UDC 621.365.2-52 : 621.314.22

STEEL MAKING ARC FURNACE ELECTRICAL EQUIPMENT OF 90-TON CAPACITY DELIVERED TO AZUMA STEEL CO., LTD.

Haruo Aoyama
Kinzo Okazaki
Shigeru Kobayashi
Yoshinobu Sakamoto

I. INTRODUCTION

In the electrical steel industry, on account of the export boom of bar steels, a unprecedented great number of equipments were installed additionally and/or newly through 1973 into 1974.

The number of steel making arc furnace transformers manufactured by Fuji during this period were as many as eleven, 330 MVA in total. These equipments are all for UHP arc furnaces and feature that a large current output is obtained with low voltage simultaneously with the transformer capacity being made larger increasingly.

Among them, in particular, 58 MVA transformer for steel making arc furnace delivered to the Sendai Plant of Azuma Steel Co., Ltd. can be said to be a product on record in Japan, which has been combined with the up-to-date UHP arc furnace. Hereunder, the details of the equipment are introduced.

The features of this equipment are as follows.

(1) The capacity is 58 MVA, which is the largest in Japan as that of furnace transformer.
(2) The furnace transformer is employing an one-step-down system from 154 kV of primary side voltage.
(3) For the load-switching made frequently, a load-switching system by tertiary circuit peculiar to Fuji has been adopted.
(4) For the power receiving equipment at primary side, 154 kV gas insulated metal clad switchgear equipment (VMH) has been employed.
(5) Computer-controlled arc furnace operation can be made.

A point mainly discussed when planning this equipment is whether 154 kV one-step-down system is adopted for the furnace transformer or two-step-down system is provided that steps voltage down to 22 or 33 kV once from 154 kV and connects to the furnace transformer.

When the one-step-down system is adopted, it offers the following advantages:

(1) Though the furnace transformer itself large and the building costs a lot, which may be disadvantageous, but the site and building of power receiving station reduce in scale, and it costs less.
(2) Since from the power receiving station to melting shop side are connected with a special high tension cable of 154 kV, the current becomes small, resulting in little loss generated across the station and shop, so less running cost.
Also, employment of the load-switching system by tertiary circuit permits the load switch and tap changer to prolong their service life.
(3) At a time of additional installation in the future, it is easier to plan the plant.
(4) The whole electric loss of arc furnace equipment is little. Further, this results in the amount of necessary cooling water being reduced.
(5) Since impedance across primary and secondary sides decreases, the net output capacity of transformer becomes large.

Furthermore, as the plant is located near the seashore, the transport conditions are good and the marine transport is possible.

For the above various reasons, it has been decided to adopt the one-step-down system.

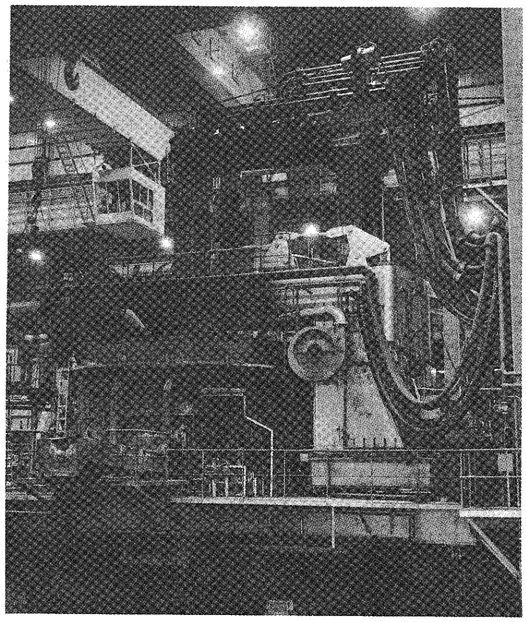


Fig. 1 Outer view of steel making arc furnace

II. OUTLINE OF EQUIPMENT

The recently-delivered equipment has been completed as the electrical equipment for large UHP arc furnace with the introduction of the up-to-the-minute techniques under the close technical tie up between Azuma Steel Co. and Nippon Kokan K.K. It is the most modern and largest UHP arc furnace electrical equipment.

This equipment consists of the following; arc furnace power distribution equipment, furnace, transformer, load switching equipment, supervisory control device, capacitor equipment for improvement of power factor, furnace operating electrical parts, etc. Listed as the features; large-sized arc furnace, introduction of new types of machines and improvement in control system.

Each equipment are outlined hereunder.

The rated capacity of the furnace transformer which is the main unit has been fixed to 58 MVA conforming to the characteristic of arc furnace. However, this unit is a product on record in Japan and has employed 154 kV one-step-down system for such reasons as described above. Therefore, the primary side bushing with an elephant construction has been used and the charging part has been shielded and further, in the elephant chamber, a phase exchanger has been installed in order to equalize the influence of the furnace wall consumption due to the hot spot in the furnace as much as possible.

The cooling system is a forced oil water cooled one; however, a separately-installed construction has been employed for easy maintenance, and a vertical type cooler has been used.

In the capacitor equipment for improvement of power factor, the total capacity of 35 MVA has been divided into two groups of 15 and 20 MVA and connected to the tertiary winding of the furnace transformer. Further, the capacitor chamber has been opened viewing from the point of radiation and the charging part has been shielded for the purpose of dust prevention and labor saving in maintenance.

The arc furnace transformer is rated as follows.

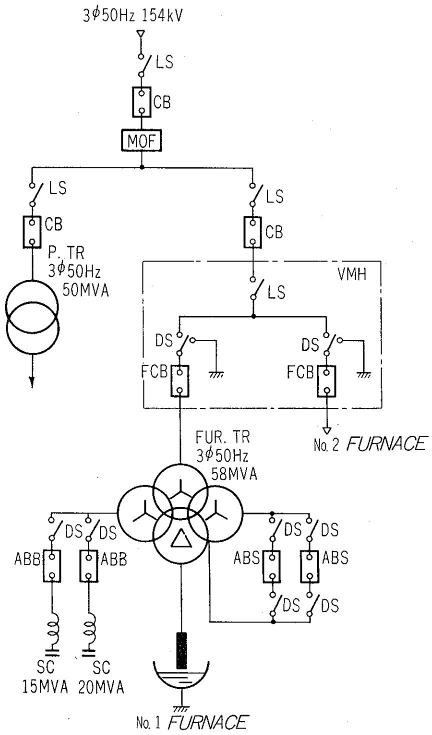
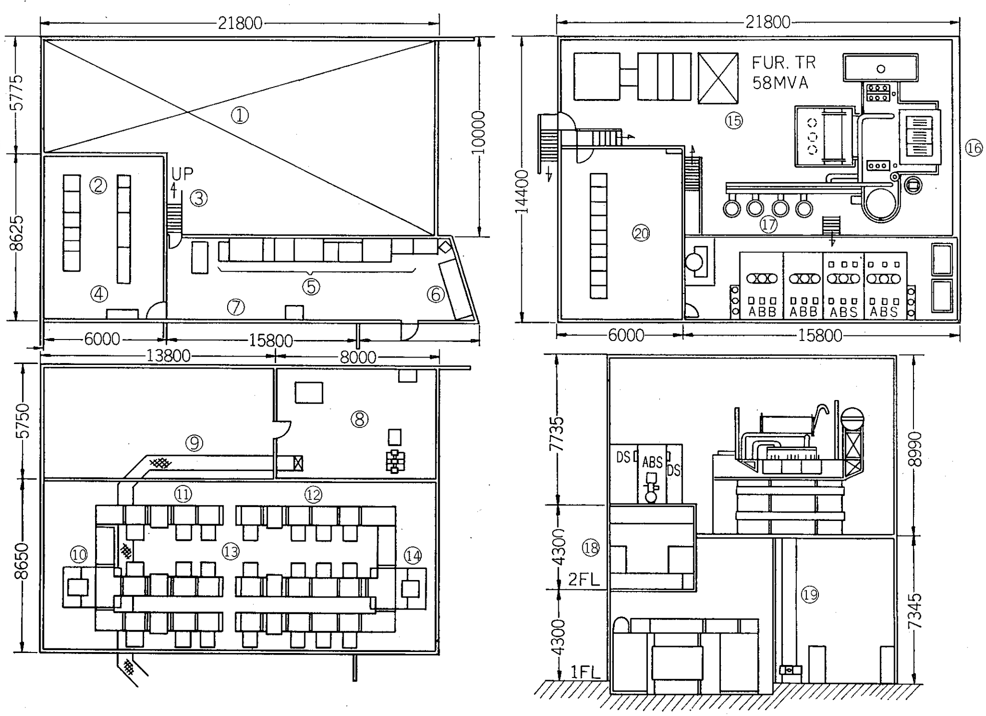


Fig. 2 Skeleton diagram of distribution



1. Stairwell at 1st floor
2. Various control panels
3. To 3rd floor
4. (2nd floor)
5. Various switchboards
6. Operator panel
7. Electric room at 2nd floor
8. Emergency power source
9. 154 kV cable pit
10. Series reactor
11. 15 MVA capacitor bank
12. 20 MVA capacitor bank
13. Capacitor room at 1st floor
14. Series reactor
15. Transformer room at 3rd floor
16. Electric furnace side
17. Separately-installed cooler
18. Furnace operation side 2FL
19. 154 kV of cable rising
20. Computor room (3rd floor)

Fig. 3 Arrangement of electric equipment

Cooling:	Forced oil water cooled system
Capacity:	58,000 kVA
Number of phases:	3
Frequency:	50 Hz
Primary voltage:	154 kV
Secondary voltage:	F700~R580~220V (30 V step and 17 taps)
Tertiary voltage:	20,010 V
Current:	Primary current: 217 A Secondary current: 58 kA Tertiary current: 1 kA
Connection:	Primary side: Wye (neutral point with 120 kV arrester) Secondary side: Open delta Tertiary side: Wye (lead-out of neutral point)
Overloading capacity:	It has been so designed as to be fully bearable as a steel making arc furnace transformer. (For the details, see Sec. IV)

The supervisory control device of arc furnace has been so modified as to conform to the large furnace.

Especially this time, a computer control system has been induced for the arc furnace operation, and this system has been developed as a result of years of research in order to improve the productivity of arc furnace, achieve labor saving and solve other various problems (For the details, see Sec. VI).

As the motor for lifting the automatic electrode control equipment, a totally-enclosed forced-air-cooled type wound-rotor induction motor has been employed, and its effective output is 50 kW (For the details, see Sec. V).

The arrangement of electrical equipments in the electric room is as shown in *Fig. 3.* The furnace transformer has successefully been made in compact and functionally as a whole owing to the employment of the elephant construction at primary side and load switching system by tertiary circuit.

In addition, it has become unnecessary to provide a voltage dropping transformer for the power receiving station since the one-step-down systems has been adopted, thus reducing the station space.

Further, as shown in *Fig. 2,* skeleton diagram of distribution, the introduction of VMH (gas insulated metal clad switchgear equipment) for two feeders of arc furnace has resulted in a considerable reduction in the space. On the top of that, as a result of employment of VMH, a great labor saving in maintenance of the power receiving station has been accomplished.

III. GAS INSULATED METAL-CLAD SWITCHGEAR EQUIPMENT (VMH)

For the primary side switchgear equipment of furnace transformer, VMH has been employed for the following reasons:

(1) In the case of additional installation in the future, the service interruption time is little and besides, by combining the units, the plan of plant can freely be changed.

(2) Since the plant is located near the sea, a countermeasure of damage by salt is necessary.

(3) There are fewer parts aging in secular change and it needs very little maintenance because the conditions of outside field have been completely shut out.

(4) There is no need to provide a large area for the power receiving station.

This equipment consists of one lead-in circuit and two lead-out circuits as shown in *Fig. 2,* and the high tension unit of the main circuit is composed of the following; disconnecting switch for leading in, grounding type disconnecting switch for feeders, double pressure type SF_6 gas circuit breaker, etc. Also, this equipment is connected to the external equipment entirely with cables, and the charging part is kept shielded completely.

The specifications of VMH are as follows.

Voltage:	154 kV
Insulation class:	No. 140
Rated current:	Main bus bar: 1,600 A Branched bus bar: 1,200 A
Interrupting current:	31.5 kA
Insulation system:	SF_6 gas sealing with atmos-

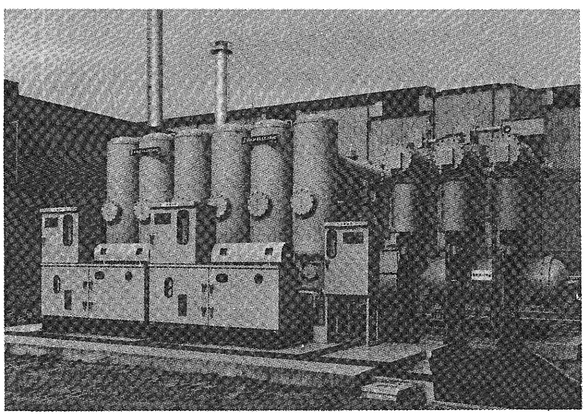


Fig. 4 Outer view of gas insulated metalclad switchgear equipment

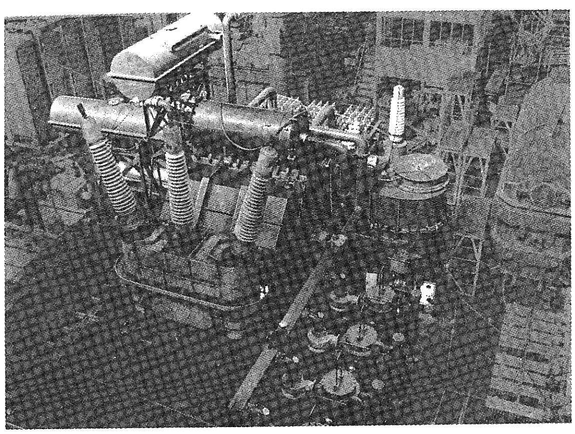


Fig. 5 Outer view of furnace transformer (When the work test is doing, so primary bushings are installed only for test.)

pheric pressure of 3.1 (20°C)

Operating system: Circuit breaker: Hydraulically
Disconnecting switch: Motor drive

Arc suppressing: Double pressure spray system with atmospheric pressure of 3.1/19 (20°C)

IV. FURNACE TRANSFORMER

1. Connection

Fig. 2 shows the overall skeleton diagram of distribution of the steel making arc furnace electrical equipment, *Fig. 6*, three-phase connection diagram of furnace transformer and *Fig. 7*, single-phase connection diagram, respectively.

As obtained from *Figs. 6* and *7*, this transformer unit has employed a secondary voltage indirect regulating system comprising the main transformer and series transformer, and load switching is made by the tap circuit. The advantages are as follows.

(1) A wide range of regulation of secondary voltage can be made easily yet at equal intervals.

(2) The voltage and current values of tap circuit are freely selectable and as a result, it becomes possible to use an optimum tap changer having a great reliability in relation to frequent tap change extending over several hundred times a day.

(3) As little current flows into the tap changer and load switch, their life longer.

Moreover, a power condenser has been connected to the tertiary winding of the main transformer in order to improve the power factor.

2. Core

For both main and series transformers, a band clamp system tripod core has been used.

When designing the main transformer core, the effect having on the core temperature rise by leading magnetic flux leakage due to a large capacity power condenser load of tertiary winding has been examined in detail by the computer.

3. Winding

Fig. 8 shows the arrangement of windings of the main and series transformers. The primary winding of the main transformer is a high series capacity winding having ample past records of manufacture in the insulation class of No. 100 to No. 200, and it fully withstands unusual voltage such as lightning surge, switching surge, etc.

For the secondary winding, an 8-shaped cylindrical plate coil laid across the main and series transformers. This Fuji's unique cylindrical plate coil has such prominent features that, 1) the space factor and cooling characteristic as a winding are great, 2) it is sturdy even mechanically and further,

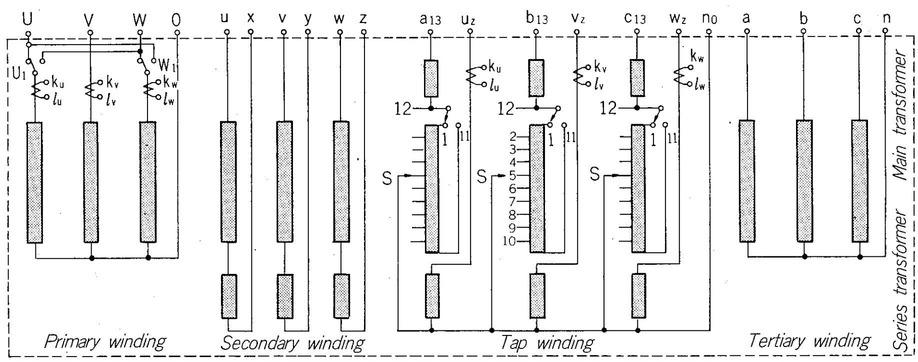


Fig. 6 Connection diagram of furnace transformer

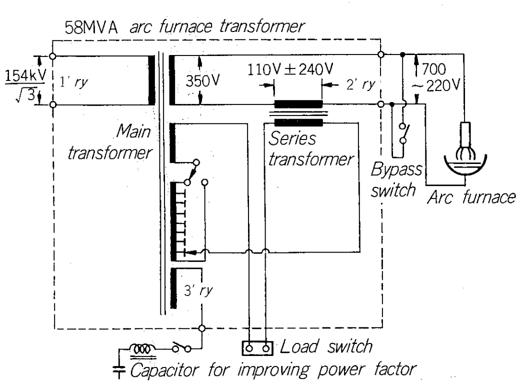
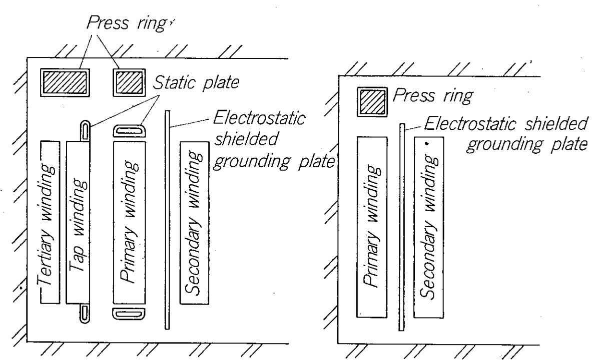
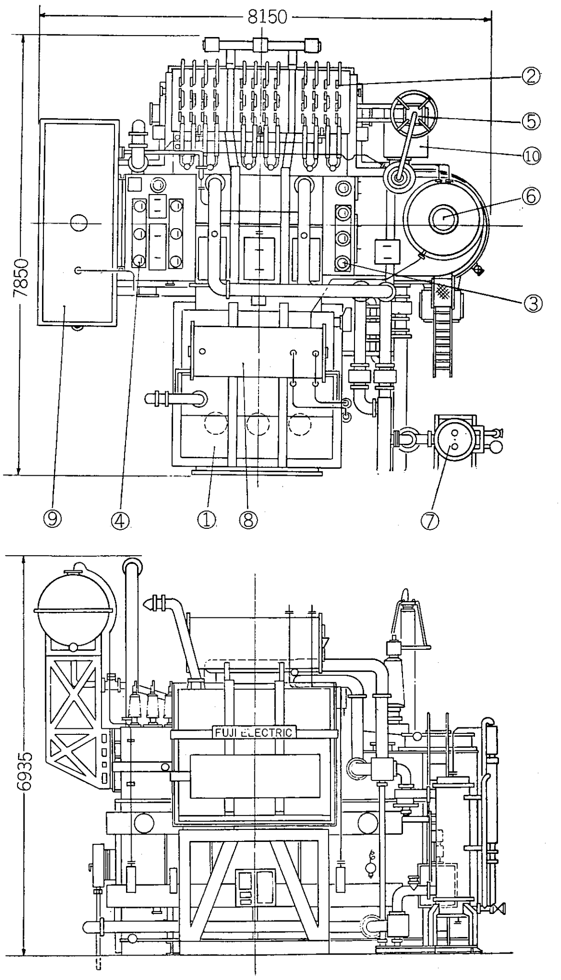


Fig. 7 Single phase connection diagram



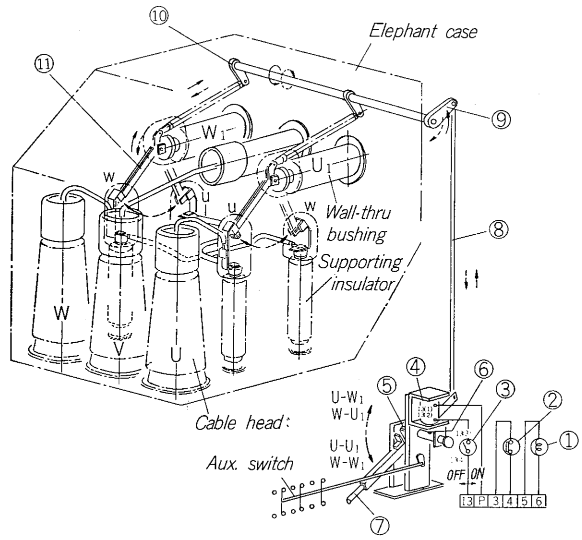
(a) Main transformer (b) Series transformer

Fig. 8 Arrangment of windings of transformer



1. Elephant case with primary phase changer
2. Secondary terminal
3. Tertiary bushing (for connection of capacitor)
4. Connecting bushing of circuit breaker for load switching
5. Primary neutral point with arrester
6. On-load tap changer
7. Separately-installed water-cooled cooler
8. Elephant conservator
9. Conservator for transformer proper
10. On-load oil purifier

Fig. 9 Outline of furnace transformer



1. Door interlock magnet
2. Limit switch
3. Selector switch
4. Interlock magnet
5. Lock pin
6. Plunger
7. Control lever
8. Connecting rod
9. Crank
10. Crank mechanism
11. Blade

Fig. 10 Construction of elephant case with phase changer

3) leads can easily be drawn out. This may be said to be a winding which is most suitable for low voltage large current.

Also, for the tap winding, a multi-parallel cylindrical winding has been employed that there is little shift of magnetic center even if the tap voltage varies and very little axial electromagnetic force is generated.

4. Special High Tension Phase Changer Elephant Case

Since the arc furnace transformer is generally installed in a dusty and small room, it is the best way to employ a so-called elephant construction that leads special high tension cables directly in the transformer without exposing the high voltage part.

The elephant case employed this time contains the phase changer which changes over the phase sequence at the primary side for reversing the phase rotation at the secondary side as the countermeasure for hot spot.

The construction of elephant case with phase change is as shown in *Fig. 10,* and it is basically identical with the disconnecting switch-equipped elephant case which has been manufactured in quantities by Fuji up to now. The higherto-acquired technical experience in the manufacture has enabled the elephant case to be made in considerably compact although being a specially high voltage said to be 154 kV.

5. Low Tension Water-cooled Terminal

Recently even in Japan, large capacity and ultra high power operations tend to be made because of the progress in the arc furnace techniques. Therefore, as the secondary side of furnace transformer is becoming lower and lower in voltage and larger and larger in the magnitude of current, the leading terminal is one of the important parts. Generally at the secondary side, open delta connection is made, and at the outside of transformer, delta connection is made. As the condition of connection at this section has a great effect on the plant efficiency, it is required to connect compactly with a water-cooled pipe conductor. Accordingly, by employing a water-cooled construction even for the leading terminal of the transformer, the terminal becomes small in size and compact external connection becomes possible.

Fuji has been employing a water-cooled terminal for the secondary terminal of electric furnace transformer since a long time ago, and its rationality has already been field-proven.

Since a few years ago, a further improved water-cooled terminal has been used, and this is highly reliable electrically as well as mechanically and also, viewing from the oil tight performance along with ease of assembly because of the epoxy mold bushing and rational gasket construction.

6. On-load Tap Changer

As the speciality involved in the arc furnace transformer, such severe performances are required that tap change is made as many as several hundred times a day and also, when short is generated across the electrodes in the furnace in the course of tap changing, short-circuit current which is a few times as many as the rated current flows and this current must be interrupted.

3DSCP type on-load tap changer employed this time has a long service life with a great reliability and fills these requirements. This tap changer has been delivered so far in quantities including that for arc furnace transformer, and its superior performance has already been acknowledged widely even from the operating records. The changeover switch room is separated from the transformer proper with a metallic cylinder, and oil contaminated by frequent tap changing can be purified by the on-load oil purifier without tripping the transformer.

Also, the inspection and maintenance of the change-over switch can be made by drawing out independently of the transformer proper and can also be replaced with new one.

7. Forced Oil Water-cooled Transformer

For this transformer, four separately-installed, unit type vertical water-cooled cooler (including one reserve) are in use. For the cooling pipe, deoxidized copper pipe has been used taking account of corrosion resistance. Fuji's water-cooled cooler is of straight pipe type which provides easy cleaning of the pipe interior.

Employed this time is a large capacity cooler with high efficiency which consists of 208 cooling pipes. It has been so designed as to enable efficient operation to be performed by changing the number of coolers used according to the rated capacity operation and overload operation.

The hydraulic pressure in the cooler has always been kept lower than the oil pressure of transformer to prevent water leak into the transformer in the unlikely event of the pipe breaking.

8. Transport

This transformer was directly put on board from the quay of the Chiba Works of Fuji, marine-transported to the quay of the Sendai Plant of Azuma Steel Co. and landed by 200-ton floating crane.

In the plant yard, it was carried about 600 meters to the building by using rollers and installed on the foundation bed by 120-ton crane.

9. Transferred Voltage

Surge voltage coming into the primary winding of transformer is transferred to other windings statically and magnetically.

The static transferred voltage is, what is called, a voltage generated in the secondary winding by the capacitor divided voltage, and it is obtained from the formula below.

$$V_2 \doteqdot \frac{C_{12}}{C_{12} + C_{2E}} \cdot V_1$$

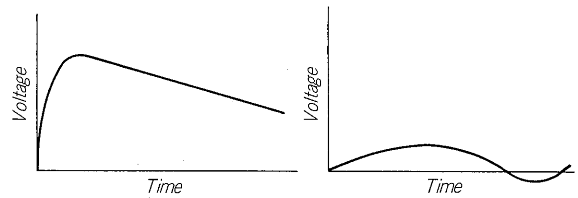
Where: V_1 : Surge voltage
C_{12} : Static capacity across primary and secondary windings
C_{2E} : Static capacity across secondary winding and ground

Electromagnetic transferred voltage, as in the principle of transformer, is a voltage produced in the secondary winding by electromagnetic induction action, and it is obtained by the following formula.

$$V_2 \doteqdot k \cdot \frac{N_2}{N_1} \cdot V_1$$

Where: k : Constant fixed by connection, etc.
N_1 : Number of turns of primary winding
N_2 : Number of turns of secondary winding

The actually produced transferred voltage is produced by superimposing the static and electromagnetic transferred ones, and it generally takes such waveform as shown in *Fig. 11-(b)* in relation to the incoming surge voltage in *Fig. 11-(a)*. However, the crest value becomes small accordingly as the earth capacitance of the secondary winding increases.



(a) Incoming surge voltage (b) Transferred voltage waveform

Fig. 11 An example of incoming surge voltage and transferred voltage

An effective step for suppressing the transferred voltage is to increase the static capacity across the secondary winding and ground, and in this transformer, a surge absorber and static shield have been installed effectively. Also, for the tap circuit and tertiary circuit, an arrester has been provided aiming at protecting against surge.

Moreover, the transferred voltage is measured by analyzer twice, i.e., before putting the interior of transformer in the tank and after the transformer is completed, to ensure that the transferred voltage is fully suppressed and there is no problem in insulation.

10. Overloading Capacity

The load conditions of this transformer are as follows. At the tap of more than 580 V of secondary voltage;

Melting period 120% (58 x 1.2 = 69.6MVA) . . 60 min.
Refining period 75% (58 x 0.75 = 43.5MVA) . 15 min.
Charging period 0% . . . . 15 min.

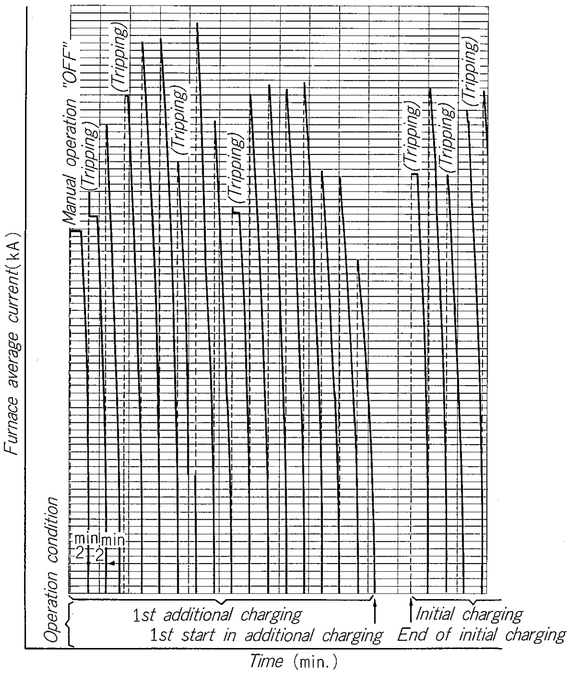


Fig. 12 Root mean square oscillograph of secondary current

Now, assuming the temperature difference at which the life halves is 6 deg., the life loss of transformer, V is expressed as follows in general taking the fact that temperature at the maximum point, θ varies as time goes by into consideration.

$$V = \frac{1}{Y_0} \int e^{0.1155(\theta-95)} dt$$

In the above formula, Y_0 is the life (normal life) in the case where continuous operation is made at the maximum temperature of 95°C.

Therefore, the life loss in the case that continuous operation is performed at the maximum temperature of 95°C a day (24 hours), V_0 becomes as follows.

$$V_0 = \frac{24}{Y_0}$$

On the other hand, the temperature curves between oil and winding with respect to the abovementioned load cycle are as indicated in *Fig. 13.*

Assuming the life loss as per day (24 hours) at the temperature curves is V_1, if V_1 is smaller than/equivalent to V_0, $V_1 \leq V_0$, the normal life of transformer can be expected.

When designing this transformer, full consideration has been given with careful examination of the life loss so that the normal life is assured.

The essential capacities of each winding are as follows:

Main transformer:

Primary winding	58MVA
Secondary winding	$58 \times \frac{350}{580} = 35$MVA

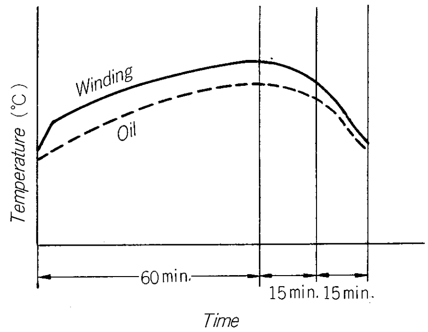


Fig. 13 Temperature curves between oil and winding

Tap winding	$58 \times \frac{350}{580} = 35$MVA
Tertiary winding	35MVA

Series transformer:

Primary winding	$58 \times \frac{350}{580} = 35$MVA
Secondary winding	$58 \times \frac{350}{580} = 35$MVA

Consequently, the equivalent essential capacity of this transformer is expressed by the numeric value obtained by dividing the total of essential capacities of each winding by 2, that is, it becomes 116.5MVA.

When taking notice of the secondary winding, the total of capacities of secondary windings of the main and series transformers becomes 70MVA.

Also, the total of capacities of tap winding and the primary winding of series transformer becomes 70MVA. To be short, the secondary and tap circuits of this transformer is 70MVA in capacity. The secondary current becomes the maximum 69,300 A in the melting period, which is the largest current value in Japan as the steel making arc furnace transformer.

Further, for the mean value of irregular current as in the steel making arc furnace, with the measurement of root mean square current shown in *Fig. 12,* the secondary current is flowed up to the allowable limit of the transformer for ensuring effective operation.

V. AUTOMATIC ELECTRODE REGULATING DEVICE

The automatic control of electrodes in the steel making arc furnace is necessary for delivering the power to the furnace effectively, and a quick control is required that follows the kaleidoscopic change in the furnace conditions due to melt-down of scrap, short across electrodes, change in arc route, etc.

Fuji has employed the so-called impedance control system which maintains the ratio of electrode current to voltage constantly as shown in *Fig. 14,* and as the motor for lifting the electrodes, a wound-rotor type induction motor with small GD^2 has been used. The torque of motor is

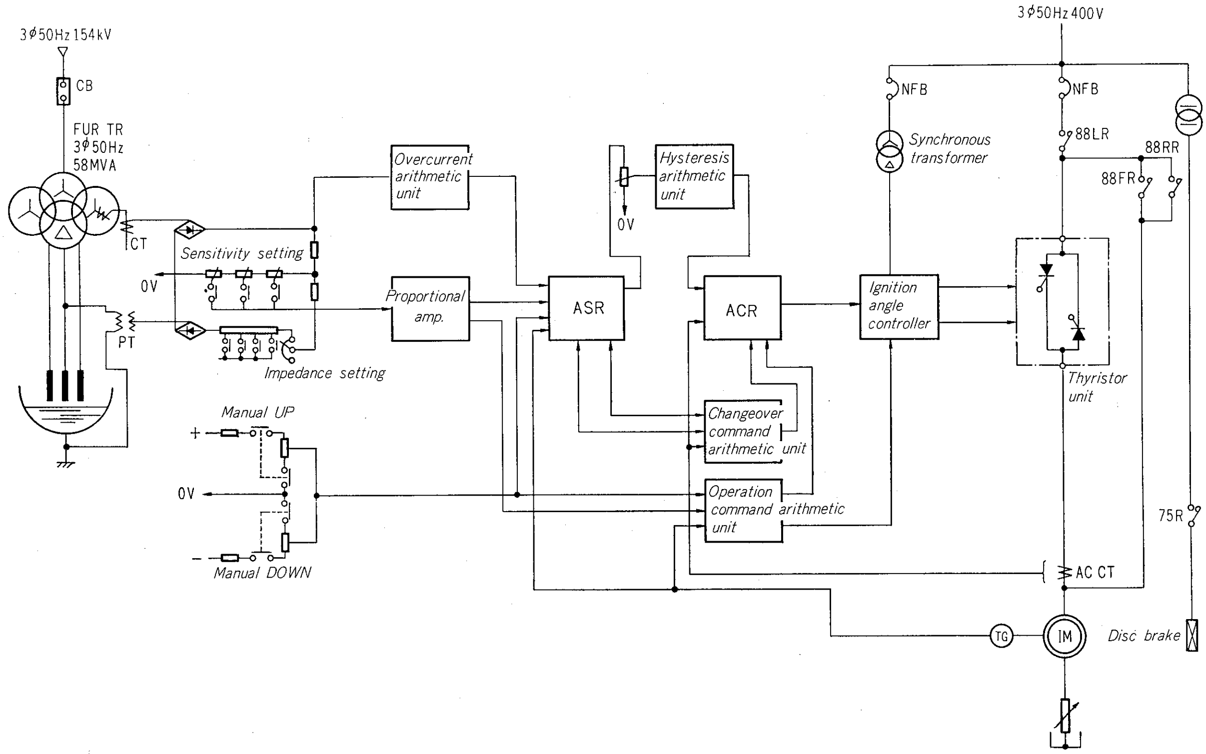


Fig. 14 Block diagram of automatic electrode regulating device

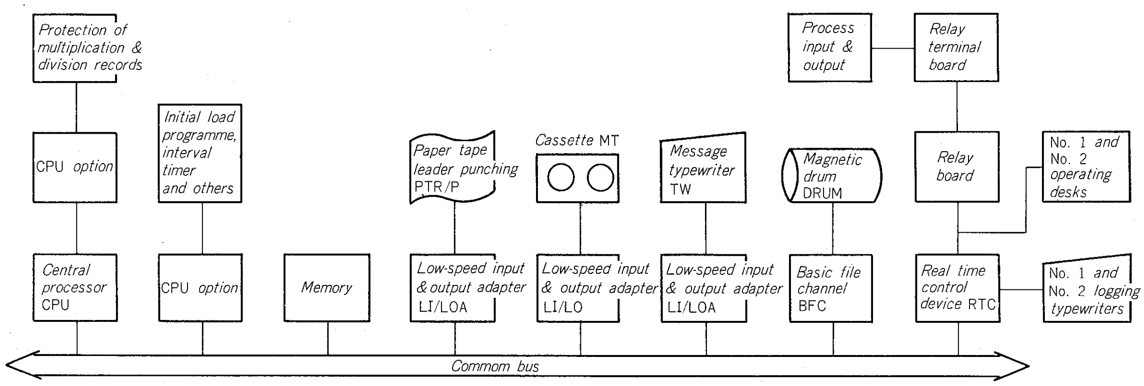


Fig. 15 Features of computer control system

changed by controlling the primary voltage through adjustment of the ignition angle of thyristor in order to control the lifting speed of electrodes.

The motor is installed adjacent to the furnace, where ambient temperature is high and much conductive dust by scrap is present, therefore it has been so constructed that maintenance can be made easily in addition to the employment of totally-enclosed forced air cooling system.

VI. COMPUTER CONTROL SYSTEM

A tendency to install an automatic optimum operation device for most steel making arc furnaces is seen lately. And, it was discussed in various aspects about whether the conventional type control device or computer control system is employed for this equipment, and as a result, it has been decided to employ the computer control system.

VII. CONCLUSION

Thus, UHP steel making arc furnace electrical equipment, which is the largest class in Japan, has been outlined. We are very happy if this report is useful as reference for the electrical steel industry which will develop more and more hereinafter.

In closing, our sincere thanks are given to the personnel of Azuma Steel Co. and Nippon Kokan K.K. Who gave us their kind cooperation and many helpful suggestions in the planning and manufacture of this equipment which will remain as a great achievement in the history of electrical steel industrial field in the world.