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MEASUREMENT AND AUTOMATIC CONTROL SYSTEM FOR BOILER

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I. PREFACE

Fuji Electric, in 1931, beginning with the three sets of automatic control and measurement systems for stoker fire boilers at Maeda power station, Chugoku Electric Power Co., Inc., has supplied measurement and automatic control systems for close to 600 boilers including those now under production, gaining the trust of a wide range of customers, and meeting with their expectations.

Looking back over these past years the transition of measurement and automatic control systems supplied by Fuji Electric is astonishing.

A total of six sets have been supplied as measurement and automatic control systems for the central power station boiler at the Chiba Iron and Steel Works of Kawasaki Steel Corporation.

These can be called the latest type of instruments from the point of view of the planning period.

Measurement and automatic control systems have also been supplied for the No. 7 boiler.

This summary introduces the new TELEPERM and TELEPNEU instruments designed to display a high sensitivity, a high reliability, and easy handling.

II. BOILER SUMMARY

The outline of the boiler under observation is as follows.

1) Boiler type: Mitsubishi Sectional Drum Boiler. (Type: CE-VU-50 outdoor type)
2) Quantity of steam produced:
   Maximum continuous load: 110 tons/hour
   Normal load: 100 tons/hour
3) Steam Pressure:
   At superheater outlet: 43 kg/cm^2
4) Steam temperature:
   At superheater outlet: 445°C
5) Fuel and combustion system:
   C heavy oil, B gas, C gas, C heavy oil (return burner) and only fire of B gas
   C heavy oil, B gas, C gas (base load fire) mixed fire
6) Ventilation system: Balanced ventilation
7) Main load: Blower turbine

III. SUMMARY OF MEASUREMENT AND CONTROL INSTRUMENTS

A list of measurement and control instruments which have been designed are given in *Table 1.*

Measurement and control instruments for No. 5 and No. 6 boilers have been supplied, and are now operating satisfactorily.

The new TELEPERM and TELEPNEU instruments designed for No. 7 boiler, compared with the Q series instruments, have the following special features.

1) A two-wire dc uniform signal (10∼50 ma) transmission system has been adopted.
2) The degree of interchangeability of the units for use in the TELEPERM and TELEPNEU instruments, and other instruments of the same system is very extensive.
3) The functions of the computing instruments for the TELEPERM are increased.
4) Ease of handling, maintenance, and inspection plus the performance and function of the instruments have been increased.

The new TELEPERM and TELEPNEU instruments, according to their characteriitics indicate the real value of the price of instrumentation of boilers above medium capacity.

IV. BOILER AUTOMATIC CONTROL SYSTEM

The control system is a dc two-wire transmission system from the detection position to the vicinity of the operating position. It drives the operating end at atmospheric pressure, and the control signal changes the electrical operation to pneumatic in that position. The block diagram of instrumentation for No. 7 boiler is given in *Fig. 1.*

Hereafter, the outline of the instrumentation and classification of each control block is related to *Fig. 1.*

1. Master Control System

The master control system controls the quantity of heat input of the boiler, so that the balance of the heat in the boiler is always uniform for any load. This is indicated by the block diagram shown in *Fig. 2.*

Table 1 **Measurement Points and Control Instruments**

Instrument		Total	Remarks
Detection Point	Temperature	19 points	
	Pressure	10 points	
	Draft	12 points	
	Flow	15 points	
	Level	4 points	
	O_2 gas	1 point	
	PH	2 points	
	Conductivity	2 points	
Supervising Instrument	Indicator	6 units	
	Indicator alarm	6 units	
	Recorder (self-balance)	5 units	Four large types, one S-series
	Recorder (moving coil)	10 units	Including one unit each installed in power center
	Adder	7 units	
	Alarm indicator	38 units	
	Operation indicator	34 units	
Controller	Normal type C-controller	9 units	
	Divided type C-controller	5 units	
	Normal type S-controller	1 unit	
	Load controller	2 units	
	Setting operator	5 units	
	Manual operator	4 units	
	Computing instrument	17 units	
	Diaphragm regulator valve	9 units	
	Operating cylinder	11 units	
	Three way solenoid valve	8 units	
	Diaphragm motor	1 unit	
Control Panel	Vertical control panel	2 units: Width 1000 mm; 1 unit: Width 800 mm; Height 2300 mm +500 mm; Depth 1500 mm; Channel base: 50 mm	

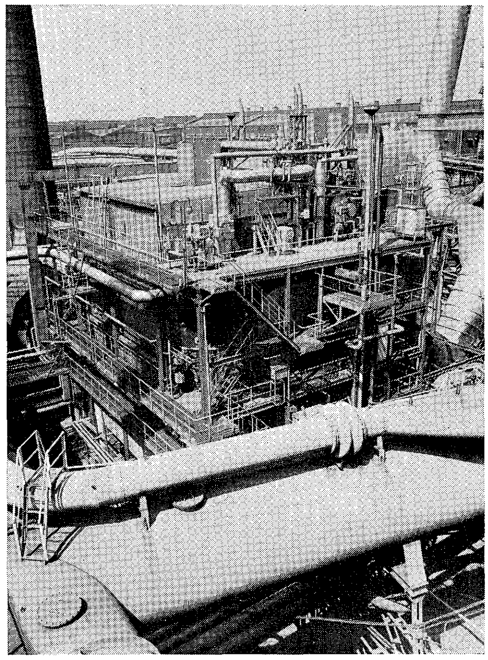


Fig. 1 External view of No. 7 boiler

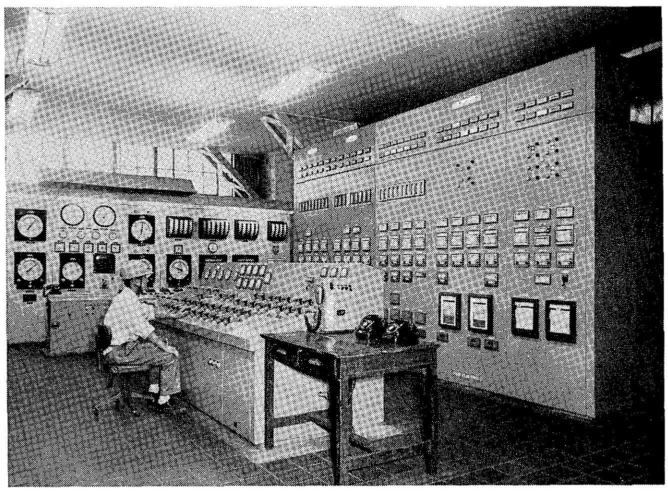


Fig. 2 Automatic control system for No. 7 boiler

The master control system has been designed, firstly, so that the balance of the quantity of heat in the boiler can be maintained, by supplying fuel (heavy oil and B gas) corresponding to the boiler load demanded from the conditions of the boiler design; and secondly, the set point of the control system indicated in the following section changes, with the control signal of the main steam pressure regulator (S-ECC-N) due to the modification of the opening function of the fuel control valve.

The total calories $E - IOA - [A_1 I_6 + A_2 I_7 + A_3 I_8]$ of the computing instrument output is 50 ma for the number of calories corresponding to 120 tons/hour of the amount of steam produced during the simple combustion of gas. For this reason, the principal approach is often B gas combustion in the plant heating control. Next, when two or more kinds of fuel aremixed, if the control system has been adjusted for fuel with the highest control gain, hunting in the control system does not occur, due to the gain of the other fuel overshooting during combustion. However, in the case of a high control gain ratio (depending on the plant characteristics) it cannot be said that every thing is all right, just because there is no hunting; therefore, it is necessary to reconsider the control system so that optimum control is possible.

The required calorie difference of the B gas, and heavy oil during MCR in the present No. 7 Boiler is about 8%. The fuel quantity and load steam of the boiler design conditions are shown in *Fig. 3*, and

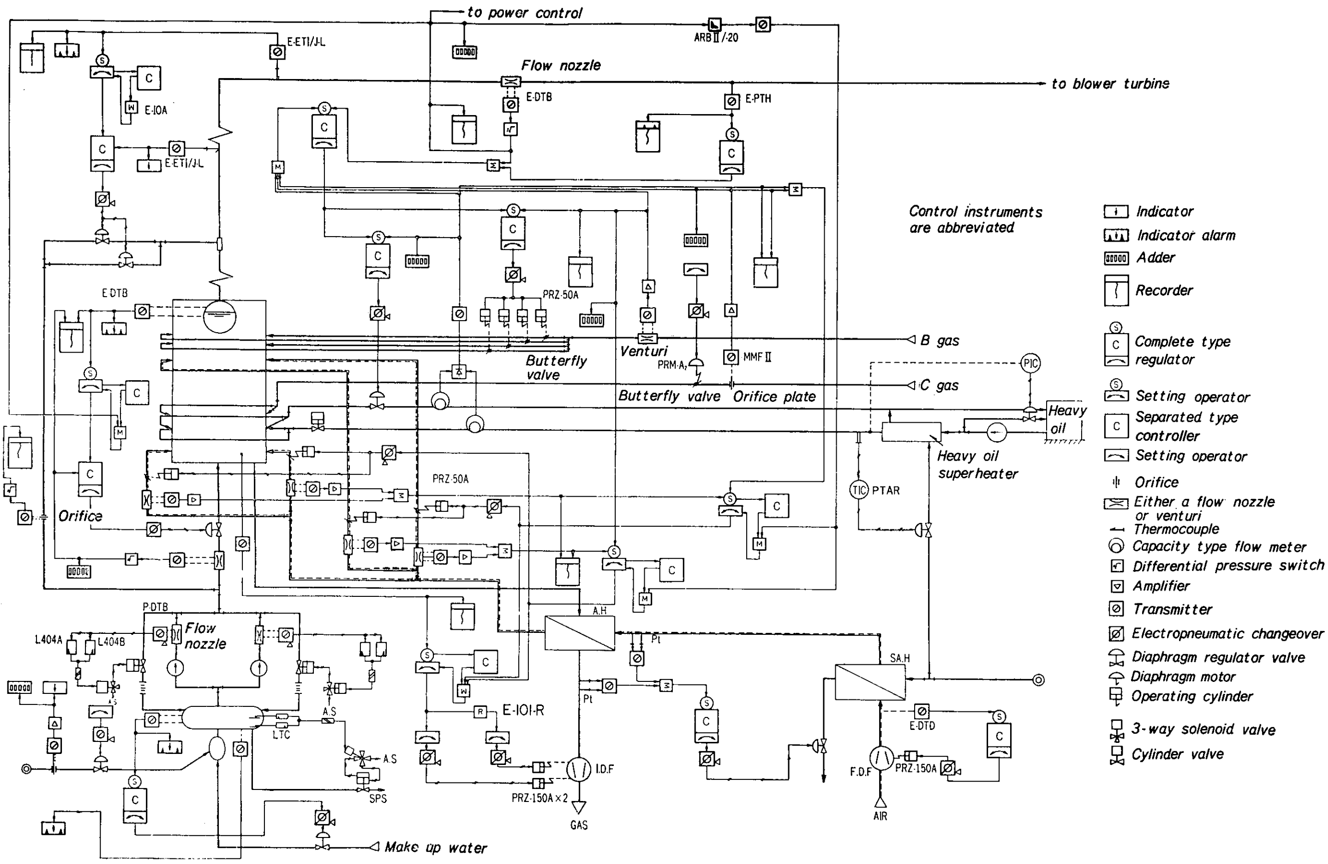


Fig. 3 Block diagram of No. 7 boiler instruments

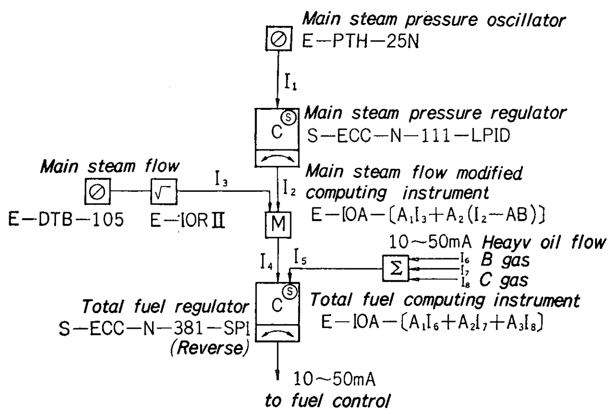


Fig. 4 Block diagram of master control system

the computing characteristics of $E-IOA$ are indicated by *Figs. 4* and *5*.

The total characteristics of the master control system are shown by *Fig. 6*. The S-ECC-N total fuel regulator has been taken into account so that set point base load operation, when this boiler is considered as one unit of the central generating station boiler plant, can be carried out.

2. Fuel Control System

This control system is indicated in *Fig. 4*.

The output signal of the total fuel controller as previously mentioned, is the required signal for the fuel quantity of this boiler, and is the cascade signal

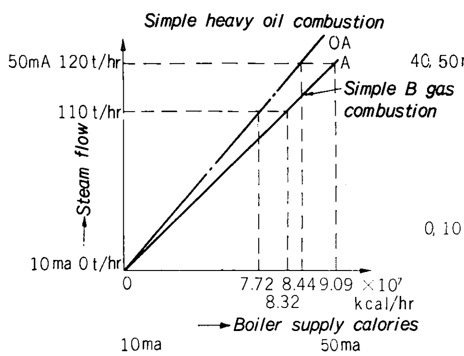


Fig. 5 Fuel quantity and system load quantity

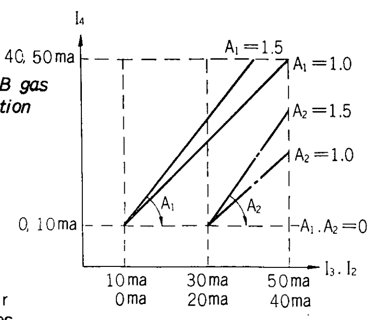


Fig. 6 Computing characteristics of $E-IOA$ separated from I_2 and I_3

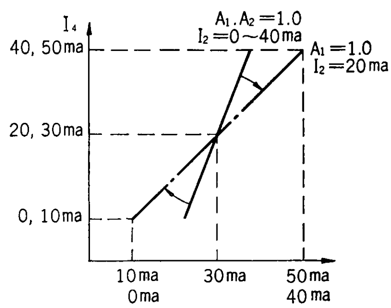


Fig. 7 Computing characteristics of $E-IOA$ with combination of I_2 and I_3 of *Fig. 4*

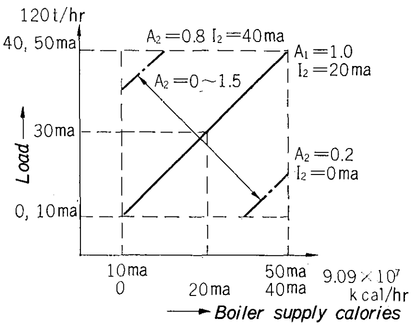


Fig. 8 Total characteristics I_2 as parameter at 0~40 ma

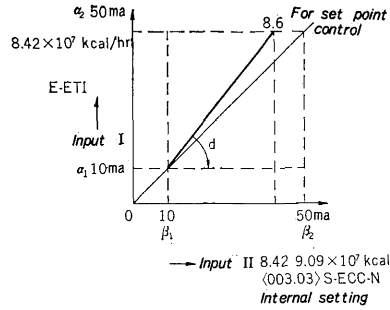


Fig. 11 Heavy oil flow controller setting and characteristics of detection

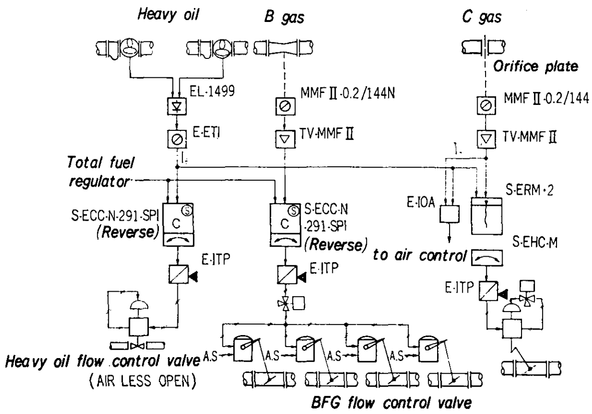


Fig. 9 Block diagram of fuel flow control system

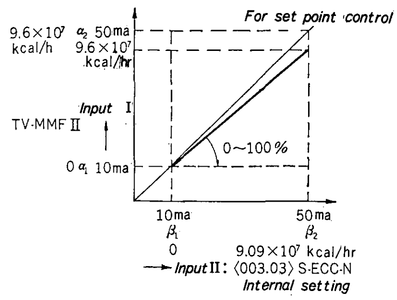


Fig. 12 B gas flow controller setting and characteristics of detection

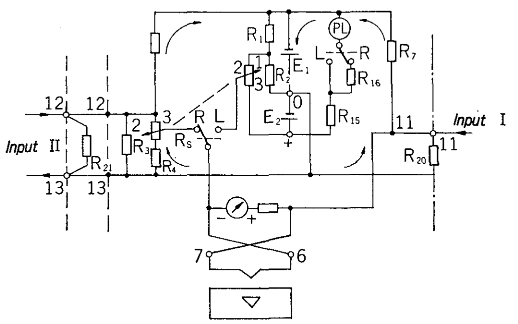


Fig. 10 Circuit diagram for setting points of S-ECC-N-291

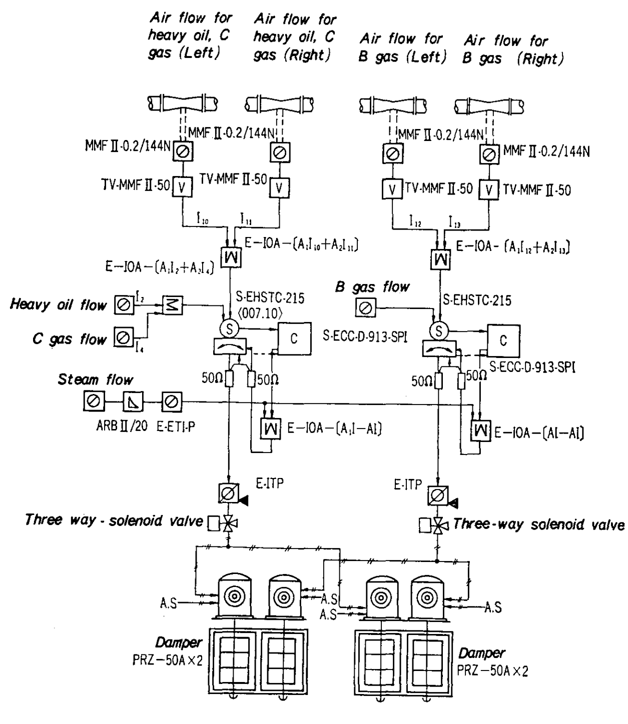


Fig. 13 Block diagram of air flow control system

for each fuel flow regulator. The fuel flow controller and the S-ECC-N circuit setting portion are indicated in *Fig. 8,* and their respective characteristics are given in *Figs, 9* and *10.*

The fuel distribution has been designed so that it can be operated freely within 0~100%, even if some other parts of the system have not been readjusted, by switching Local-Remote changeover switch to " Remote ", if the total scale graduation of the setter has been set, so that it is 100% as shown in *Fig. 8.* Moreover this changeover operation is possible from the front of the panel, and can be confirmed by the brightness of the power supply lamp on the face of the controller. In other words, if the switch is changed to the remote position as was shown in *Fig. 8,* the lamp lights one stage more brightly.

3. Air Flow Control System

The block diagram of this control system is indicated in *Fig. 11.*

Compensation during a sudden change of load, which is based on the series combustion system, is carried out by producing a differential signal in the main steam flow and adding it to the respective air flow control systems. The circuit producing the differential signal is indicated in *Fig. 12.* If R_D, equals the direction of easy flow of the internal resistance of the diode, and R_D is the reverse direction of the internal resistance as indicated by *Fig. 12*, then the voltage e_i during a sudden increase becomes the differential voltage of the time constant e_0 and amplitude $R_0 \cdot C$.

Here $R_D' \ll R_0$

e_0 when the voltage e_i suddenly decreases is

$$e_0 = R_D' \frac{dq}{dt} = -\frac{Q}{(R_2 + R_D') \cdot C} \cdot e^{-\frac{t}{(R_1+R_D')\cdot C}}$$

where Q is the charge of condenser C

Here, $R_D' \ll R_0$, $R_1 = 200\ \Omega$, $C = 1{,}200\ \mu F$

Accordingly, $e_0 \doteqdot 0$, and the signal in the minus direction can be cut. Moreover $R_0 \cdot C$ is sub-divided into nine steps of 5, 10, 15, 20, 25, 30, 40, 50, and 60 seconds.

The total variation condition of the qualitative steam, air, and fuel added to these circuits is shown in *Fig. 9.*

4. The Boiler Furnace Pressure Control System

The block diagram for this system is indicated in *Fig. 14.*

The dynamic characteristics relating to the furnace pressure are complex, influenced by the type of fuel, and combustion system, also the construction, size, and heat transfer system of the furnace. However, it can be generally said that the furnace pressure characteristics is dead time lag. Accordingly, the air flow operating signal has been added to this control system as a preceding signal. Also, in order for a severe oxidation action to take place in the furnace, that is, the combustion to present an explosive phenomenon, a neutral valve has been fitted in the furnace pressure detection, so that, whenever possible an average furnace pressure can be detected, by absorbing part of the high frequency of the measured output.

The $E - IOA - [A_1(I_{18} - A_1 B) + A_2 I_{19} + A_2 I_{20}]$ computing characteristics are indicated in *Fig. 15.*

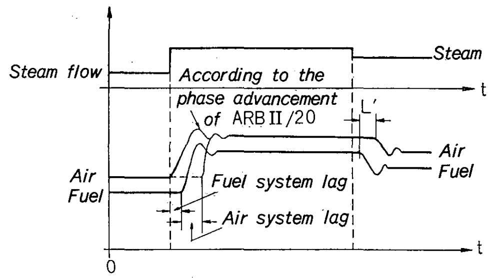


Fig. 15 **Whole transient state of steam, fuel and air**

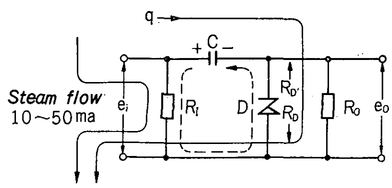


Fig. 14 **Internal circuit diagram of ARBII/20**

5. Main Steam Temperature Control System

The control system is indicated by *Fig. 16.*

Concerning plants equipped with boilers, the requirements of this steam temperature control are severe, especially in the case of turbines. Here, as indicated by *Fig. 16*, the cooled water is forced

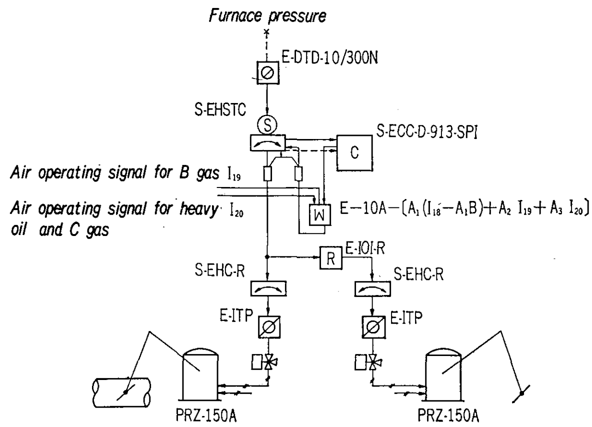


Fig. 16 **Schematic block diagram of boiler furnace pressure control system**

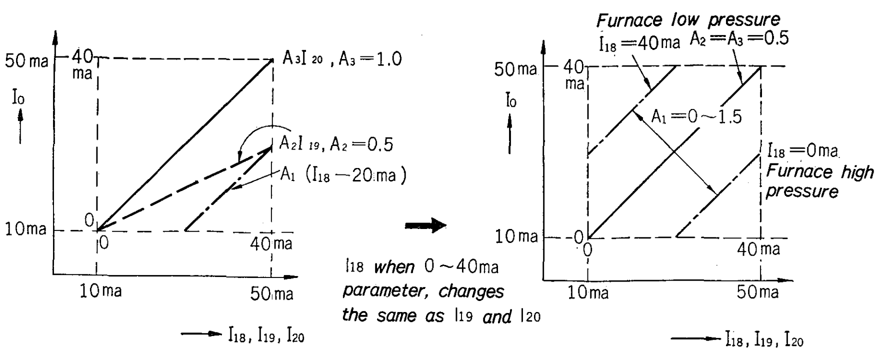


Fig. 17 **Computing characteristics of** ***E—IOA***

out of the main steam pipes by the adoption of a temperature cascade system. The method of carrying out this operation is by proportionally adding either load or a required quantity of air to the temperature control system. However, due to the many cases where the changed components of these elements and the supply water quantity are not proportional, they have not been adopted this time, due to the ill effect caused. In large capacity boilers, this control system is effective, as the response of the temperature detection element is by far superior to that of the propagation velocity of the superheater temperature. The qualitative characteristics of the superheater and superheater reducer are shown in *Fig. 17*.

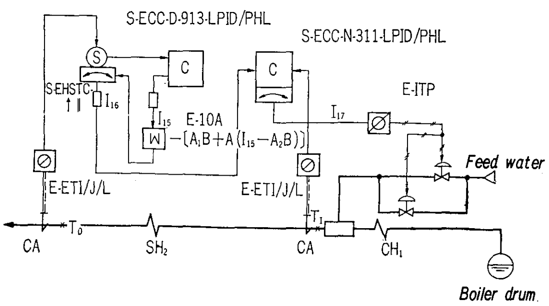


Fig. 18 **Schematic block diagram of the main steam temperature measurement and control system**

The *E—IOA* computing device is of the buffer type and its computing characteristics are shown in *Fig. 18*. Moreover, the operating end has been designed so that the degree of control is extensive, and a two stage sequential operation is carried out by using a primary and secondary valve arrangement as shown in *Fig. 16*. An upper and lower proportional operating mechanism has been installed in the main steam temperature regulator, and has been designed so that the amount of "overshooting" is minimized.

6. Feed Water Flow Control System

The layout of this control system is indicated in *Fig. 19*.

The object of this control system is to try and uniformly maintain the mass balance of the boiler (the relationship between the quantity of boiler closing feed water and amount of steam lead), no matter what the load. This mass balance can be thought of as the drum boiler water level, as Boiler No. 7 now in operation.

The quantity of boiler heat accumulation is remarkably small for a large capacity boiler.

A good effect cannot be obtained, if we consider the load variation conditions, as the amount of feed water is controlled by only the drum level signal. Accordingly, what is commonly known as a three-point water level control system has been adopted.

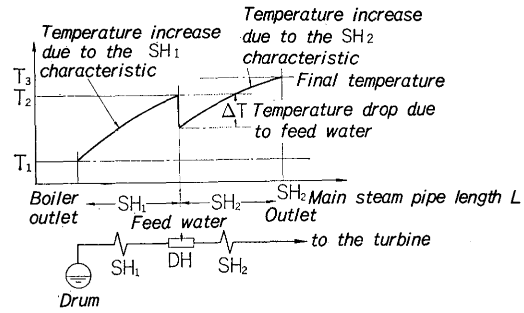


Fig. 19 **Length of main steam pipe and temperature distribution**

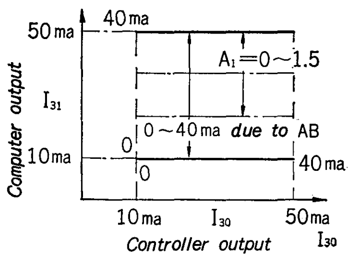


Fig. 20 **Computing characteristics of *E—IOA***

$A_1B = 26.7$ ma, $I_{15} = 0$ ma, $A_2B_2 = 20$ ma
(Main steam temperature drop)
$AB \fallingdotseq 26.7$ ma, $I_{15} = 20$ ma, $A_2B = 20$ ma
$A_1B \fallingdotseq 26.7$ ma, $I_{15} = 40$ ma, $A_2B = 20$ ma
(Main steam temperature increase)

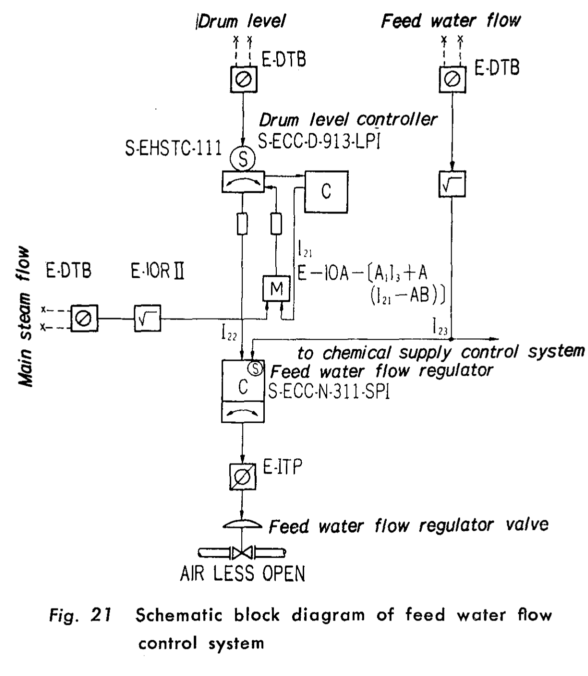
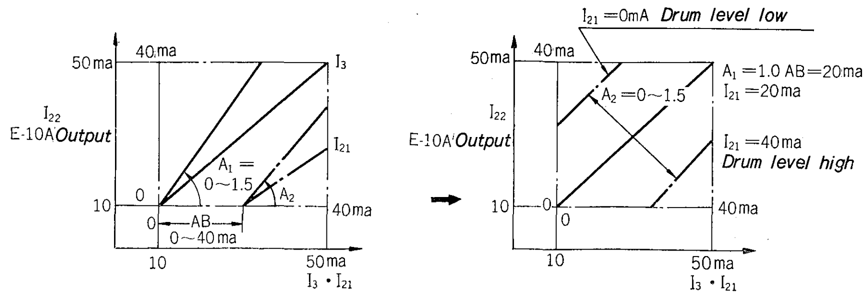


Fig. 21 **Schematic block diagram of feed water flow control system**

In order to separate the flow control system and water level control system, two controllers are utilized, as shown in *Fig. 19*.

The $E-IOA-[A_1I_3+A(I_{21}AB)]$ computing characteristics are shown in *Fig. 20*.



Main steam flow and drum level control signal

Fig. 22 Computing characteristics of E—IOA

The output of the above primary regulator is based upon the basic thought that, the increase and decrease of the comparison of the quantity of the steam load and the feed water for only the same width, is modified. The modification width is made optional, so that the internal volume of the computing device can be set.

Here, the utilization of five separated type regulators are not for the propose of vertical panel or control desk type instruments, but have been designed for control systems including computing devices so that a shockless operation can be carried out.

The summary was mentioned above; concerning ABC in *Fig. 3*, FDF inlet atmospheric pressure, SAH inlet air temperature, and heavy oil superheater inlet oil temperature control systems have also been designed. However, these are simply abbreviated as set point control systems. Moreover (a) FDF inlet air pressure measurement and control system have been designed in order to prevent mutual interference, due to the separation of the air duct as indicated in *Fig. 3*.

V. CONCLUSION

These control systems are presently operating satisfactorily. There was much to be desired in introducing the control results from the point of view of space, however, the control characteristics and actual control results which were anticipated during their conception will be compared, when an opportunity presents itself.