valve is closed and the commerical power is kept constant.

In this way reverse power transmission never occurs no matter what type of operation is performed in parallel with an outside system.

Output and amounts of extraction outside the adjustment range are controlled as follows:

(1) Turbine output for load $P_L>$ required amount of extraction

When the amount of commercial power is large, the low pressure contrcl valve is opened by APC. When the load is larger with the low pressure control valve completely open, the amount of commercial power is increased.

(2) Turbine output for load $P_L<$ required amount of extraction

Since the amount of commercial power is less than the set value, the low pressure control valve is closed by APC. When the load P_L is smaller with the low pressure control valve V_L completely closed, APC operation depends on high pressure control valve V_H and the high pressure control valve is also closed.

At this time, the extraction pressure control PCT is cut out and the extraction pressure is controlled by PCB.

3. Test Operation Results

Installation at the site for this turbine was completed in August, 1970 and after adjustment test operation, governor tests and performance tests were completed satisfactorily, the turbine went into continuous commercial operation.

IV. ARRANGEMENT, BUILDING AND FOUNDATION

In order to reduce construction costs in recent power generation plants, turbines and generators are being placed together rather than constructing a separate turbine room and there are many cases where an outdoor turbine case is used to protect the generator against bad weather and to eliminate noise. An outer view of the turbine is shown in *Fig. 1* and *Fig. 6*, and an inner view is shown in *Fig. 7*.

The following advantages are obtained by the use of this turbine outdoor case.

1) The construction costs for the turbine housine are greatly reduced.

2) The time required for construction of the turbine housing is much less.

3) Removal and insertion of the turbine and generator are easy.

4) Since no insertion opening is required, the turbine housing can be smaller.

At the time of actual manufacture, it is necessary to fulfil the same conditions and functions of the turbine room, therefore many considerations are required. Of these the most important point are given as below:

1) There must be no leaks or deflection during

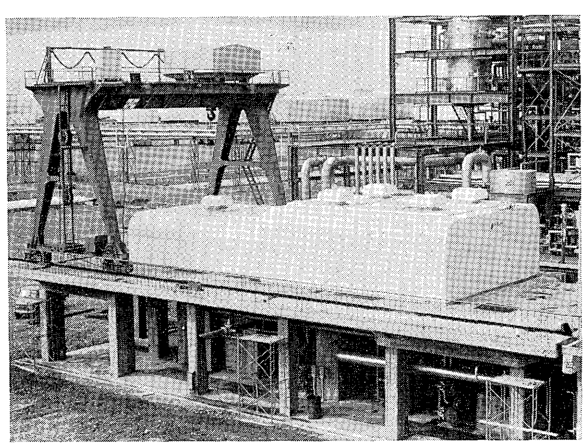

Fig. 6 Outer view of outdoor case

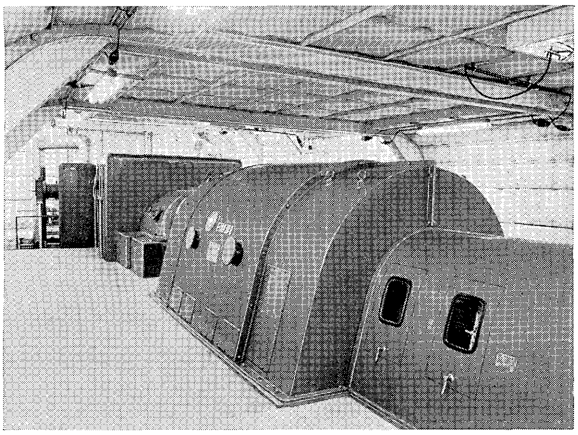

Fig. 7 Inner view of outdoor case

typhoons, heavy snow, etc.

2) It must have sufficient strength to resist earthquakes and the case must not have any deflection or distortion.

3) There must be no hot air staying inside the case.

4) Convenient transportation and simple assembly and disassembly.

5) It must be considered to prevent noise going to the outside.

6) It must have sufficient space inside for maintenance and inspection of the generator and to accomodate the various devices and panels.

7) Because of its direct exposure to the exterior, attractiveness must be considered.

To be more precise, weather conditions at the site such as the temperature, most prevalent wind velocity, wind pressure, maximum rainfall, maximum height of snow and humidity must be sufficiently studied and considered. The horizontal degree of vibration in case of an erthquake must be considered as 0.2 g. To prevent rain leaks, special care is taken with all seams especially for the turbine outdoor casing ceiling plate, the horizontal parts and the vertical parts. The construction is completely rain-proof as shown in *Figs. 8* and *9*.

Since turbine and generator are provided inside the turbine outdoor case, the the temperature becomes high but it must not have bad influence on operation or working. In order to provide effective ventilation between the hot air inside the case and the atmosphere, there are three fans only for air exhaust and three fans which can be converted between air exhaust and air intake. All of these fans are effectively arranged for good ventilation.

Since noise-preventing requirements have increased, the inside of the case is lined with noise-eliminating materials of sufficient thickness that the noise is held under 75 phons one meter from the case. The absorption of sound is completely prevented.

In order to facilitate assembly and disassembly of the turbine outdoor casing, the casing is divided in a manner in keeping with freight transport highway limits as well as limits of trucks and trailers. When the turbine and the generator are assembled and disassembled, the side walls of the case can be left standing and the units can be lifted out by crane after removing the ceiling plate if required.

The layout of the equipment in the turbine building is shown in *Figs. 10* and *11*. When the accessory equipment is arranged, the oil pump and oil cooler must be positioned by considering maintenance and accessory piping. To provide easy operation, they are arranged horizontally on first floor near the oil tank.

These are two steam jet air ejectors. The pressure loss of the driving steam pipe and the condensate water pipe is kept low so that the ejectors can be operated at their optimum point. Thn ejectors are arranged on the mezzanine floor to avoid wind and rain. The condensate pumps are of the upright type to save space.

V. CONTROL OF INCOMING POWER AND TURBINE

In section II, the principles of steam turbine control were described. In this section, the basic concepts and operation of the various control units in respect to changes in conditions, electrical load and steam load are described.

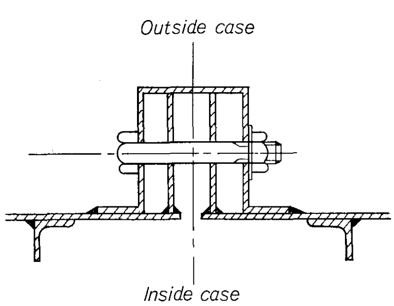

Fig. 8 Horizontal joint part of roof plate

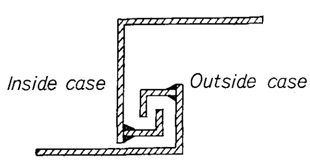

Fig. 9 Vertical joint part of roof plate

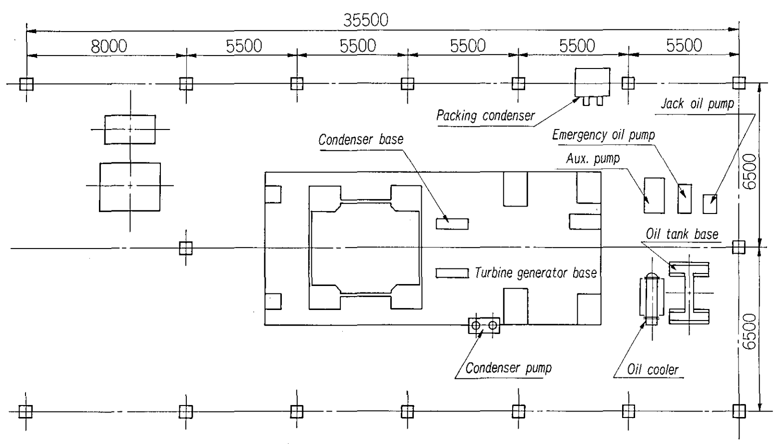

Fig. 10 Plan view of first floor

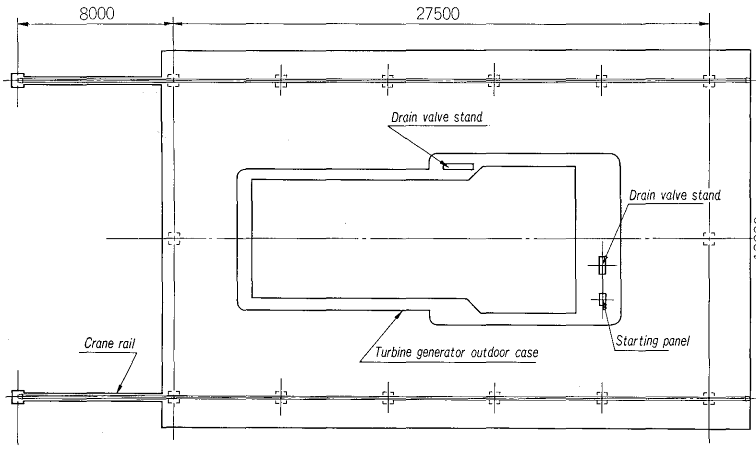

Fig. 11 Plan view of second floor

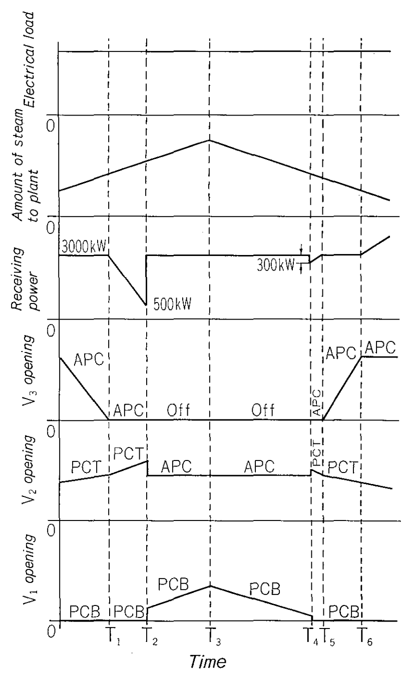

Fig. 12 Explanation diagram of turbine control (process control constant)

1. Basic Concepts

This plant can be operated in parallel with incoming power from an external power system. In this case, the incoming power is kept as low as possible and changes in the process electrical load within the permissible range of the turbine and process steam so that there is no reverse power transmission are controlled automatically by changing the turbine output. When this occcurs, the low pressure turbine output is extremely low in comparison with the total output (maximum : approx. 3,500 kW) and therefore, during the process load is constant, the regulation of output must be within the 3,500 kW range, but the output can be reduced to zero by using the turbine bypass steam conversion valve. Below are the basic design concepts. The control systems and abbreviations are as in *Fig. 5*.

1) APC control is constant incoming power control.

2) The APC set value (incoming power setting) is generally from 2,000 kW to 3,000 kW. The setting value can be changed in the range 0 to 7 MW.

3) When incoming power parallel operation is used, the power which flows through the bus-tie breaker which connects the private power and the incoming power is either zero or the amount from the private bus line to the incoming bus line.

4) The set values of the bypass control PCB and the turbine extraction control PCT are such that PCT > PCB. In other words, extraction pressure control has priority.

5) APC is affected by the piston which moves in accordance with the turbine low pressure control valve. However, when the low pressure control valve V_L is completely open, this switches to the piston which moves in accordance with the high pressure control valve.

6) The extraction pressure control depends on the piston which moves in accordance with the high pressure control valve. However, it is cut off when the APC is shifted to high pressure.

7) During independent operaiion, the pistons which move in accordance with the high and low pressure control valves are extended to their maximum positions and speed control is given priority.

8) Changes in power system frequency

In this system, the turbine output during parallel operation is influenced by the frequency of the power system. When the turbine speed adjustment percentage is 5%, the turbine output change in respect to a frequency variation of $x\%$ is as follows:

$$\frac{x\%}{5\%} \times 22\ \text{MW} = 4.4x\ \text{MW}$$

Therefore, if $x = 0.5\%$ the change in the turbine output is 2,200 kW. In order to avoid reverse power transmission due to this change, it is necessary that the APC set value be greater than this value.

Since there is hysteresis due to the shift of APC from V_L to V_H or from V_H to V_L, and since V_B is opened which its minimum control flow rate limit is exceeded, the incoming power is 500 kW when the APC is shifted from V_L to V_H.

2. Operation

Mutual operations for APC control, extraction pressure control and bypass control during parallel operation will be explained below. For convenience, the APC set value is considered as 3,000 kW.

1) When the electrical load changes at a constant process steam load (*Fig. 12*)

(1) T_0

APC depends on the low pressure control valve V_L at the incoming power set value of 3,000 kW. Just at this time, V_L opens completely. The high pressure control valve V_H is controlled by the extraction pressure control PCT.

Bypass valve V_B is completely closed.

(2) $T_0 \rightarrow T_1$

The electrical load is reduced.

V_L is closed by APC.

V_H is closed slightly by PCT in order to make the extraction pressure constant.

V_B is completely closed.

(3) T_1

V_L is completely closed.

(4) $T_1 \rightarrow T_2$

V_L is completely closed. V_H is controlled by PCT and V_B is completely closed.

During this time, the turbine output is constant and therefore the reduction in the electrical load appears as a reduction in the incoming power.

(5) T_2

The incoming power is reduced to 500 kW.

APC shifts from T_2 to V_L and the V_H PCT is cut off. In this case, the set value of 3,000 kW and since the value of the incoming power at this time is 500 kW, APC depends on V_H and simultaneously V_H is closesed when the incoming power reaches 3,000 kW. In other words, V_H closes when the turbine output is 2,500 kW. Therefore, the amount of extraction corresponding to the 2,500 kW output is not sufficient, the extraction pressure decreases, the bypass valve V_B is opened by PCB and the insufficient amount is supplied.

(6) $T_2 \rightarrow T_3$

V_L is completely closed.

The electrical load is reduced.

V_H is closed by APC so that the incoming power becomes 3,000 kW. Owing to the insuficient steam supply, V_B is opened by PCB

(7) $V_3 \rightarrow V_4$

The electrical load is increased.

V_L is campletely closed.

V_H is opened by APC so that incoming power becomes 3,000 kW. This causes extraction to increase and V_B to close.

(8) T_4

Since the minimum control flow rate of V_B is approx. 3.3 t/h APC shifts from V_H to V_L and PCT depends on V_H when this value is detected by the limit switch and a signal is given. Since the PCT set value is higher than that of the PCB, the V_B is closed and the extraction pressure is maintained by V_H. Since V_H is opened only at the V_B minimum control flow rate of 3.3 t/h, the turbine output is increased by about 300 kW and the incoming power is decreased.

(9) $T_4 \rightarrow T_5$

When the electrical load is increased by about 300 kW, V_L remains completely closed until the incoming power exceeds 3,000 kW.

(10) $T_5 \rightarrow T_6$

The incoming power is a constant 3,000 kW.

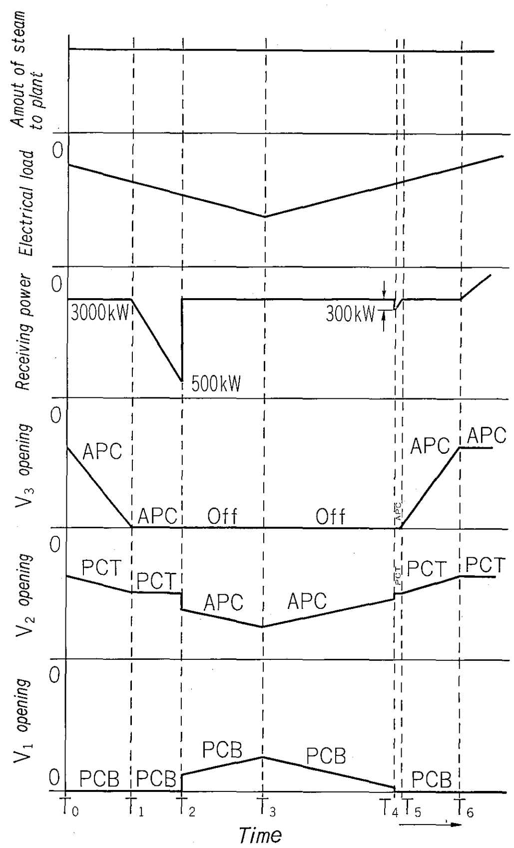

Fig. 13 **Explanation diagram of turbine control (process electrical load constant)**

V_L is under APC control and V_H is under PCT control.

V_B is completely closed.

(11) T_6

V_L is completely open, V_H is under PCT control and V_B is completely closed.

(12) $T_6 \rightarrow$

The electrical load is increased, V_L is completely open and V_H is under PCT control. V_B is completely closed. Incoming power is increased.

2) When the process steam load changes at a constant electrical load for this case, refer to *Fig. 13.*

VI. CONCLUSION

This article has described outdoor type generator and turbine equipment. However, this generator and turbine are of the ordinary indoor type but they are placed in an outdoor type case. When economy is stressed, this turbine and generator can be considered as the outdoor type without being in the outdoor case.

Finally, the authcrs wish to thank sincerely all those in Idemitsu Kosan, Ltd. who cooperated and provided guidance in the planning, manufacture and construction of this equipment.