UDC 621. 311. 22-523 : 5. 082. 6

UNIT MASTER AND TURBINE WALL STRESS EVALUATOR FOR THE NO. 4 UNIT OF HACHINOHE THERMAL POWER STATION, TOHOKU ELECTRIC POWER CO., LTD.

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PREFACE

A thermal power plant is required to be operated as efficiently, safely and smoothly as possible, and should have a quick response of a turbine output corresponding to the power demand of the electric power system.

In addition, it goes without saying for the thermal power plant to be required the highest reliability.

The control system of the thermal power plant is designed to utilize fully the characteristics of various pieces of equipments and attain the purposes of the equipments.

Recently, the plants have been provided with equipment of large capacity and high performance, and so complicated system. Additionally, for saving manpower of operation and obtaining a high safety and reliability the importance of the control systems increase more and more.

The steam turbine for Hachinohe No. 4 Unit is of European type, has excellent starting characteristics and the highest responsibility for load change, and is able to be operated continuously at no load or with a load of its own auxiliary machines only.

The Unit Master and Wall Temperature Evaluator take charge of the control of not only the turbine but all of the plant for full application of this turbine's excellent features.

For the hard ware of the controllers the latest electronics and techniques are fully adopted in all elements.

In this paper, the system configuration, functions and features of the Unit Master and Wall Temperature Evaluator are introduced. Unit Master is a pet name given to its functions of control by the project team of this plant.

I. OUTLINE OF PLANT

The No. 4 unit of Hachinohe thermal power station, Tohoku Electric Power Company, has the largest capacity of 250MW in Japan as a plant of European type and includes a barrel type steam turbine and a brushless excitation system manufactured by Fuji Electric Co. and a Zulzer type boiler by Ishikawajima-Harima Heavy Industries, Co., Ltd. The features of this plant are a quick starting and a quick response to load change.

The principal equipments are as follows:

1. Boiler (Ishikawajima-Harima Heavy Industries Co., Ltd.)

Type:	Zulzer type once-through mono-tube boiler
Capacity:	Max. 875 t/h continuous
Main steam pressure:	197 kg/cm²g (at super-heater outlet)
Main steam temperature:	541°C (at super-heater outlet)
Reheat steam pressure:	41 kg/cm²g (at reheater outlet)
Reheat steam temperature:	540°C (at reheater outlet)
Feed water temperature:	283°C (at economizer inlet)
Fuel:	Heavy oil and raw oil
Type of draft:	Forced draft

2. Steam Turbine

Type:	Reaction type 3½-cylinder 3-exhaust 1-reheat tandem compound condensing turbine
Rated output:	250MW (at alternator terminals)
Main steam pressure:	190 kg/cm²g (at main stop valve)
Main steam temperature:	538°C (at main stop valve)
Reheat steam pressure:	36 kg/cm²g (at reheat stop valve)
Reheat steam temperature:	538°C (at reheat stop valve)
Cooling water temperature:	15°C
Vacuum of condenser:	728 mm Hg
Revolution speed:	3,000 rpm
No. of extraction:	8
Blade length of last stage:	750 mm

3. Alternator

Type: 3 phase, horizontal shaft, revolving-field, hydrogen-cooled synchronous generator

Rated capacity: 290 MVA

Rated power factor: 0.9 (lag)

Rated voltage: 15.5 kV

Rated frequency: 50 Hz

Rated revolution speed: 3,000 rpm

Cooling method: Hydrogen cooling

Hydrogen pressure: 3 kg/cm^{2}g

Excitation system: Brushless

Insulation: B class

4. Boiler Feed Water Pump

(1) Steam turbine driven feed water pump

Number: 2 sets

Type: Multi-stage turbine pump (Booster pump: Double suction volute pump)

Capacity: 450 t/h (50% of boiler feedwater)

Pressure: 260.1 kg/cm^{2}g

Revolution speed: 4,850~2,600 rpm (Booster pump: 1,150~610 rpm) (control of revolution)

(2) Motor driven feed water pump

Number: 1 set

Type: Multi-stage turbine pump (Booster pump: Double suction volute pump)

Capacity: 225 t/h (25% of boiler feed water)

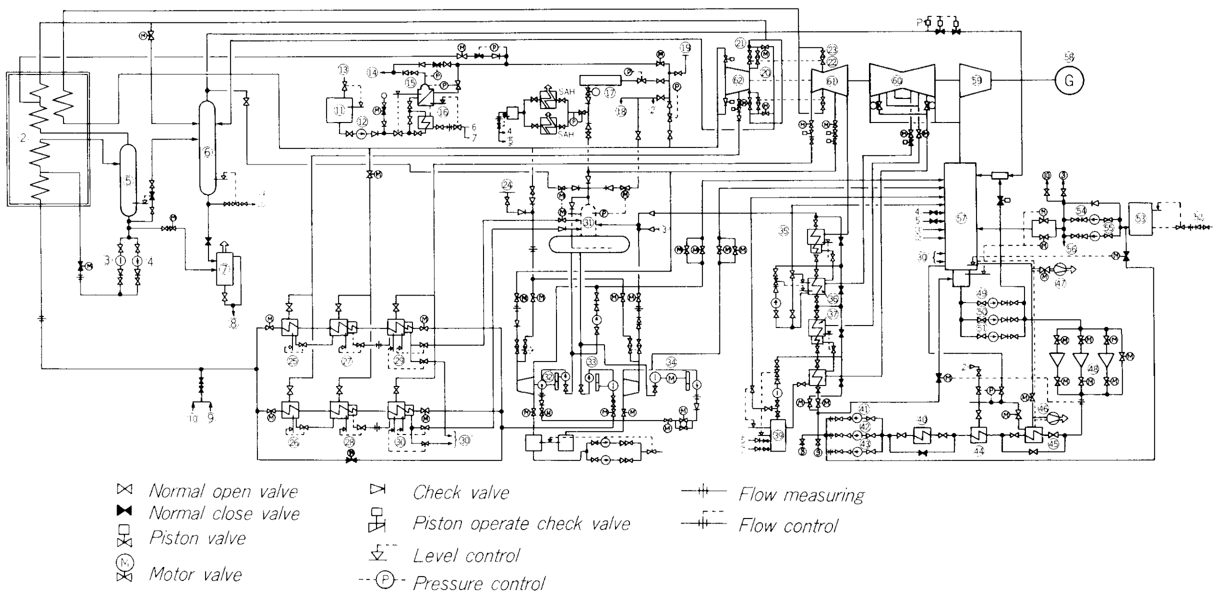
Pressure: 247.1 kg/cm^{2}g

Revolution speed: 4,490 rpm (rated speed) (Booster pump: 1,450 rpm)

(3) Steam turbine for feed water pump

Number: 2 sets

Type: Reaction-type, single-cylinder condensing turbine



(2) Boiler
(3) 4A Evaporator recirculation pump
(4) 4B 〃 〃 〃
(5) Steam/Drain separator
(6) Flush tank
(7) Blow down tank
(8) To drain exhaust pit
(9) Vent
(10) To condenser
(11) Evaporator feed water tank
(12) Evaparator feed water pump
(13) From water treating equip.
(14) To 18 atg header
(15) Evaporator
(16) Pre-heater
(17) Auxiliary steam header
(18) To condensate demineralizer
(19) To No. 3 unit 28 atg line
(20) Main steam control valve
(21) Main stop valve
(22) Reheat intercept valve
(23) Reheat stop valve
(24) To No. 3 unit cold reheat
(25) No. 1A HP heater
(26) No. 1B 〃 〃
(27) No. 2A 〃 〃
(28) No. 2B 〃 〃
(29) No. 3A 〃 〃
(30) No. 3B 〃 〃
(30′) To condenser
(31) Deaerator
(32) 4A Feed water pump
(33) 4B Feed water pump
(34) 4C 〃 〃 〃
(35) No. 5 LP heater
(36) No. 6 〃 〃
(37) No. 7 〃 〃
(38) No. 8 〃 〃
(39) No. 8 LP heater drain tank
(40) Condensate heat exchanger
(41) 4A condensate booster pump
(42) 4B 〃 〃 〃
(43) 4C condensate booster pump
(44) Gland steam condenser
(45) Ejector steam condenser
(46) Main air extractor
(47) Starting air extractor
(48) Condensate demineralizer
(49) 4A condensate pump
(50) 4B 〃 〃
(51) 4C 〃 〃
(52) From demineralizing equip.
(53) Demineralized water tank
(54) 4A Demineralized water pump
(55) 4B 〃 〃 〃
(56) To condensate demineralizer
(57) Condenser
(58) Alternator
(59) LP II turbine
(60) LP I turbine
(61) MP turbine
(62) HP turbine

Fig. 1 **Basic flow diagram**

Rated output: 3,804 kW
Max. output: 4,540 kW
Revolution speed: 5,000～2,500 rpm
Steam pressure: Lower pressure steam 8.06 kg/cm²g (at rated operation)
High pressure steam 37.87 kg/cm²g (at rated operation)
Steam temperature: Low pressure steam 343°C (at rated operation)
High pressure steam 319.6°C (at rated operation)
Vacuum of exhaust: 720 mm Hg

5. Steam Condition

The steam condition of 169 kg/cm²g and 566/537°C are adopted in most case for conventional plants of 250 MW class.

However by adopting the steam temperature within allowable limit of ferrite steel, operation is become so much easier and by adopting higher steam pressure as higher efficiency is obtained also.

Therefore, in this plant the steam condition of 190 kg/cm²g 538/538°C is adopted. With the combination of a barrel type casing and a once-through mono-tube boiler, some problems based on the high pressure are coped and the performance of quick starting and quick response to load change is obtained.

6. Steam and Feed Water System

As shown in *Fig. 1* the turbine has 3½ cylinders and 8 extractions. The condensate, extracted by condensate pumps from condenser, passes the condensate demineralizer, the ejector steam condenser, gland steam condenser and condensate heat exchanger. And then it is boosted up by the condensate booster pump and led to the deaerator via four low pressure feed water heaters.

The deaerated condensate is pressurized with the boiler feed water pumps and fed as boiler feed water to the boiler through the three high pressure heaters (50% × 2 lines), with which the feed water temperature is raised up to 277.5°C at rated condition.

At normal operation the steams for deaeration is supplied from No. 4 extraction of the turbine, but at the load of lower than 50 MW it is supplied from No. 2 extraction (cold reheat steam) or auxiliary steam extracted from the boiler or the flush tank. Accordingly, the deaerator can be operated under the pressure kept above 1 kg/cm²g at the output below 50 MW and under the pressure according to the No. 4 extraction of the turbine above 50 MW.

At sudden load-change such as load-damping, the down speed of the deaerator pressure is limited to 0.2 at/min. for preventing the cavitation of the boiler feed water pumps with automatic change-over of steam supply from No. 4 extraction to auxiliary steam line.

The turbines for boiler feed water pumps have the control valves for the low pressure steam from the No. 4 extraction and control valves for the high pressure steam from No. 2 extraction—cold reheat (connected to the cold reheat of No. 3 unit too). At the load larger than 125 MW the feed water pump turbines are driven by the low pressure steam, but at the load lower than 125 MW the low pressure steam is not sufficient to drive the feed water pumps, and the control valves for the high pressure steam are automatically open.

In this case the feed water pump turbines are driven with both steam of No. 4 extraction and No. 2 extraction.

As a rule, this unit is started up by the motor driven feed water pump, but it can be started up by the turbine driven feed water pump with the cold reheat steam from No. 3 unit.

In this unit turbine bypass lines are provided from the main steam pipe to the flush tank and from the flush tank to the deaerator and the condenser, where the bypass steam is saved as drainage water or condensate in the case of starting up or abrupt load-change such as the load damping. The capacity ot the turbine bypass line is 20% of max. boiler capacity 875 t/h, that is determined by the quantity of the drainage and steam to be saved at starting up the unit.

7. Operating Characteristics

In recent years, share of thermal power plant included nuclear power have been occupying so much percentage to total electric power generation, and nuclear power stations are operated as base load power station and load fluctuation is absorbed by the conventional thermal power generating facilities. Therefore, middle load thermal power plants have been needed in place of base load thermal power plants. This unit is provided with sufficient characteristics needed for the middle load thermal power plant, i.e. can respond to quick start, rapid load change and frequent start and stop.

The starting curves of the unit are shown in *Fig. 2* and *Fig. 3*.

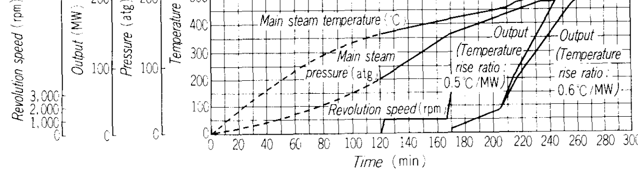
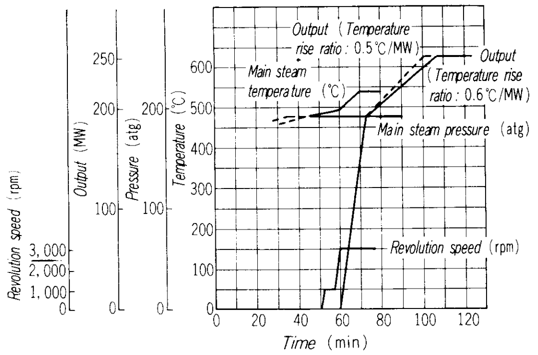


Fig. 2 Starting curve (Cold start)



At 8 hours after stop, turbine casing temperature: Ca. 400°C

Fig. 3 Starting curve (Hot start)

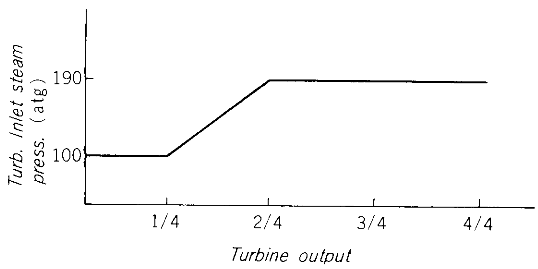


Fig. 4 Load-pressure curve at sliding pressure operation

8. Sliding Pressure Operation

This unit is designed as a constant pressure unit and then can not be operated as same as a sliding pressure unit coupled to a Benson Boiler.

But it can be operated under such sliding pressure as follows:

As shown in *Fig. 4*, it is operated under the constant pressure operation at the load larger than 2/4 load and under the sliding pressure at the pressure of 190∼100 atg in proportion to the load in the range of 2/4∼1/4 of the rated load.

In the sliding pressure operation the main steam temperature and reheat steam temperature are able to be kept at higher temperature than at the constant pressure operation. (In case of 50 MW, the steam temperature 480/472°C of the constant pressure operation corresponds to 525/504°C of the sliding pressure operation) and the driving power for the feed water pump decrease. In case of 50 MW, a plant thermal efficiendy is improved by 3%.

9. No Load and Auxiliary Load Operation

Generally, it is very difficult to operate continuously the large capacity turbine and boiler at no load.

This unit is able to be operated continuously at no load and, of course, at the load of the auxiliary machines.

When the generator is disconnected from the electric net work by opening the main circuit breaker due to some trouble in the net work, this unit is operated at the load of the auxiliary machines. At the boiler unnecessary burners are cut off and the boiler output is rapidly decreased to the load corresponding to auxiliary machines and the feed water flow is controlled and kept at the limited value by automatic start of the boiler recirculating pump.

The turbo-set is operated and controlled at the

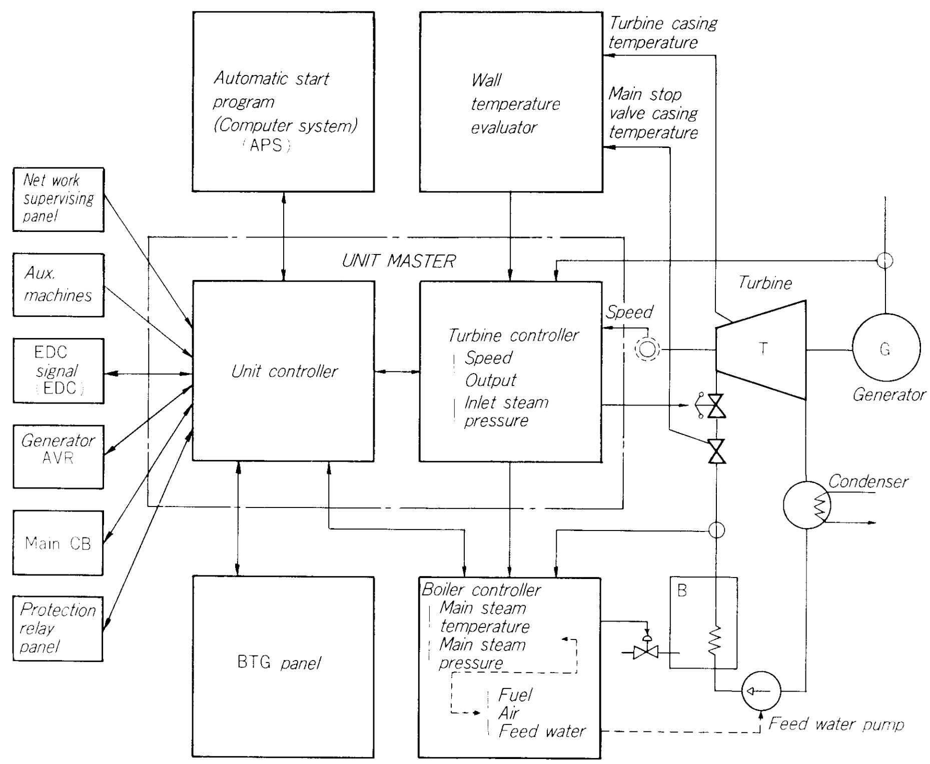


Fig. 5
Constitution of control system

Table 1 **Function of unit master and W.T. evaluator**

Equipment		Function
Unit control part	1. Control mode	(1) CONV (Manual select) (2) APC (〃 〃) (3) Turbine tracking (aut. change) (4) Boiler tracking (aut. change)
	2. Operation mode	(1) Hold (2) ATSC (3) Computer (4) Output setting in unit (5) Output setting by EDC signal from central dispatch power controller
	3. Setting of Rev.	(1) Manual at BTG Panel (2) APS (Computer)
	4. Aut. synchronize (ASS)	(1) Aut. voltage matching (2) Aut. speed matching (3) Aut. detect of sycnhronizing
	5. Setting of output	(1) Manual setting at BTG panel (2) Setting by computer (3) Setting by EDC signal (4) Load track-run back control
	6. Setting of gradient	(1) Revolution speed change rate (2) Output change rate
	7. Limit of output	(1) By no. of operating aux. machines (2) Quick output decrease at aux. machines trip
	8. Aut. output change	(1) Increase by net work condition (2) Decrease by net work condition
	9. Local AFC	(1) AFC at local net work
	10. Interface	(1) To BTG panel operators console (2) To protection relay (3) To boiler control system (4) To APS computer (5) To EDC signal
Wall temp. eval.	1. Monitoring	(1) Allowable thermal stress (2) Allowable output variation
	2. Control	(1) Control of revolution and output variation
Electric-hydraulic governor part	1. Connection of E-part & H-part	(1) Lower select connection with E-H converter
	2. Revolution control	(1) Setting within allowable gradient (2) Revolution control
	3. Output control	(1) Setting within allowable gradient (2) Output control
	4. Pressure control	(1) Limited pressure control (2) Fore pressure control
	5. Droop characteristics	(1) Stabilize of power system frequency (2) Local AFC

load corresponding to the auxiliary machines. The surplus steam, remained transiently in case of sudden load change such as load damping, is led to the condenser through the motor driven drain valves provided at the main steam piping, the flush tank and the spill over valves. (A part of steam is led to the deaerator).

By this control and operation the unit is operated at the auxiliary load, and can be synchronized, parallel-operated and increased with its load immediately after the trouble in net work has been removed.

II. FUNCTION AND CONSTITUTION OF UNIT MASTER

1. Constitution of Control System and Function of Unit Master

The control system is shown in *Fig. 5*, where Unit Master is located at the center of the system.

In *Fig. 5* the part consisting of unit control and turbine control is named "Unit Master".

The function of Unit Master and "Wall Temperature Evaluator" is indicated in *Table 1*.

The Wall Temperature Evaluator is one of the

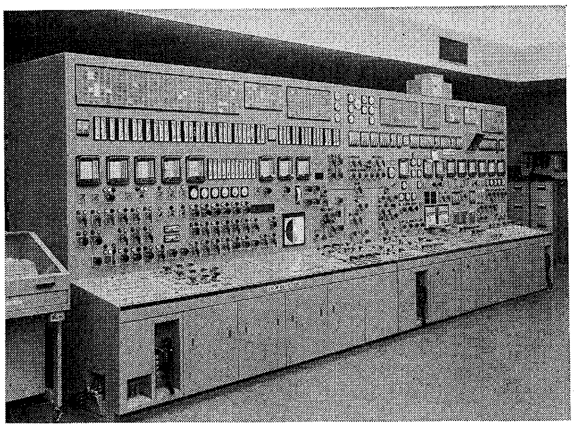


Fig. 6 Exterior view of BTG panel

special features of the control system, and is in close connection with Unit Master.

The outline of this control system is clear from *Fig. 5* and *Table 1.*

The unit control part performs totalized control of the unit, and the turbine control part controls the revolution speed and the output of the turbine.

Therefore the turbine control part is named electric-hydraulic governor too, and is provided with miscellaneous devices for safe operation of the turbine.

The Wall Temperature Evaluator calculates and indicates an allowable thermal stress and an allowable range of revolution and load variation at the indicator as a guide of operation, and limits a range and a gradient of variation of turbine revolution speed and output.

Fig. 6 is the exterior view of the BTG control panel, and *Fig. 7* is the exterior view of the console of Unit Master, and the indicator of Wall Temperature Evaluator.

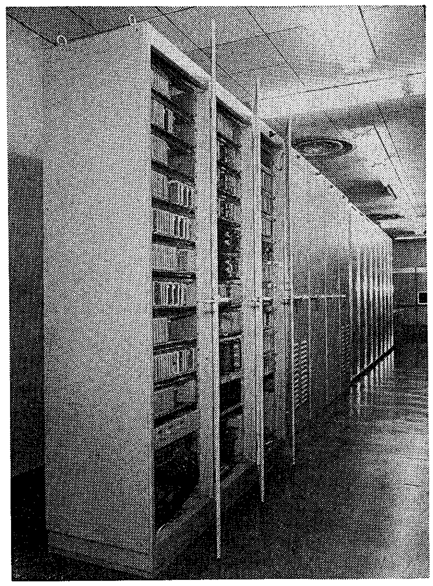
2. Control Mode of Unit

The control system of the boiler and turbine has two control modes. One of them is a setting value tracking mode, in which the setting value of output is tracking to EDC signal from the control despatching power control office or to a setting value of a manual output setter of Unit Master that is settled from the operator's console on the BTG panel by an operator.

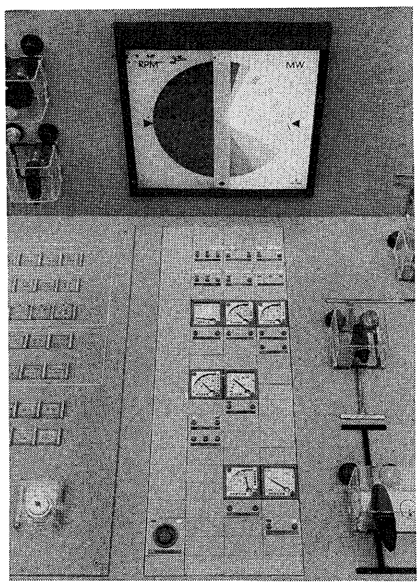
The other is a load tracking mode, in which the setting value of output is tracking to the generator output.

The former is further classified to two categories: the conventional control (CONV) and the automatic power control (APC). Further the latter is classified to two categories: the boiler tracking control and the turbine tracking control.

The response time of the boiler system is longer than that of the turbine system, and then the control of the two systems is coordinated through the main steam pressure. For the coordination the



Control cubicle



Operator's console
(Upper indicator is for Wall Temp. Eval.)

Fig. 7 Exterior view of unit master

limited pressure control or the fore pressure control is adopted.

At the limited pressure control an increase of turbine output is temporarily limited when the main steam pressure goes down to a setting value, for the boiler output can not quickly respond to it.

At the fore pressure control the turbine output is controlled to hold the steam pressure of the turbine inlet at the rated value by the turbine inlet pressure controller. In case of a load variation a disturbance to boiler is able to be smaller at the fore pressure control than at the limited pressure control. And it has also an allowable small range of the pressure variation, which is a dead band of the controller to attain a better control result.

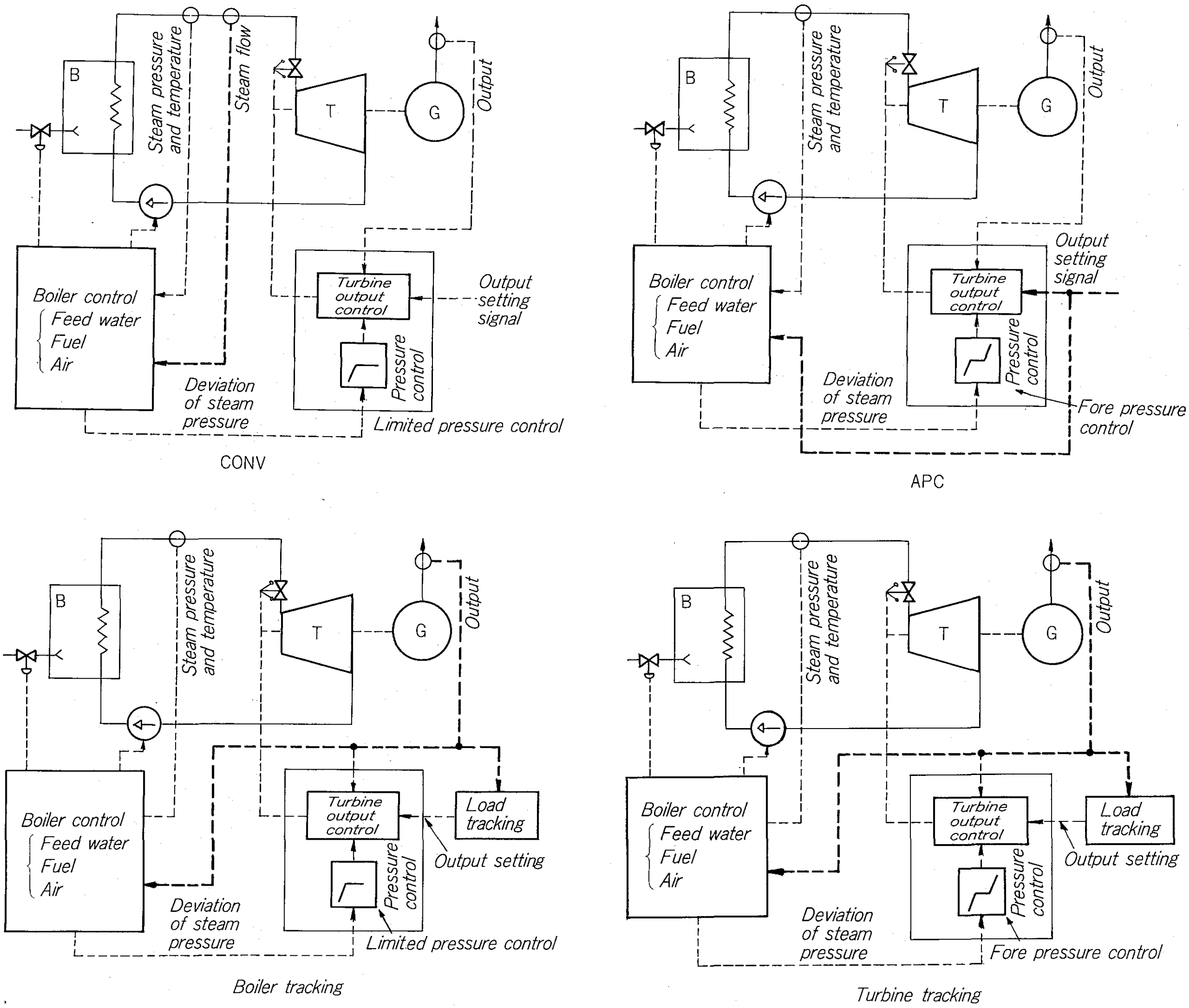


Fig. 8 **Control mode of unit master**

The schematic diagrams of the above mentioned control modes are shown in *Fig. 8*.

One difference between APC and CONV is that APC takes the load setting value for the boiler control system (Master signal of boiler control) from the setting value of Unit Master, whereas CONV uses the main steam flow as the master signal of the boiler controller.

Even in case of APC mode the boiler control system controls also the main steam pressure, in the same way as CONV mode, for the stability of the overall control system. Accordingly, the pressure controller of the turbine side shall be provided with a dead band to prevent both control systems from interfering each other two pressure control systems. (for example, for a slight error of the pressure setting values). Here, the dead band is effectively used to utilize the stored energy of the boiler and improves the fringe response of the unit.

3. Measures for Reliability

Unit Master is the center of the unit control and unit operation, and therefore the extremely high reliability is required.

To obtain the high reliability, not only the solid state (contactless) circuit and the control technique with electronics are fully used, achieving a sufficient aging, but also the following measures are adopted:

(1) Multiplication of the Electric Source and Interlocking with other Control

The electric source to Unit Master is dually supplied from the DC/AC inverter and the electric source for control equipments, and moreover in Unit Master the two electric source units are also provided in order to continue the operation of the plant even if one of electric source units are out of order.

To assure safety operation even in case of loss of electric sources, the Unit Master and the boiler control system are interlocked each other.

(2) Duplication of detector

The all detector or converter such as the output (Watt) detector, the position detector of the E-H converter and the revolution speed detector are duplicated, and the plant can be continued to operate in case that one of duplicated devices is out of

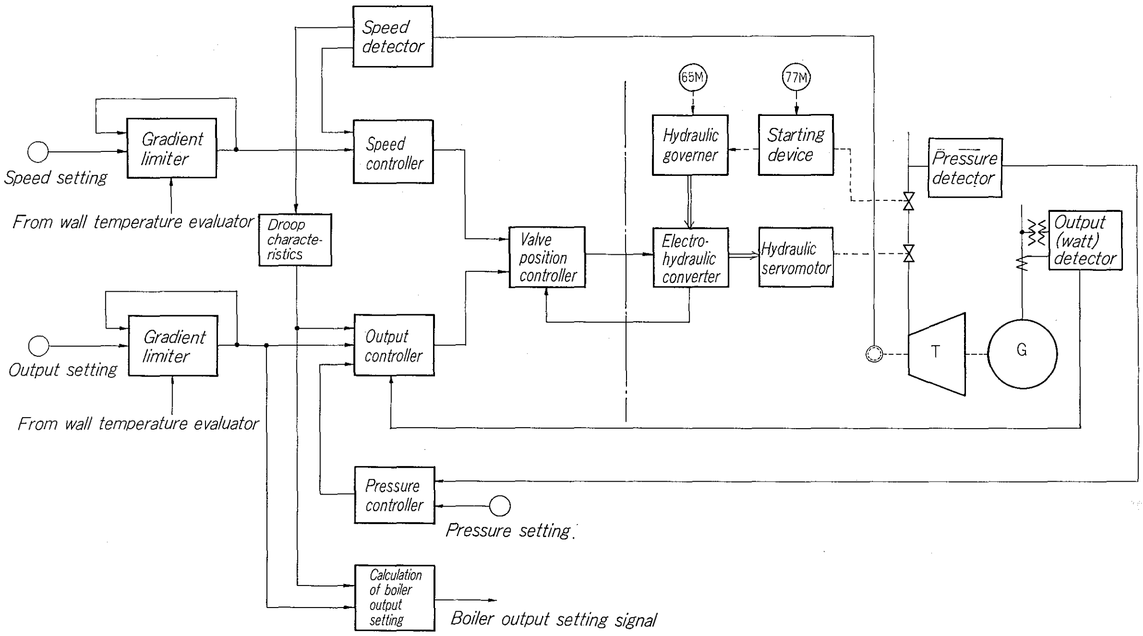


Fig. 9 **Electric-hydraulic governor**

order.

The output signals of the two detectors or converters are always compared each other and when a difference of the two signals is detected, a fault is announced to operators.

(3) Limitation of output signal of controller

Each controller is provided with the output signal limiter, and it is limited to a reasonable range to make the disturbance of the unit operation as small as possible when a controller is out of order.

(4) Consideration as a control system

When a part of the unit such as the auxiliary machines of boiler and turbine or electric network is out of order, it is expected to continue the operation of the unit by means of the load tracking control, the quick output decreasing control in case of tripping the auxiliary machines, the local AFC, etc.

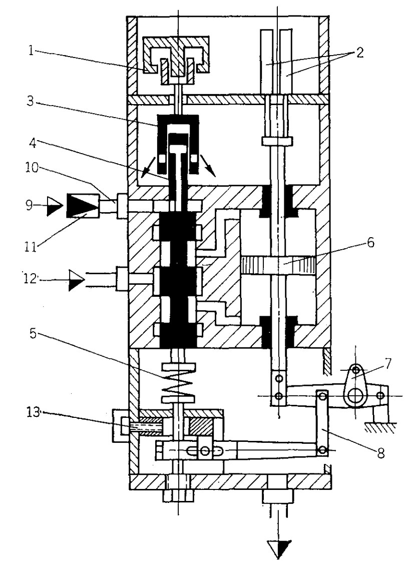
Moreover, the automatic output control for stabilizing of electric network and Wall Temperature Evaluator for preventing the turbine from a large thermal stress are provided.

III. ELECTRIC-HYDRAULIC GOVERNOR

The electric-hydraulic governor has the functions listed up at *Table 1* and its block diagram of function is shown in *Fig. 9*.

The electric-hydraulic converter in *Fig. 9* transmits a signal from the electric part to the hydraulic part. The E–H Governor is featured by this E–H converter.

As shown the principle of E–H converter in *Fig. 10*, the electric governor and hydraulic governor act always independently, and the control valves respond to a lower level signal of two, which are transmited by the electric governor and the hydraulic governor.



1. Solenoid mechanism
2. Differential transformer
3. Control sleeve
4. Pilot valve
5. Spring
6. Servo piston
7. Lever for operating the follower piston
8. Feedback mechanism
9. Secondary oil pressure
10. Hydraulic pressure after having been throttled
11. Throttle
12. Pressure oil
13. Speed regulation setting device

Fig. 10 **Electric-hydraulic converter**

In *Fig. 10*, the secondary oil pressure oil "9" which is proportional to the valve opening signal from the hydraulic governor, is blown off through the throttle "11", from slit between control sleeve

"3" and pilot valve "4".

Accordingly the pressure on the pilot valve 4 is set by the position of the control sleeve 3 which is controlled with an electric current of the solenoid mechanism 1.

The pressure on the pilot valve 4 is not able to increase higher than the secondary oil pressure from the hydroulic governor in any case. In case of a high secondary oil pressure the slit of the control sleeve 3 and the pilot valve 4 is made open by the solenoid mechanism and the pressure on the pilot valve 4 is limited.

It is possible to limit the pressure on pilot valve 4 by the output current of the valve position controller, and to give priority to the signal from the valve position controller of the E-H converter. It is very simple and easy to change over the control from the electric governor to the hydraulic governor or vice versa.

The pilot valve 4 moves the servo piston 6 by oil pressure, but the position of the servo piston 6 is fed back to the pilot valve 4 through the feedback mechanism 8 and the spring 5. Therefore, the displacement of the servo piston 6 is proportional to the change of the secondary oil pressure 9, and the proportional coefficient of this mechanism is equal to the speed regulation of the hydraulic governor which is able to be set by the speed regulation setting device 13.

The servo piston 6 is connected to the hydraulic servo motor mechanism (follower piston) of the steam control valves with the Lever "7", and can control steam flow into the turbine.

Fig. 11 shows the speed setting circuit.

The speed setting device is operated by a motor controlled manually from the operators console of BTG panel or automatically from a signal of the ATS program in the computer.

But the speed setting signal is, through the speed change rate (gradient) limiting circuit, transmited to the speed controller to prevent the turbine from a large thermal stress. The gradient limiting circuit consists of DC amplifiers and integration circuit and the gradient is set by limiting an input signal to the integration circuit.

The maximum gradient is set by the limiter of amplifier A_1, and the output signal of A_1 is limited by a signal that is fed from the Wall Temperature Evaluator, corresponding to the allowable thermal stress of the turbine.

The speed setting circuit is connected to the automatic synchronizing circuit, and can be adjusted by max. $\pm 5\%$.

It is one of the features that the speed setting device is not operated, for synchronizing purpose, but another speed adjusting circuit is provided only. The speed setting device is always set at 3,000 rpm, and at synchronizing the speed is adjusted only supplementally by the speed adjusting circuit. After synchronizing the automatic synchronizing circuit is disconnected, and the turbine speed is able to be surely kept at rated speed even when the load is damped and the turbine is operated at the house load or the no load.

The adjustable range of the automatic synchronizing circuit is limited to $\pm 5\%$ so that a danger-

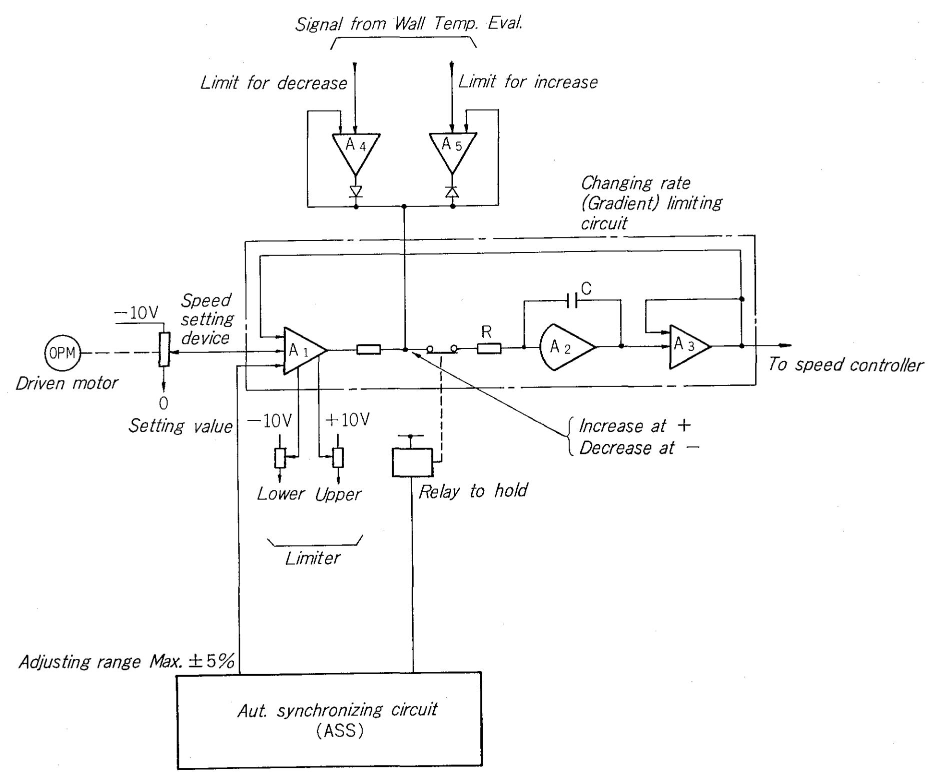


Fig. 11 Speed setting circuit

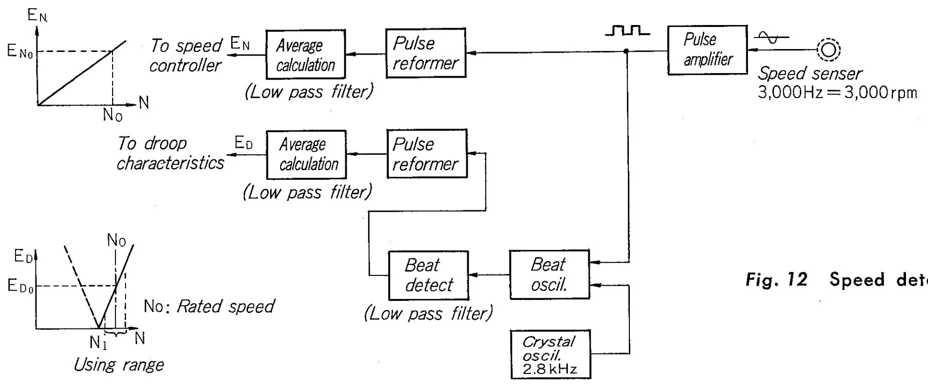


Fig. 12 Speed detecting circuit

ous speed rise can be prevented even in case of a trouble in the circuit.

The output change rate (gradient) limiting circuit (if the output) is almost same as the circuit of the speed limiting, but the maximum gradient limiter of the output can be set from the operators console of BTG panel.

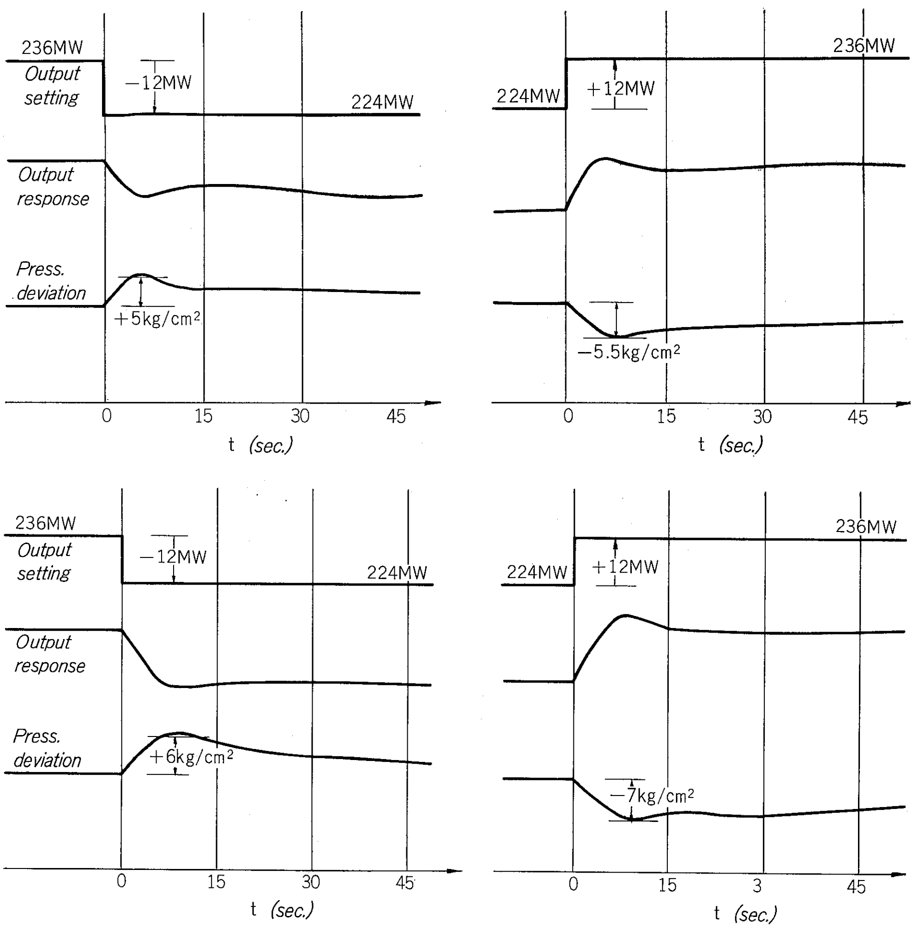
Fig. 12 is a block diagram of the speed detecting circuit. In this circuit the speed can be very accurately measured using a beat signal composed of the signal of the revolution speed and that of a crystal oscillator, and it is used for the droop characteristic circuit of the governor as well as the speed adjusting device. The rated speed is N_0, the voltage corresponding to N_0 is E_{D0}, the speed corresponding to the crystal oscillator frequency is N_1 and the signal voltage of detector corresponding to the speed $N(>N_1)$ is E_D:

$$N=\frac{E_D}{E_{D0}}(N_0-N_1)+N_1 \qquad \text{..............(1)}$$

If an error ε is included in E_D, the error of the measuring speed is:

$$\varDelta N=\frac{\varepsilon}{E_{D0}}(N_0-N_1) \qquad \text{..............(2)}$$

Accordingly, a error to N_0 is



(a) APC (Fore press. cont.)

(b) CDNV (Limited press. cont.)

Fig. 13 Step response of unit master

$$\frac{\Delta N}{N_0}=\frac{\varepsilon}{E_{D0}}\times\frac{N_0-N_1}{N_0} \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

ε/E_{D0} is an error of the detecting device itself. In this equipment N_1 is 2,800 rpm, resulting in $(N_0-N_1)/N_0=1/15$, and then the relative error is reduced to 1/15. For example, if the droop characteristics (speed regulation) of unit master is 5% and the error of the speed detecting circuit is 1%, the error of output is 20%. Therefore, extremely high accuracy is required for detecting the speed for droop characteristics.

In case of $\varepsilon=0.5\%$, $N/N_0=0.033\%$ and a sufficient accuracy is able to be expected by using of this equipment.

The pressure controller in *Fig. 9* can performs the limited pressure control as well as fore pressure control, and both of which can be selected from the unit master.

Fig. 13 shows the test results of the step responce for the unit. In *Fig. 13* the dead band of the pressure controller at APC mode (fore pressure control) is ± 5 kg/cm²g and the pressure deviation is kept within ± 5 kg/cm²g, but it is shown that the output response delays slightly. One more feature of Unit Master is, that the speed controller is always connected to the control system and able to control and suppress a speed rise of turbine at any time for example in case of damping load.

To keep the output control system out of unnecessary disturbance by a slight frequency variation, a limiter is provided at the output of the speed controller. The speed setting valve of speed controller is biased by about 2% when the main circuit breaker is switched on and connects to the net works, to make the output signal of the speed controller saturated at the normal operating condition.

Fig. 14 shows an oscillogram of load damping from 100% load to house load operation.

IV. TURBINE WALL TEMPERATURE EVALUATOR

The temperatures of an inner surface and that of a middle part at the main stop valve casing and the turbine HP casing, are detected, and a thermal stress is calculated from the temperature difference

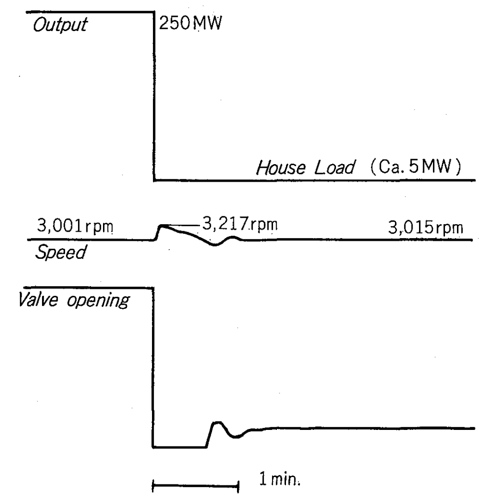


Fig. 14 Response of 100% load damping to house load

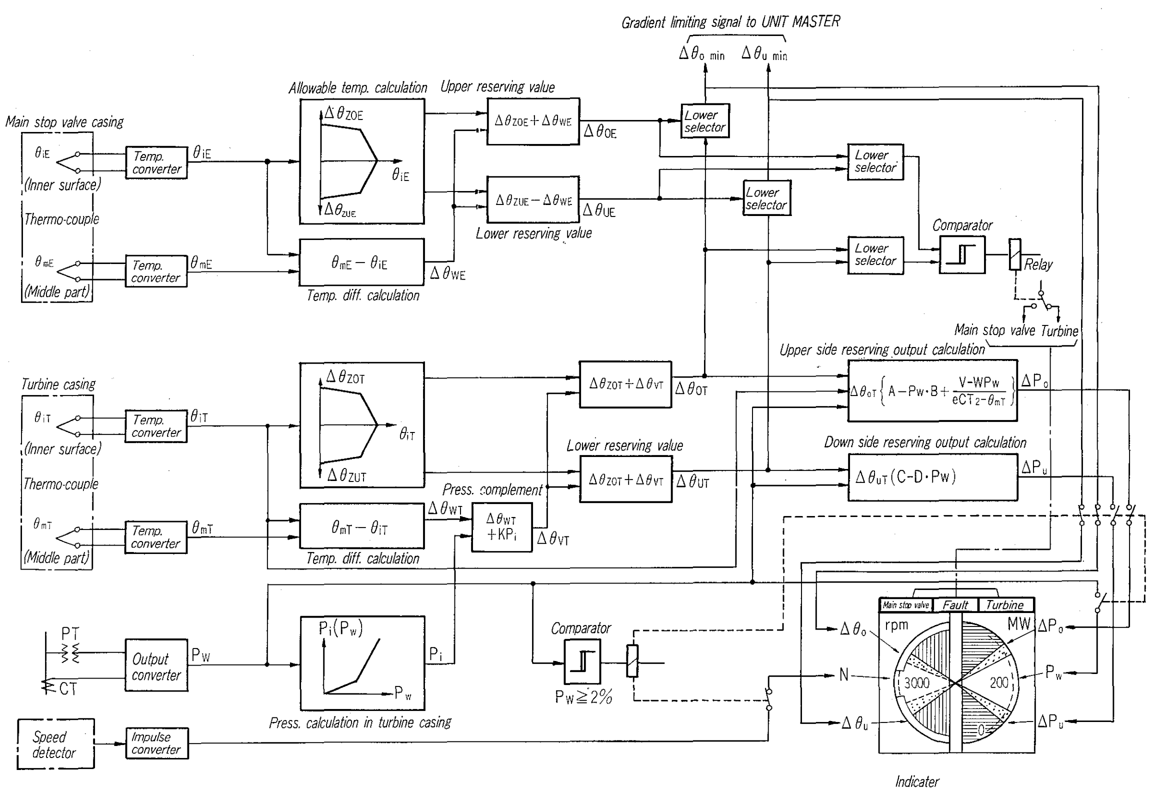


Fig. 15 Schematic diagram of wall temperature evaluator

of the inner surface and middle part, and the allowable thermal stress is calculated from the temperature of the inner surface corresponding to each casing.

The thermal stress is compared with the allowable thermal stress, and in accordance with its difference the allowable speed change rate and output change rate are automatically determined. The speed and a reserving stress to the allowable value is indicated at the indicator of Wall Temperature Evaluator in case of accelerating the turbine, and after connection to a network the output and the reserving value of output change rate is indicated at the indicator as a guide of operation.

The turbine of this unit is heat-soaked at 1,000 rpm, and accelerated quickly from 1,000 rpm to rated speed 3,000 rpm. At heat-soaking a reserving stress to the allowable value is checked to be larger than 10 kg/cm^2, and the signal (larger than 10 kg/cm^2) is transmitted to APS program for passing the critical speed of the rotor as soon as possible.

Fig. 15 is a schematic diagram of Wall Temperature Evaluator which consists of analogue calculating elements, including addition, substruction, multiplication and division.

As mentioned above the allowable temperature difference (allowable stress) is calculated from the temperature of the inner surface of the casing with arithmetic function generators, and the reserving temperature to allowable value i.e. the reserving stress to allowable value (upper side and lower side) is calculated from the temperature difference.

At the main stop valve the steam pressure is considered constant i.e. the rated pressure, but at the turbine casing the steam pressure in the casing changes according to the turbine output so that the allowable stress of the turbine casing is corrected by pressure, which is related to the turbine output. The lower reserving value of the main stop valve and the turbine casing is selected as the signal transmitted to Unit Master.

At the lower output than 2% the indicator shows the speed and the allowable stress and at larger than 2% indicates the output and the allowable limit of output change.

Accordingly the left half of the indicator is used at starting up and the right half is used at the normal loading operation, and it is illuminated to show which half is used.

Those values are indicated with the semitransparent moving scale plates coloured with light red and red. The light red part shows a warning zone and the red part shows too much thermal stress, which send out an alarming signal.

At any time the reserving stress value of the valve or the turbine is able to be indicated at the indicator by pushing the push button switch and when the checked reserving value is larger than others, a flickering lamp informes that other reserving values are smaller.

The evaluator is provided with a testing circuit, and at any time it can be tested during the turbine operation by a push button. In case of pushing the button the indicator is designed to indicate a predetermined value at all times in the event the evaluator is in order.

V. UNIT CONTROL PART

The unit control part has the functions listed *Table 1*, of which the major functions are explained as follows:

1. Change of Operating Mode

The operating modes can be selected with the push button switches on the operator's console of BTG panel.

(1) Hold

At this mode the turbine speed or output is held at the state as it is. For example as shown in *Fig. 11* the input signal to the integration circuit is switched off with relay. This mode is selected manually or automatically, and the automatic selection is set at any abnormal condition to watch temporarily a state of the unit for future necessary actions, or to stabilize the operation of the unit in case of changing-over some circuits.

(2) ATSC

ATSC is an abbreviation of Automatic Turbine Speed Control and used at start-up without using APS program stored in the computer.

(3) Computer

All start-up procedure, accelerating and loading the turbine is carried out in accordance with APS program. Setting the various value of Unit Master, putting in operation the automatic synchronizing device and other operations are proceeded by the signals from the computer.

(4) Output setting at Unit

The output of the unit is set at the operators console of BTG panel.

At changing over from EDC signal to the output setting at unit the setting value of the Unit Master is matched to the turbine output and then the operating mode is able to be changed without bumping. When the main circuit breaker has been switched on after starting up with ATSC, or a turbine output has reached the setting value after starting up with APS program, the unit is automatically operated with this mode.

(5) Control by EDC signal

The output of the unit is controlled by EDC signal from the central dispatch power control office.

2. Load Tracking Control

At the load tracking control the unit is controlled and operated according to own output. The setting value of unit output is tracking to its own

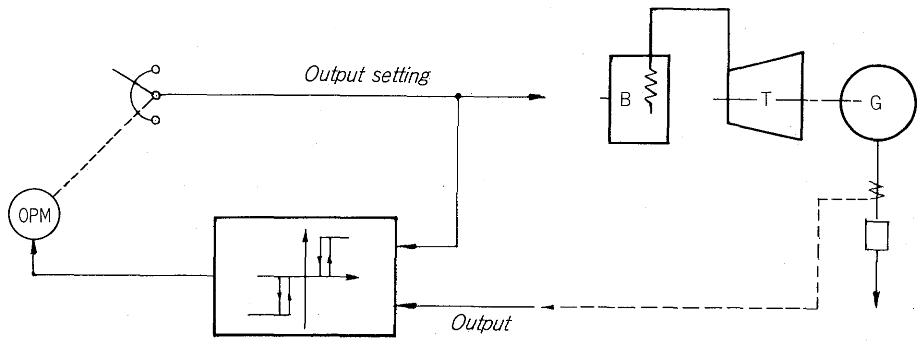


Fig. 16 Load tracking control

output, and a positive feed back control circuit is formed.

To obtain a stable operation in spite of the positive feed back a dead band as shown in *Fig. 16* is provided.

Residual off-set of the outputs is compensated by the pressure control or the droop characteristics. The load tracking control has two modes, the boiler tracking mode and the turbine tracking mode. At the boiler tracking mode the setting value of the boiler output tracks the turbine output aud the boiler output is controlled to match the turbine output which is fixed and uncontrollable due to some trouble. The turbine tracking mode is opposite mode to the boiler tracking mode. In uncontrollable case of the boiler or the turbine the positive feed back loop mentioned above is not active, but the dead band as shown in *Fig. 16* is necessary to stabilize the operation with the positive feed back circuit, of which function revives as soon as the trouble is cleared.

3. Output Limit in Case of Tripping out Auxiliary Machines

Fig. 17 shows a output limiting circuit by the number of operating auxiliary machines.

A maximum allowable output of the unit is calculated from the number of operating auxiliary machines and the setting value of output is limitted by the maximum allowable value. In case of any auxiliary machine being tripped out during operation of the unit, the output of the unit must be quickly reduced down to a balance point.

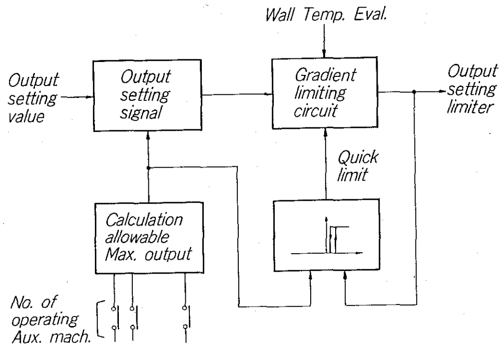


Fig. 17 Output limit

In *Fig. 17*, when the maximum allowable output is smaller than the setting value of output, the time constant for integration of the output change rate limiting circuit is automatically shortened, and the output will be quickly reduced to the limited value. *Fig. 18* is a record in case of one fuel oil pump being tripped out.

4. Local AFC

Local AFC is used when the power network is in trouble and the unit must be operated according to the local load and keep the frequency of the local network at the rated value.

At local AFC the droop characteristics and the load tracking control are used at same time. In *Fig 19* 1–1′ and 2–2′ indicate the droop characteristics.

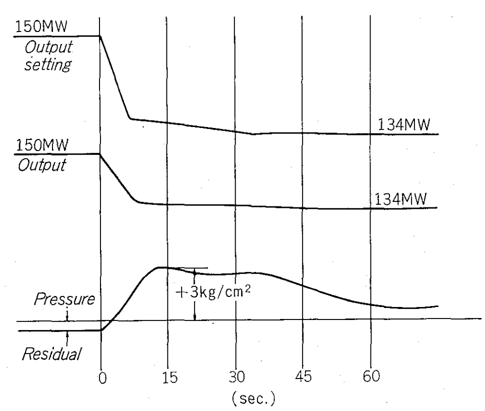


Fig. 18 Output limit at aux. mach. trip.

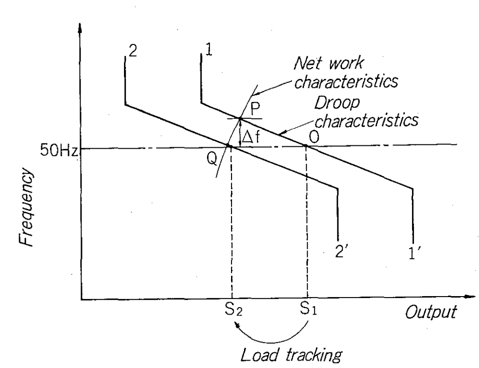


Fig. 19 Local AFC

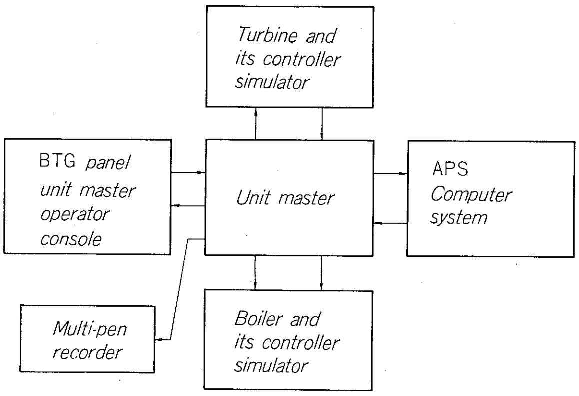


Fig. 20 Test of unit master and the simulator

Assuming that both the setting value and the actual value of output are S_1, and the unit is operated at the point O, the operating point is shifted to the point P in accordance with the droop characteristics 1–1′ and the frequency deviation becomes Δf, when the load of net work decreases. The load tracking control removes the output setting value from S_1 to S_2 and the droop characteristic is also shifted to 2–2′.

A new operating point is accordingly removed from point P to point Q and the frequency deviation Δf is made almost zero.

POSTSCRIPT

In this paper the composition, the functions and the features of Unit Master are introduced as a control system.

Unit Master is provided with not only many control loops, but also very close connection with the boiler control system, APS program and other so many control systems.

For the shop tests, the site test before unit operation, the confirmation of interface with other control systems and a test of the dynamic characteristics for overall system of UNIT MASTER, a simulator of the boiler and the turbine control systems as shown in *Fig. 20* was used.

By using Unit Master and this simulator, various closed loop tests were able to be proceeded without the boiler and the turbine, and moreover the site tests of the boiler, the turbine and the allover unit were very effectively excecuted in short time.