UDC 621. 365. 3-523

ELECTRICAL EQUIPMENT FOR 27,000 kVA GRAPHITIZING FURNACE TO KANAZAWA WORKS, KYOWA CARBON CO., LTD.

Haruo Aoyama
First Industiial Div.

I. INTRODUCTION

In the graphitizing process used in the manufacture of artificial graphitizing electrodes, the quality of the graphite is changed by the heat treatment of the baked amorphous carbon electrode.

The features of the graphitizing furnace are single phase circuits with low voltages and high currents, a high reactance of the furnace body, i. e. although the power factor during the initial operating period is over 95%, the resistance inside the furnace becomes small as the baking proceeds and drops to less than 40% after the middle of the baking period.

Therefore, in order to improve the power factor, a series capacitor system is used in this circuit. The power costs, voltage regulating transformers and the active capacity are reduced and the baking time is shortened so that the power per net ton can be reduced and productivity improved.

In order to improve quality and save labor, a sampling program control best suited to the characteristics of a graphitizing furnace in which the baking time is 40～70 hours and changes inside the furnace are very slow is employed.

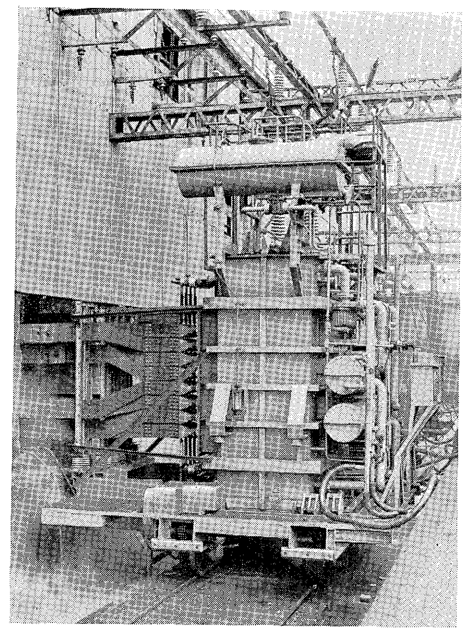


Fig. 1 Outerview of furnace transformer

II. OUTLINE OF EQUIPMENT

1. Graphitizing Furnace

In order to achieve the various characteristics required for the artificial graphitizing electrodes, treatment must be performed at temperatures in keeping with applications. The temperature used in this graphitizing furnace is 2,500～3,000°C and the most important factors technically are the temperature rise process and the holding time at the maximum temperature. However, from the standpoint of economics, treatment with good heat efficiency is a very important point in the process. The following sections give an outline of the graphitizing furnace construction, and electrical characteristics.

1) Construction of graphitizing furnace

Since the material treated in a graphitizing furnace, i. e. the electrodes (actually baking electrodes, but hereafter referred to only as electrodes) are heated to temperatures of 2,500～3,000°C, the electrodes are inserted in a rectangular furnace consisting of refractory bricks and a silicon carbide lining. In order to prevent oxidation, coke is inserted in the spaces between the electordes and heating is performed by current applied directly coke and electrodes from the guide electrodes at the ends of the furnace (*Fig. 2*).

Copper or aluminium bus bars are located between the transformer and the guide electrodes and is necessary to consider the position of the conductors so that the reactance value is a minimum.

2) Electric and heat characteristics of the graphitizing furnace

The furnace resistance decreases as the temperature rises and at the power supply end period when the maximum temperature is reached, the resistance is only about 1/5 of the original value. Therefore, a large current is required to achieve the maximum temperature and a large power is needed.

Since the reactance is determined more or less by the position of the conductors between the transformer and the furnace, there is almost no change

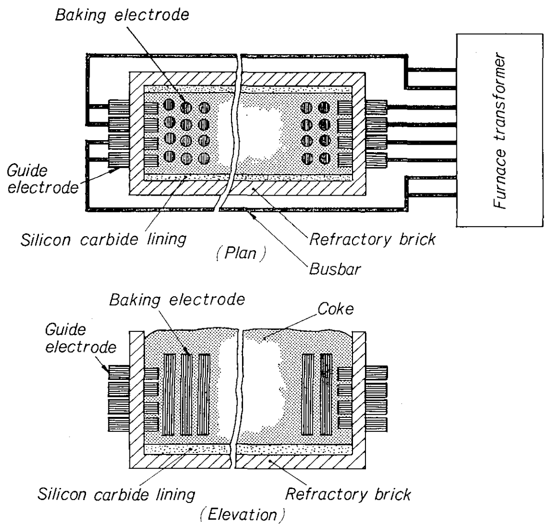


Fig. 2 **Structure of graphitizing furnace**

during the electrical heating, and the power factor on the secondary side of the furnace transformer decreases remarkably to only about 30%. Therefore, a large capacitor must be used in order to improve the power factor.

The electrical resistance of the furnace differs in accordance with the treatment temperature of the coke, the particle size, the pressure when it is inserted, the section area of the furnace, the length of the furnace, the spaces between the electrodes, etc. However, when the current starts and the temperature rises to 800°C, oxidizing combustion starts because of the air in the gaps between the coke and for a short time the resistance tends to increase. However, when the temperature coefficient becomes more negative and the pressure inside the furnace increases due to thermal expansion, the resistance value gradually decreases. When the temperature is over 2,000°C, the coke reaches the graphitizing temperature range and the resistance decreases rapidly, although it becomes stable at about 3,000°C.

2. Equipments Components

There are two capacitor systems to improve the power factor: the parallel system and the series system. Although the furnace reactance is kept almost constant during the baking process, there is a great change in the resistance between the initial and final baking periods. Therefore, to make the power factor on the input side constant, the capacitor banks must be divided when the parallel capacitor system is used, switches must be provided for each capacitor, the number of the capacitor banks must be changed in accordance with load capacity variations and the power factor must be regulated.

When the series capacitor system is used, however, this change is not necessary since the reactance is almost constant throughout the process and the power factor can be regulated autonomously. In this equipment, therefore, the series capacitor system best suited to the characteristics of the graphitizing furnace is used. *Fig. 3* is a system diagram of the plant. The specifications and features of the main units are as follows:

1) Voltage regulating transformer — one
   - Type: outdoor use, oil immersed, self-cooling type
   - Capacity: 7,000 kVA
   - No. of phases: single phase
   - Primary voltage: 73.5 kV (however, can be used up to overvoltages of 80.5 kV)
   - Secondary voltage: F 11.55 kV~R 7.59 kV~4.07 kV
   - Step voltage: 220 V
   - No. of taps: 35
   - Frequency: 60 Hz
   - Tap changing system: on-load tap-changing system

2) Furnace transformer
   - Type: outdoor use, forced oil, water cooled type
   - Capacity: 27,000 kVA
   - No. of phases: single phase
   - Primary voltage: 29.3 kV
   - Secondary voltage: 270 V

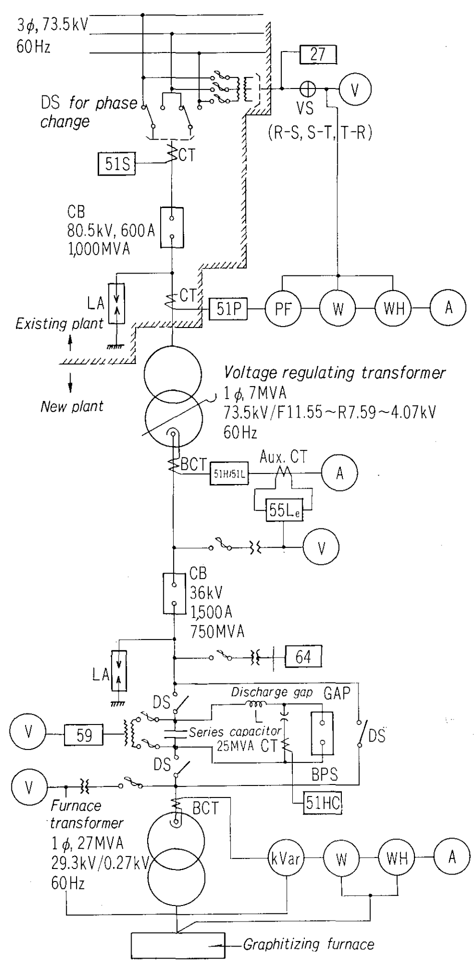


Fig. 3 **System diagram of plant**

Frequency: 60 Hz

Fundation of furnace transformer: foundation with wheels which can be moved by motor drive.

Since the power supplies for the seven furnaces are supplied in succession from the transformer, the transformer can be moved up to the front of the respective furnace by a motor driven wheel system and power supply is simplified.

Movement speed: 5 m/min.

Motor: 3-phase, 1.5 kW, 4 P, AC 220 V, 60 Hz brake motor

Reduction ratio: 1/623

Load weight: 40 t

Since the series capacitor system is used to improve the power factor, there is a major problem of abnormalities due to core saturation of the transformer during power source closing and therefore the flux density of the transformer is lower than in usual transformers.

3) Program control cubicle
   (1) Power detection circuit
       Power variation detection circuit
   (2) Power quantity correction circuit
       Power variation input circuit
       Power variation detection circuit
   (3) Current limiting circuit
       Current setting circuit
       Current detection circuit
       Operating comparison circuit
   (4) Logical operating and intermittent circuits
4) Monitoring and operating panel

When the power source circuit breaker is open, a reverse induction voltage occurs on the primary side of the voltage regulating transformer due to the residual energy of the capacitor. Therefore, during opening other than for interruption of faults, the copacitor can be short circuited and the power source opened. In order to avoid any abnormalities during closing due to core saturation of furnace transformer as decribed in 3) above, when the power source is closed, the capacitor circuit is shorted and afterwards, the capacitor short is released.

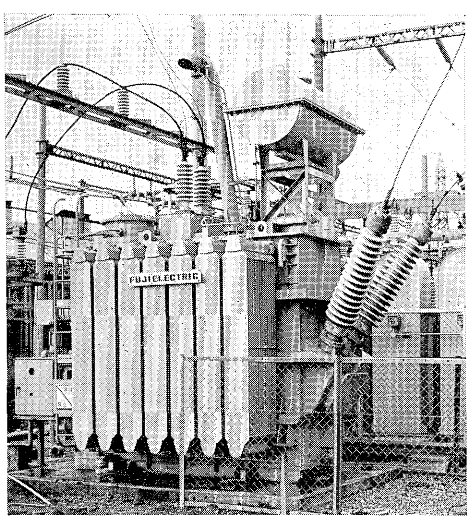


Fig. 4 Outerviw of regulating transformer

5) Series capacitor one set

   Type: outdoor use, OF self-cooled type

   Capacity: 25,000 kVA (however, 4,000 kVA for existing plant)

   No. of phases: single phase

   Terminal voltage: 26.4 kV

   Frequency: 60 Hz

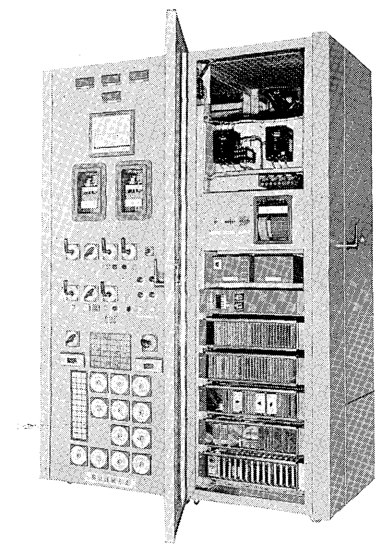


Fig. 5 Outerview of control cubicle

III. PROBLEMS POINTS CONCERNING APPLICATION OF SERIES CAPACITOR

1. Outline

The series capacitor system is most suitable for power factor improvement in circuits such as those in the graphitzing furnace here the resistance value changes considerably with a constant reactance. However, careful consideration must be given beforehand. The main points to be investigated are as follows:

1) The reactances of the furnace, conductors and furnace transformer must be correctly estimated and series capacitors with the correct reactance must be used.
2) It must be determined whether or not any abnormalities will arise when the furnace transformer is closed and the design conditions of the furnace transformer and sequence of the operating circuits must be decided.
3) It is necessary to prevent any abnormal voltage due to saturation phenomena when the furnace is opened, and prevent damage to the various devices in the system.
4) A suitable protective system must be used which can rapidly eliminate any abnormal phenomena and protect the series capacitor when any ab-

normal phenomena arise or there is a fault in the circuits.

The above points were all carefully investigated for this equipment and the equipment construction was chosen as shown in *Figs. 3* and *6*.

2. Selection of Series Capacitor Reactance

The reactance of the series capacitor must match the total reactance of the furnace, the conductors and the furnace transformer. The reactance must also be selected to maintain the power factor of the furnace circuits at 100% and provide a furnace current up to the rated value. When the power factor and furnace current were measured after the equipment was installed, the initial baking period was almost 100% and the final baking period was the rated value.

3. Prevention of Abnormal Phenomena During Furnace Closing

Since the abnormal phenomena which arise in the series capacitor system circuits shown in *Fig. 6* due to core saturation in the furnace transformer during closing of the power source breaker can cause operation accidents, the furnace constants and furnace transformer planning constants were fed into an analog computer and it was confirmed whether or not such abnormal phenomena would occur as well as the limits of the phenomena.

The results indicated that there was absolutely no possibility of any abnormal phenomena in these circuits during normal operation. Since it was clear that the limits of the phenomena were above the rated values, it was not necessary to take any special precautions at the time of closing the power source circuit breaker. *Fig. 7* shows the results of analog computeı investigations at the time of closing and opening.

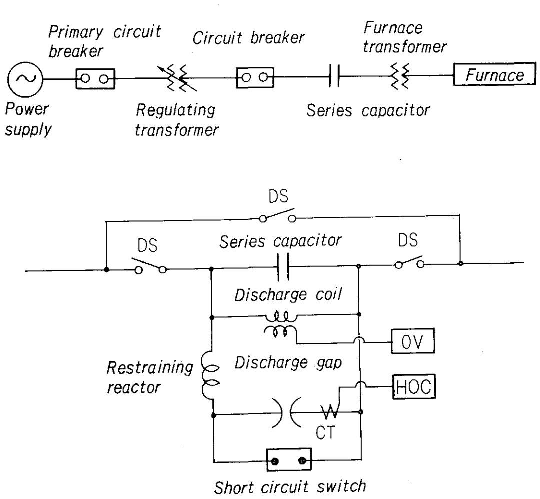


Fig. 6 Protecting device of series capacitor

4. Prevention of Abnormal Phenomena Due to Transient Phenomena at Switching off Furnace Circuit

In the series capacitor system circuits shown in *Fig. 6*, there is a possibility of damage to the devices due to abnormal voltages induced by residual energy in the series capacitor when the circuits breakers for the power souıce or the primary side of the transformer are opened. The suitable countermeasures for these phenomena were used formerly.

1) A short circuit switch is placed in parallel with the series capacitor and when the furnace power source is opened, the series capacitor is always short circuited by the short circuit switch so that a resistive/inductive reactance circuit is formed.
2) In those case when the series capacitor is short circuited at the time of a fault interruption, and the fault can not spread, the power source breaker is opened after the short circuit switch is closed. For other faults, the short circuit switch is closed at the same time as the power source breaker is opened.
3) The power source breaker is of the resistance interruption type and the resistance value is selected to be about 50% of the inductive reactance of the circuit so that the furnace current is decreased when the furnace power source is opened. In addition, there will be no abnormal phenomena when faults occur in such a way that the breaker operates at the same time as the short circuit switch.

Because of the above countermeasures, there is no need to worry about such abnormal phenomena. *Figs. 8* and *9* show the excellent results obtained in switching tests using actual circuits.

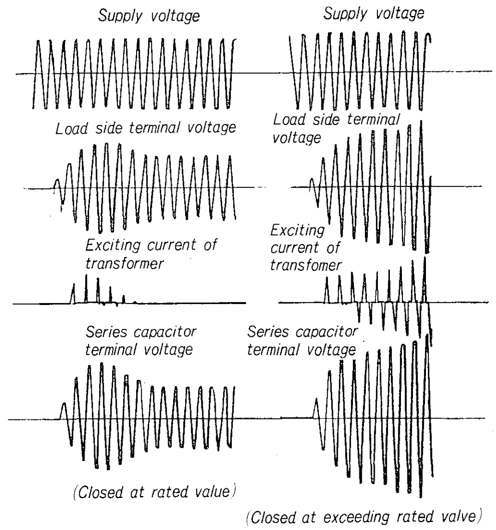


Fig. 7 Data by analog computer

5. Protective Equipment for the Series Capacitors

The standard protective system for the series capacitors consist of a discharge gap, restraining reactor and discharge coil as shown in *Fig. 6*. The results of using such devices are as follows:

1) Discharge gap

Overvoltages applied to the series capacitor for any reason are kept down so that they do not exceed the withstand voltage of the series capacitor and if the discharge gap operates, the capacitor discharge current is detected by an instantaneous overcurrent relay in the secondary circuit of the instrument current transformer, the short circuit switch is closed and this prevents wear of the discharge electrods.

2) Restraining reactor

This reactor is arranged in series with the discharge gap and short circuit switch. When there is a short circuit in the series capacitor, the discharge current is kept to the rated value or less and there is no decrease in the life of the series capacitor.

3) Discharge coil

This coil is used to prevent any danger due to residual charge in the series capacitor after opening of the power source breaker by discharging the capacitor. An overvoltage relay is connected to the secondary coil so that overloads in the series capacitor can be detected.

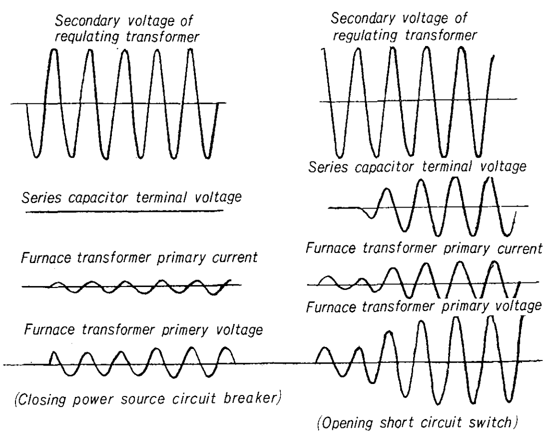


Fig. 8 **Oscillogram when closing furnace circuit**

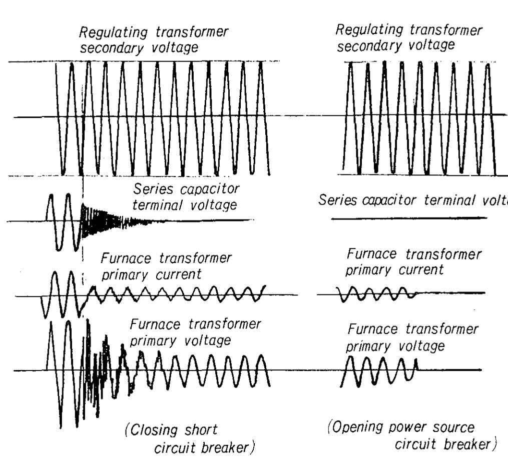


Fig. 9 **Oscillogram when opening furnace circuit**

4) Others

In addition to the above protective devices, a pressure relay is attached to the series capacitor for detection of faults inside the series capacitor.

IV. PROGRAM CONTROL EQUIPMENT

1. Outline

In order to improve quality and save labor, the power is controlled according program for the furnace and the capacity limits of the regulating transformer are monitored during the middle and final processing periods. In other words, because the resistance in the furnace decreases and the secondary current increases during the baking period, the tap voltage of the voltage regulating transformer is lowered and the current is controlled so that it is within the capacity limits.

1) Circuit construction

These circuits control the power so that it matches the set power given on the program sheet. The setter is the Fuji Prozet (PZP). The optional set values are obtained by varying the resistance, these values are converted into voltages and supplied to the subsequent addition operator (± signal). In the addition operator, the set value and the actual supply power are processed, a signal is given to the subsequent comparator and the power is matched with the power by increasing or decresing the number of taps of the voltage regulating transformer in accordance with the polarity of the power variation.

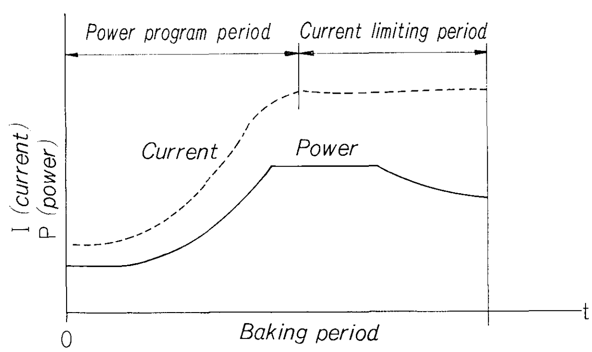


Fig. 10 **Baking program of graphitizing furnace**

2) kWh correction circuit

Since it is necessary to provide a dead band of power above the one tap voltage in order to prevent hunting of the tap changer in the program control given in 1) above, there is a variation between the set power and the supply power. Because of the long baking period of 40～70 hours, this power variation can become large and have an adverse effect on the quality of the graphite produced. In order to ensure good quality, it is essential to keep the variation to within the set value.

By utilizing the fact that changes in the graphitizing furnace are extremely slow, the following type of sampling control system was used in order to keep the number of figures of the reversible counter circuit to a minimum.

The integration is not for the entire T_S period but only for the period t_S and $T_S - t_S$ is equal to t_S in this system. The total kWh counting numbers of the counter circuit is as shown in equation (1).

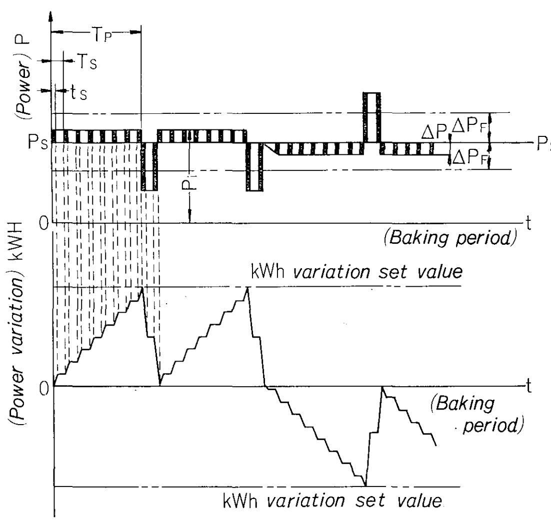
$$N = n \cdot T_P \cdot \frac{t_S}{T_S} \quad \cdots\cdots(1)$$

where N : total number of kWh variation pulses
n : number of pulses per unit kWh
T_p: time until accumulated kWh reaches set value
T_S: power variation sampling time
t_S : power variation sampling time (actual counting time)

In equation (1), the whole range is integrated if $T_S t_S = t_S$. In the equipment supplied, t_S is from 1 to 1/10 in order to reduce the number of counter circuit elements.

3) Current limiting circuit

When the resistance in the furnace decreases as baking continues and the secondary current of the furnace transformer exceeds the rated 100 kA, this circuit operates and lower the tap voltage.



P_t : supply power ΔP : $P_S - P_t$
P_S : set power ΔP_F : dead band power
T_P : time until accumulated kWh reaches set value
T_S : power variation sampling time
t_S : power variation sampling time (actual counting time)

Fig. 11 **Schematic diagram of power sampling**

4) Logical operating and intermittent circuits

The logic operating circuit decides the priority among the control signals for 1), 2) and as given above. The intermittent circuit is used for stable operation of the tap changer.

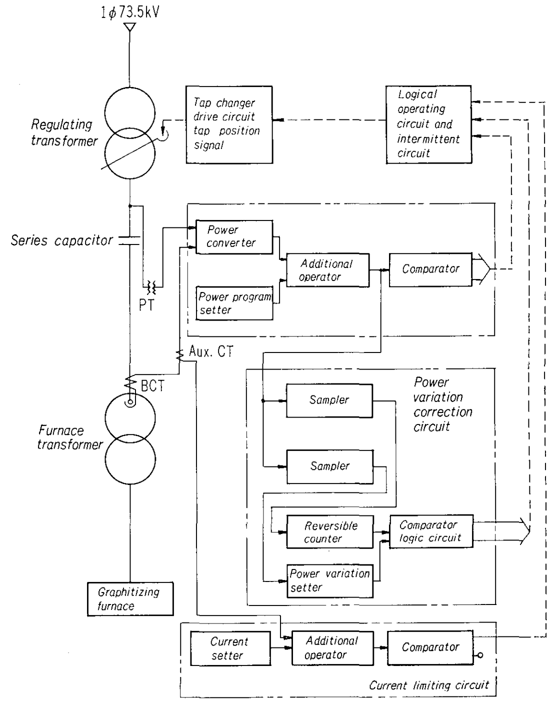


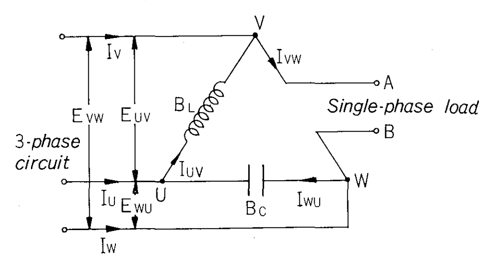
Fig. 12 **Block diagram of control circuit**

V. PHASE BALANCING EQUIPMENT

In the Kanazawa Works of Kyowa Carbon Co., Ltd., there are several furnaces and each furnace is connected among different phases of three phases. Phase balancing equipment was unnecessary since phase balancing was possible.

However, when there are few furnaces in the case of normal graphitizing or induction furnaces which require single-phase large capacity power supplies, three-phase balancing equipment is required in order to prevent decreases in the utilizability of the three-phase power supply and accidents in the loads of rotating machinery due to reverse phase components.

There are various types of phase balancing equipment which can be considered but the Grebeau circuit is given here because of its simple construction and economy.



B_L : phase balancing reactor
B_C : phase balancing capacitor
PkVA : total load of A and B
cos ϕ : power factor of A and B

Fig. 13 **Grebeau phase balance circuit**

1. Phase Balancing Condition of the Grebeau Circuit

In *Fig. 13,* of Grebeau circuit,

I_U, I_V, I_W : phase current respectively
P : total load between A and B
$\cos\varphi$: load power factor
B_L : total load between U and V
B_C : total load between W and U

if the three phase voltage is balanced and

$$\left.\begin{array}{l}\cos\varphi=1\\ B_L=B_C=\dfrac{P}{\sqrt{3}}\end{array}\right\}\quad\cdots\cdots(2)$$

then

$$|I_U|=|I_V|=|I_W|\quad\cdots\cdots(3)$$

and thus complete balancing is achieved.

Under actual operating conditions, the regulation will take place in steps to maintain $\cos\phi=1$ and $B_L=B_C=\dfrac{P}{\sqrt{3}}$. Therefore, the phase balancing is at its worst just before the subsequent step is inserted.

2. Phase Balancing Detection and Automatic Regulation

Phase balancing detection is performed by the currents I_U, I_V and I_W as shown in *Fig. 14* and at the time of complete balancing the condition is as shown in equation (4).

$$|\dot{I}_W-\dot{I}_V|=\sqrt{3}\,|\dot{I}_U|\quad\cdots\cdots(4)$$

When considering the voltage division of R_1 and R_2 on the secondary side of the CT, then the following equation is obtained:

$$e_1=\sqrt{3}\,e_2\quad\cdots\cdots(5)$$

If R_1 and R_2 are each adjusted so that the complete balancing in equation (5) arises, then:

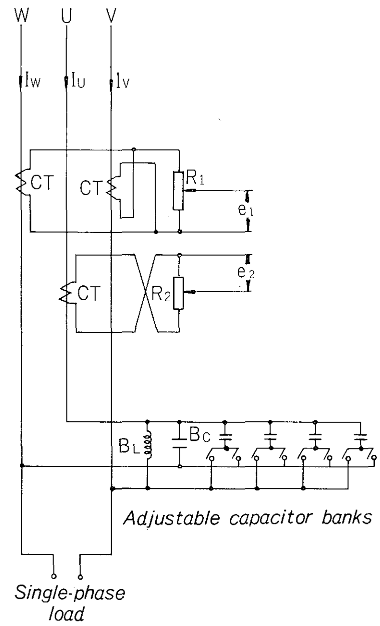
$$e_1>\sqrt{3}\,e_2\quad\cdots\cdots(6)$$

$$e_1<\sqrt{3}\,e_2\quad\cdots\cdots(7)$$

Therefore equation (6) shows the condition of insufficient phase balance and when the adjustable capacitor banks are closed by the time the situation is nearly as in equation (5), the balance is maintained. Equation (7) shows a condition of over-balancing and this is controlled by opening the adjustable capacitor and regulating so that the condition is almost as in equation (5).

From the viewpoint of economy, the regulation can only be carried out in steps and thus a dead band is provided at ($e_1-\sqrt{3}\,e_2$) and when the phases are unbalanced above this dead band, the adjustable capacitor banks are automatically turned on or off.

This dead band is decided by the permissible value of the degree of unbalance for the power company and the minimum capacity of the adjustable capacitor banks.



$e_1=\sqrt{3}\,e_2$ (perfect phase balance)
$e_1>\sqrt{3}\,e_2$ (under phase balance)
$e_1<\sqrt{3}\,e_2$ (over phase balance)

Fig. 14 Detecting circuit for phase balance