ELECTRICAL ASPECTS OF FERRO-ALLOY FURNACES

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Introduction

Quality and quantity of the product of ferro-alloy furnace depends on the availability of desired intensive electrical power at required voltage and current, reliability of furnace control. Economy of the furnace, demands for proper planning and operation of ferro-alloy furnace to utilise electrical power at optimum condition to achieve the desired goal.

An attempt is made to describe in brief about the entire electrical aspects of ferro-alloy furnaces. These are:

- Power supply system
- Furnace control
- Economy of furnace operation
- Effects of electrical quantity
- Maintenance and further scope of development of automation

1. FERRO-ALLOY FURNACE

1.1 Basic Principle

Ferro-alloys are normally produced in a submerged-arc electric furnace, in which electrical energy is converted to heat energy by applying a.c. voltage between electrodes, submerged into charges. Heat is mainly produced due to resistance of charge, whereas heat by arc is avoided.

Heat generated by electric current through the arc (if any), melt and charge in a given time is given by:

$$Q = I^2 R\ t$$

where: Q is the quantity of heat, in Joules; I is the furnace current, in amps; and T is the time, in seconds.

Ferro-alloy furnaces are divided into main groups: (a) ore smelting furnaces and (b) refining furnaces. These furnaces may be of one or three phase type.

Furnace components are mainly subdivided into three groups:

A) Power suply equipment
B) Controlling equipment
C) Main furnace

There are two types of process operation: (a) continuous and (b) batch smelting. In continuous operation, power is applied uninterruptedly and furnaces has a constant power input. Charging is done in small batches and metal is tapped periodically. Silicon alloy, ferro-chrome, ferro-manganese are examples for this.

Batch smelting processes such as the production of refined ferro-chrome, requires variable power input at different period and causes unstable operating conditions.

Each furnace requires definite operating condition i.e. a relationship between furnace, electrical characteristics (rating, current, voltage, corresponding electrode position) to provide maximum furnace productivity with minimum consumption per ton of alloy.

1.2 POWER SUPPLY SYSTEM

Electrical power required in ferro-alloy furnace for ore smelting is 3-phase power of the order of 5000 to 20000 kva, at a voltage in the range of 50 to 170 volts. As such the current drawn at the low voltage is of the order of 30000 to 100000 amps. Various electrical equipment used in the ferro-alloy furnace is given in Fig. 1. Brief description of their functions and rating is given here.

Three phase power at the sub-station at 6.6/11/33 k.v. is made available by two independent sources of power supply : A and B, and fed to the transformer through H.V. isolating switch, operating at no load. The power supply from the two sources are linked in such a way that only one of the isolating switch is put on to feed power to OCB either from source A or B keeping the other isolating switch in off position.

1.2.1 OIL CIRCUIT BREAKER (OCB)

Three phase power from supply system coming out of the isolating switch is connected an OCB of suitable rating. OCB is an electric device which can interrupt (make, or break) power supply under load and may withhold very high current under short circuit for a specified time. OCB is interlinked with protective system to tripout under condition of over load, short circuit and earth fault. In ferro-alloy furnaces interruptions are quite common, interruption of the order 130 per days are reported in the literature [1]. OCB used for ferro-alloy furnaces are provided with proper moving and fixed contacts and an arc extinguishing device.

The important parameters of an OCB is its rated voltage, rated full load current, rated short circuit current and making and breaking capacity. These have to be carefully chosen, based upon the circuit parameters of the ferro-alloy furnace.

1.2.2 TRANSFORMER

Transformer is a device to step down/step up the supply voltage. Iin ferro-alloy furnaces, transformer is used to step down power supply from high voltage to a desired low voltage, to be supplied to the electrodes. Variation in secondary voltage is often desired (a) due to different power input requirement at start of furnace and during smelting, (b) due to change of resistivity of charge of varied characteristics. The transformer is provided with several output voltage tappings to meet the different power requirements. Transformer primary is kept open to enable them to be connected either in star or delta made. Generally 4 to 12 taps are provided in the transformer. Variable voltage can be obtained by changing the tap, which changes the turn ratio. Secondary voltage of transformer, is given by formula :

$$E2 = \frac{E_1}{n1/n2}$$

where n1 and n2 are the number of turns of transformer primary and secondary and n1/n2 can be changed by changing taps.

Primary winding of the transformer is strongly secured in position against the strong mechanical stresses developed in the winding during short circuits. Because of the low voltage in the secondary of the transformer, current is very high, of the order of upto 100000 amps. As such secondary winding is very carefully designed. To minimise the resistance and reactance of the transformer, secondary winding is kept nearer to the electrode.

Resistance and reactance of the transformer plays an important role in operation of furnace. Low resistance is preferred to minimise copper loss and low reactance is used (a) to minimise voltage drop to provide good voltage regulation and (b) to improve the power factor. Generally the transformer of ferro-alloy furnace is designed for low reactance of the order of 3-4%. Shell type transformers provides low reactance and better support for winding under mechanical stress produced under short circuits. Materials of core and its thickness is properly selected to minimise care losses.

Losses (of the order of 2%) of the transformer generates heat in the core and in the winding. To dissipate the heat generated the core is kept in tank filled with transformer oil, which cools the core and winding. Besides cooling the core and winding, transformer oil preserved them from injurious action of air. Furnace transformer have a cooling system with forced circulation of oil through water cooled column. The diagram of such a device is given in Fig. 2.

In brief, a transformer possess the following properties:

a) Ability to withstand great loads without temperature rise
b) Withstand mechanical stresses developed during short circuits
c) Sufficient number of taps available to adjust power input as required for the process
d) High transformer ratio

1.2.3 REACTOR

Reactance of the transformer, of the order of 3 to 4% is not sufficient to keep short circuit current and surges within the desired limits. Small transformers are therefore frequently equipped with separate reactors which can be assembled in the oil tank of the transformer. The reactors are iron core type and are conveniently equipped with taps so that the inductance can be selected to meet the operational needs. The supplementary reactors provides additional reactance in the range of 30% (for small transformer) to 15% (for large transformer).

Switches for selecting the reactor taps can be combined with the tap selector switch on transformer. The latter also takes care of the star-delta connection on the transformer. Reactor, instead of being ahead of the transformer, can be combined with the primary winding, in which case the reactor has two windings;

one for line to line and other for line to ground operation.

1.2.4 BUSSES

Current flowing in the low circuit, from the transformer secondary to the electrode of the furnace is of the order of upto 100000 amp. This calls for a careful design of current carrying elements. In fact, the maximum power from a transformer is limited by factors such as inherent resistance and reactance and a successful design of the busses.

Current carrying system consists of three parts: rigid busses - current from transformer to the vicinity of furnace; flexible cables - connecting rigid busses to electrode column. and current conducting pipe - connecting flexible cable to electrodes.

The length of current carrying element should be as small as possible to minimise resistance and reactance for minimising losses, improvement of power factor and for improvement of voltage regulation; which is essential for stable operation of furnace. Selection of desired voltage drop, energy loss, cross section and arrangement of busses are important. Copper is used for rigid busses, either as a number of parallel conductors of small cross section or hollow water cooled copper tubes.

Flexible cables are made of stranded copper (700-1200) of 60 to 40 mil thick. For very large currents, a number of such cables may be used. However this may increase reactance due to proximity effect.

In some instances, water cooled cables have been used. Number of relatively smaller diameter cables are arranged around a core and cooled from out side by a rubber hose. The necessary cross section of copper has been decreased to 25% of the cross section needed without water cooling.

Power to electrode is fed through copper pipe and clamp. Clamp is meant to hold the electrode in a definite position and to ensure perfect electrical contact between clamp and electrode.

Electrode clamp operates in high temperature condition of the order of 400-600°C and consequently should be provided with reliable water cooling system. Contact clamps are made of copper or copper alloy to have low resistivity and satisfactory heat conduction and designed for current density is 1.4-1.7 A/cm2.

A number of electrode holders equipped with remote control slipring mechanism have been designed to facilitate the slipping of electrode.

Water consumed to cool contact clamp, electrode holder, electrode shell and supporting frame work is 5 m3/hr per 1000 kVa of transformer rating. Salt deposits in water cooling system is removed by flowing dilute solution of hydrochloric acid.

2. FURNACE ECONOMY

Heat losses play a major role in determining the economics of a furnace. Heat losses can be classified to two types, proportional and nonproportional. Proportional losses are those losses, which changes with load of the furnace, non proportional losses are those, which do not. The entire economics behaviour of a furnace changes with the prevalance of one or other type of loss. General streaking furnaces, with predominantly proportional losses will be superior at low load, while furnace with predominantly nonproportional losses will be superior at high loads.

There are a number of furnace in which an increase in one type of loss automatically brings forth an increase in the other type. These losses are called dependent losses. If the losses do not depend on other losses, they are called independent losses. A graphical representation of heat balance is shown in Fig. 3(a) and 3(b). Most of the electric losses are dependent losses, whereas losses through lining are independent losses.

Heat efficiency of a furnace can be entirely different for different processes even if all processes are carried out at the same temperature. The efficiency for some operation also differs for different types of services: continuous or intermittent. Efficiency is also effected by type of loading and duration of door opening. Specific power consumption under various operating conditions is an appropriate term for the comparision of heat efficiency.

2.1 FACTORS AFFECTING ECONOMY

Economic operation of a furnace, is largely dependent on the power consumption and power cost. To decrease the power consumption, following steps are taken into consideration:

a) Avoid additional heat losses, such as, that may result from keeping the door/cover open longer than required.
b) Avoid as far as possible temperature changes in furnace
c) Maximum utilisation of ruance volume and timely charging and tapping.

For decreasing the power cost, furnace operation may be properly plananed, keeping into consideration of other electric loads (i) to reduce maximum demand and (ii) to save energy. Power factor should also be improved to avoid tarriff restriction and to reduce power demand.

2.2.2 ENERGY LOSSES

Energy losses are compared of heat and electrical power losses.

In ferro-alloy furnace, heat losses occurs in various parts of the furnace. Electrical power loss occurs in the equipment supplying power to furnace. These are:

A Heat loss through walls, doors, electrodes
B Heat loss through escaping gases
C Power loss through electrical equipment and supply line

(i) Transformer (ii) Reactors (iii) Busses, (iii) Flexible cables (iv) electrodes.

The losses occuring in the transformer and the reactor are independent core losses and dependent copper losses.

Figure (4) indicates the energy balance where UF designate the useful heat, including the energy absorbed to raise the temperature and energy necessary for endothermic reaction. UE is the energy input at the electrode (where UE>UF). UE-UF takes into account electrode losses due to current only. UB indicates the energy input at the busses. The difference UB-UE is the energy losses in busses. These losses are proportional to the current passing through busses. UTS is the energy at the secondary of the transformer. UTS-UB indicates energy losses in the secondary winding of transformer. UTP is energy input to the primary winding of the transformer and UTP-UTS indicates losses in the primary winding of transformer or UTP-UB is the total energy losses in the primary and secondary winding of the transformer, known as copper losses, which is dependent on load current. Independent core losses is considered separately and shown in Fig. 4. These core losses are total core losses occuring in the transformer and reactor.

Independent losses like losses through walls, window, roof, electrode, gases are also indicated in Fig. 4. Calculation of losses through wall is difficult due to various reasons:

a) Non homogeneity of wall
b) Changed shape and thickness of lining in service
c) Heat storage in furnace walls
d) Interaction with other heat loss item

Wall losses are low for new lining and increases with time and wall losses are higher for a larger furnace. Figure 5 shows the total wall losses plotted as a function of furnace size for a new lining and old lining seperately.

Hot gases, which carry away sensible heat escapes through the electrode and doors. This can be minimised by cutting down the operation time to a minimum. In ferro-alloy furnaces which operates without cover, the amount of these losses is estimated to be of the order of 35% of the energy supplied to the furnace.

2.3 WATER COOLING

Water cooling of the furnace shell and electrical contacts are necessary to minimise over heating. The water cooled components are transformer, reactor and various parts of furnace shell, components, electrode ring, roof ring (if any), door frame, and entire electric busses.

Electrode rings are water cooled to protect the lining of roof, to cool outgoing gases and to avoid burning of the electrode. Cooling of electrode will increase the life of lining but at the cost of heat loss. Average loss through cooling water is estimated to be 18 kw. Flexible cables are also water cooled and the losses is of the order of 10 kw per electrode.

Total water used in electric furnace is of the order 400 to 6000 litres per hour including water cooling of electric equipment. The exact amount depends on the size of the furnaces. Figure 6 shows a plot of water consumption for various capacities of furnace.

In transformer, increase in water temperature should not be more than 5-10 ^{0}C whereas that in furnace parts, not more than

10-20^{o}C. Hence, if water flow is in series, then water is first fed to electrical parts and then to the furnace part.

Automatic control of water adjustment as per temperature is feasible and could be result in saving. Water being good conductor to avoid earthing through a water, electrical parts cooled is insulated or are not made direct contact with water, e.g. electrode ring is cooled instead of electrode.

3. FURNACE CONTROL

Smelting of different ferro-alloys required different temperature of operation of furnace.

The control of temperature is achieved by control of power input, the input being selected by the operator, to meet the requirements of operation. The input power is controlled by a change of the secondary voltage and/or a change of current. Selection of voltage is carried out by change of taps on transformer and reactors. Change in current for a given voltage can be done by changing the resistance. This achieved by lowering/raising the electrode in the charge.

3.1 CURRENT DETERMINATION

Electrical parameters for ferro-alloy furnace can not be determined before hand. It is therefore desirable to investigate the manner in which experience acquired from an existing furnace can be applied to the design of new furnace. If the data are available for one furnace in operation, the relationship of resistance, voltage, power and current to the electrode can readily be determined. However problems of parameter determinational will prevail for a process involving new raw materials of changed sizes and compositions.

A study of several furnaces of different sizes working on the same product with the same raw materials seems to show that for satisfactory conditions, the product of resistance in the furnace times the diameter of the electrode varies within narrow limits. This means that the path of the current between the electrode and the furnace bottom has a constant resistance for a certain fixed segment of electrode periphery. It is made of a certain number of parallel circuits of same width, the resistance (R), varying indirectly proportional to the periphery (or diameter)(D) of the electrode. This is expressed by the formula :

$$RD = C$$

where C is the proportionately constant.

The value of "C" varies with the product and further same product with raw materials used; D is the diameter of electrodes and R is the furnace resistance.

For normal conditions of electrode operation, the current should be changed with (3/2) power of the electrode diameter [2] i.e.

$$\frac{\underline{I}}{I} = \left[\frac{\underline{D}}{D_1} \right]^{3/2} \quad \frac{\underline{W}}{W} = \left[\frac{\underline{D}}{D_1} \right]^{3/2} \quad \frac{\underline{E}}{E} = \left[\frac{\underline{D}}{D_1} \right]^{3/2}$$

It is seen that power densities (w/cm2) in electrode are constant.

3.2 CHARACTERISTIC FUNCTIONS

Plots shown in Figure 7, shows limit between which the furnace will operate satisfactorily. This is drawn for carbon electrode of 30o diameter and for indirective reactance of 0.0009 above. The characteristic parameters of the electric furnace are : the contract power factor, the maximum current, which the electrode will stand; the highest and lowest taps; the highest resistance at which the furnace will operate satisfactorily; and the capacity of the transformer.

The above diagram also indicate that these taps should be close for satisfactory operation of ferro-alloy furnace. Further, resistance and power factor decreases with the size of furnace and becomes unsatisfactory at furnace size more than 4000 kw.

3.3 CURRENT DISTRIBUTION

3.3.1 SINGLE PHASE FURNACE WITH ONE CENTRALISED ELECTRODE

This is schematically represented in Fig. (8). In this case, the dimensions of the furnace are important : D1, the diameter of electrode; D2, inside diameter of crucible; H, distance between electrode tip and hearth.

In the zone "d", resistance of charge and facing 'd' is so high that no appreciable current passes there. liquid ferro-alloy accumulates in zone g-j, being of different level before and after tapping. The shape of zone "f" of most intensive reaction is not known. It depends on value of D1, D2, and H as well as the current density of the electrode. From any point, m on the perimeter of the tip of the electrode, the current flows in two direction : towards bottom, 'b' and side 'c'. The current path towards the bottom has constant cross-section. The energy production of various levels change only with the resistivity of the material.

The flow towards sides 'c', however is a radial cylindrical flow, having at its disposal increasing cross section, with decreasing resistance. The energy production towards the outside becomes smaller due to decreasing resistance consequently the temperature at outside is lower. The ratio D2/D1 determines the electrode resistence for radial flow. If D2/D1 is too small an excessive amount of current flows to sides and sides burnt-out. As this ratio increases, current flow to sides decreases and at some value of D2/D1 there will be no current flowing from the electrode sides. When such condition reached, the walls "c" are protected by a layer of unmolten areas and entire current flow is directed downward. This result in saving in life of side wall, but probably a decrease in electrode life. Almost entire electrical energy is now forced downward. A higher electric load in such a case can be achieved only by increasing D1 (off coarse also D2 in order to maintain desired ratio D2/D1). Actual value of D2/D1 at which no lateral flow occurs depend on the material in question and on the value of "H", the greater the 'H' is, the higher D2/D1 must be to avoid lateral flow. Practical current takes curves as shown in Fig. (9). Practice favour this axial flow of current.

3.3.2 SINGLE PHASE TWO ELECTRODE FURNACE

If electrodes are placed too close together, current will flow from one electrode to the other, rather than from either electrode to the bottom. Under this condition, the electrode would burn off unevenly. It is desirable to space the electrodes so far apart that the current flows only from the electrode to the bottom.

3.3.3 THREE PHASE FURNACE

In this case, electrodes should be placed sufficiently away such that current does not flow from one electrode to the next electrode. The furnace should really consists of a number of single phase unit; each being connectd to a diferent phase on one side and to a common neutral on the other side.

3.4 PERMISSIBLE ELECTRODE CURRENT

The temperature drop in the electrode is very steep. If the end of electrode extending into the charge is deep, in such a case, the temperature of electrode tip increases resulting in burning of the electrode. The greater the depth of immersion of electrode, the smaller the permissible electric load of the electrode. If in a shallow furnace, the current charging capacity is 30000 to 32000 amps, current would be only 19000 amps, if depth of immersion is 10 ft. Figure (10) shows that the permissible current decreases with increasing depth of immersion for various electrode diameters.

3.5 METHODS OF ELECTRODE CONTROL

The measuring element in any electric control is a current relay. Figure (11) illustrates the wiring diagram for one electrode. For a three phase furnace, three such circuits are necessary. The electrode motor is d.c. operated and has a shunt field supplied directly from an independent source. Armature is fed from amplidyne generator, the polarity and voltage of which depend on the direction and magnitude of the current in regulating field. The regulating field is supplied by two rectifiers "A" & "B", which are connected through a Rheostat with opposing polarity. Rectifier "A" supplies a direct current proportional to the electrode current; rectifier B supplies current proportional to the voltage between electrode and ground. When two voltages from A & B are equal, no current flows in the regulating field. As one or the other voltage predominates, the current in the regulating field will flow in the direction of dominant voltage. Limit switch are used to prevent travel of the electrodes beyond limits. The rheostat is used to adjust the equilibrium ratio A & B, so that any desired electrode current can be maintained. All parts of secondary importance are omitted in the diagram.

4. EFFECT OF SOME ELECTRICAL QUANTITIES ON FURNACE OPERATION AND PERFORMANCE

4.1 EEEFECT OF VOLTAGE FLUCTUATION

Line voltage fluctuations in ferro-alloy furnaces is of more concern, because of large sizes and load of alloy furnaces. As the entire operation of furnace depends on secondary voltage, the input to the furnace decreases if the sub-station voltage drop is more than can be compensated by the change of taps of transformer. Undesirable effects of line voltage fluctuation are difficulties in (A) operation (B) control (C) power contract

4.1.1 DIFFICULTIES IN OPERATION

Furnace is normally operated at constant load. Therefore currents remains constant if the voltage remains constant. If voltage drops, current drops. To maintain a constant power, current is increased by lowering the electrode. This however, results in a decreased power factor due to decreased resistance.

4.1.2 DIFFICULTIES IN CONTROL

A control based only on total power is unsatisfactory. This is substantiated by the data given in table 1. Ideal control should be based on useful power, with provision made for automatically reducing the power setting, particularly, if the electrode comes close to the bottom of the furnace.

However, since the measurement of the useful power is not practically possible, control based on total power, automatically adjusted with voltage charges, would be the desirable solution.

4.1.3 DIFFICULTIES WITH POWER CONTRACT

Power contract is based on demand charges during maximum peak over a predetermined period (30 minutes or 1 hr) and have PF clause penalizing the customer when the power factor drops below a given value. This PF is taken at the time of peak. During low voltage, current is increased to maintain constant power, by lowering the electrode, effecting low PF. If low voltage and monthly peak occurs at the same time, the PF will be most unfavourable and user is penalized for this poor PF.

During period of high voltage supply, to increase the resistance of the furnace, electrode to minimise current for maintaining cores power. This may create danger that electrode may leave the furnace. To avoid this operator will risk an overload during high voltage supply, without changing the position of electrode. This will increase kva demand. In order not to exceed his demand charge, he may, then shut down the furnace for the balance of the measuring periods (15 minutes). Cutting out so heavy loads in furnace would creat considerable disturbance in system and in other plants.

These problems can be solved (a) by liberal contracts, which is not practical as supply authorities will not agree (b) by installation of voltage regulator to provide constant voltage at the supply input.

4.2 SURGES

Voltage surge in electric furnace occurs when:

a) load is changed suddenly - low to high or vice versa by raising or lowering the electrodes
b) breaking of current by circuit breaker
c) changing the taps of transformer during load

If instant of switch off coincides with extinguishing of the arc, surges appear. Surges due to switching do not occur in all three phases; in fact 72% occur in one phase only 25% in two phases and only 2% in all the three phases [2].

4.2.1 EFFECT OF SURGES

Usually surges of short duration (fraction of cycle) affects the equipment : transformer, reactor etc. while surges of larger duration (few cycles) cause fluctuation of voltage hence flicker of light. The surges, effecting voltage fluctuation also produces effect as discussed in 4.1. Surges can be reduced by capacitor or lightening arrester between line and ground as shown in Fig. 12. It can also be reduced by a reactance added in the circuit.

4.3 POWER FACTOR

Power factor in a.c. supply defined as cosine of phase difference between voltage and current. If the AC supply, if the AC supply is connected to a pure resistance, voltage and current will be in the same phase, with m = 0 and CoSm equal to unity. If AC is supplied to a pure reactance or pure capacitance will be 90o and CoSm is zero. For AC supply to resistance inductance or capacitance, m will range between 0 to 90o, with current lagging or leading respectively for inductive and capacitive load. Correspondingly, PF will be less than unity. For three type of load connected with AC, phase relation is shown in Fig. 13 (A to C) and for combination of resistive and inductive load, it is shown in Fig. 13 (D). Load of ferro-alloy furnace is inductive, resulting in a power factor lag. If the inductive reactance of the furnace increases due to any operational control then pit may become so poor that penality clouse may be imposed by supply authority. Under that situation it may become necessary to improve the P.F. power factor.

4.3.1 METHODS OF IMPROVEMENT OF POWER FACTOR (PF)

The most common method of improving power factor is with the application of a capacitor bank. Phasor diagram of inductive load of Fig. 14 (A) is shown in Fig. 14 (C), indicating power factor angle m, which is lagging. Angle m can be decreased by putting a capacitance in circuit as shown in Fig. 14 (b), corresponding phasor diagram is shown in Fig. 14 (C). Capactive reactance neutralises the inductive reactance to reduce m to m1 and improves correspondingly. Power facter (CoS m). Depending on the requirement, capacitive reactance can be increased to achieve desired PF by changing capacitance of capacitance bank.

4.4 KVA, KW & KVAR

Electrical power in AC circuit is indicated by KVA, KW, KVAR in which KW is the actual power consumed by the load, whereas KVAR is the reactive power responsible for deviatian of PF. Phase relation of these power is shown in Fig. 15.

4.5 ENERGY MANAGEMENT

With increasing rate of electrical power, particularly under insufficient availability of power, it becomes very important to provide proper management of power in power intensive ferro-alloy furnace. Electric charge is based on (i) fixed charge on contracted demand and (ii) energy charge on actual energy consumed. Besides this penality clause is imposed if PF of load decreases beyond desired value. As such effort is made to estimate the power requirement as far as possible near actual requirement and thereafter perform the operation of furnace in such a way that even peak power demand do not exceed contractual demand, keeping PF above the desired PF restriction imposed by supply authority. If the load diagram of the load of entire plant, excluding furnace is known then furnace can be operated in such a way that constant demand of power can be achieved round the clock. (8)

4.6 MEASUREMENTS

During the operation of furnace, it is essential to measure (i) voltage, (ii) current, (iii) KVA, (iv) KW, (v) KVAR; (vi) temperature at various parts of furnace, oil, water, (vii) flow of water, P.T. is used for the measurement of voltage where as C.T. used for measurement, sensing of current for various relays.

5. MAINTENANCE

For reliable and continuous operation of electric furnace, maintenance (routine and preventive) plays an important role. Furnace equipment should be thoroughly inspected every shift and during preventive maintenance special attention should be made for inspection and necessary repair of:

(i) Transformer - oil, relay, breather, contacts, insulator, taps
ii) Reactor - oil
iii) OCB - oil, contacts
iv) Busses, cables and clamps, electric holder etc
v) Electrode suspension mechanism
vi) Oil and water per unit
vii) Measuring, sensing and controlling devices

6. FUTURE SCOPE OF DEVELOPMENT OF AUTOMATION IN PROCESS CONTROL

During the last two decades, a lot of development has been made in utilisation of thyristor in various field, for : switching, voltage/current control, PF improvement, temperature control and micro-processor based automation. Though rating of the thyrister may not suit the requirement of the very high current demand of large ferro-alloy furnace in small and medium size ferro-alloy furnaces, thyristor can be used for various purposes.

General References

1. V Paschkis, Industrial Electric Furnaces and Appliances, Inter Science Publishers INC, New York.
2. A Riss & Y Khodarosky, Production of Ferro Alloys, Foreign Language Publishing House, Moscow.

For development of process control recommended firms:

A. Teltron Instruments (I) Pvt Ltd, P B No. 49, 6-3-1199/2, Vaman Naik Lane, Umanagar Colony, Begumpet, Hyderabad 500016
B. Fenner India, Calcutta, Bombay
C. Allen & Bradely, Calcutta, Bombay
D. Crompton Greaves, Calcutta, Bombay

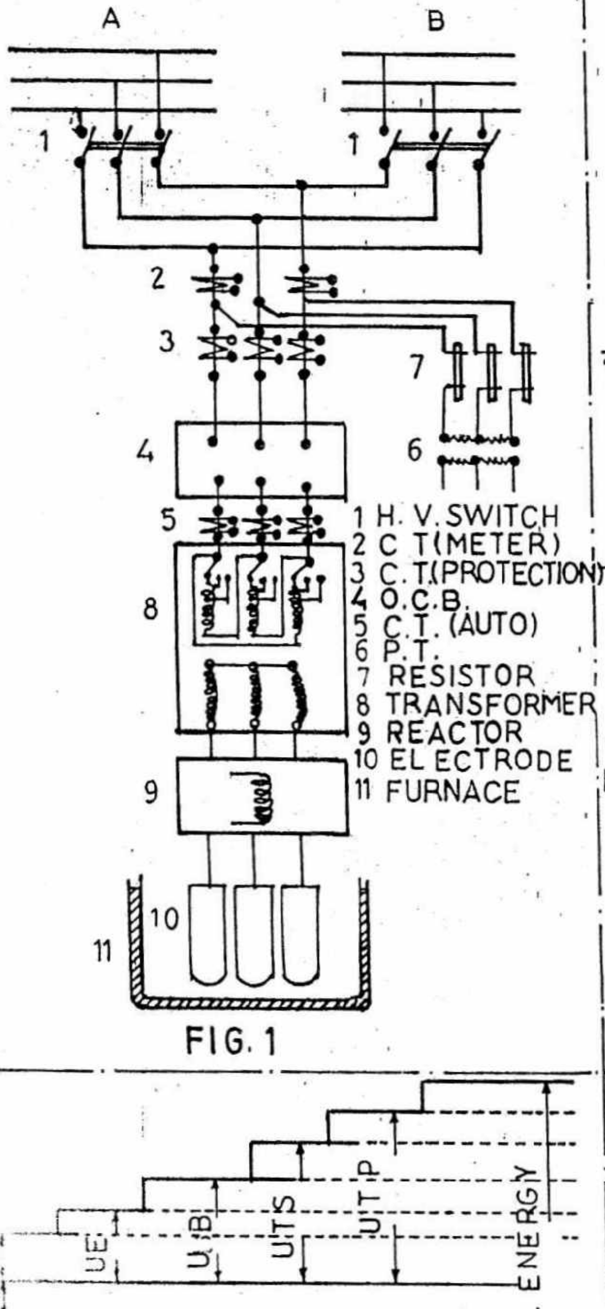

FIG. 1

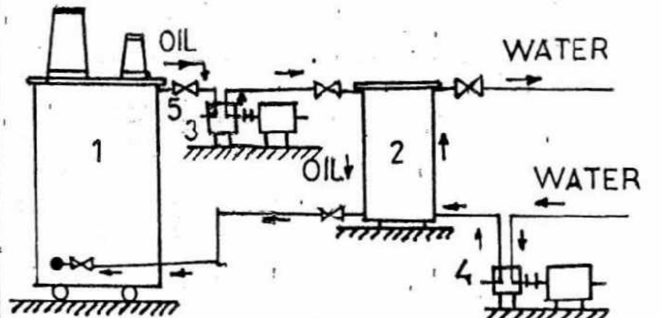

FIG. 2

1 TRANSFORMER
2 COLUMN
3 OIL PUMP
4 WATER PUMP
5 OIL LINE

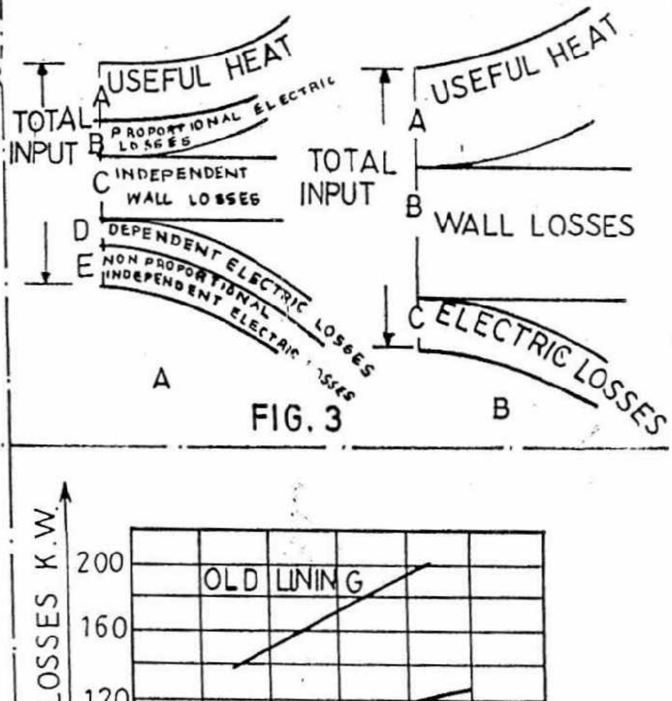

FIG. 3

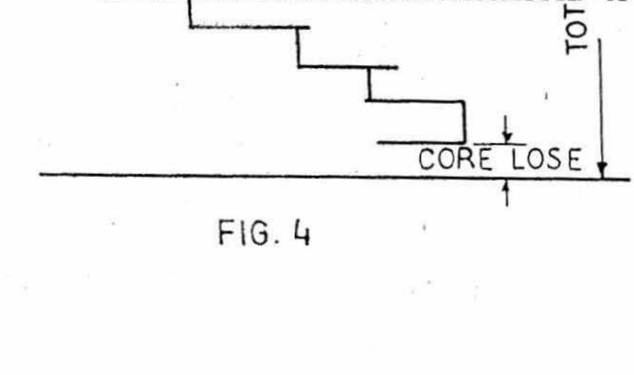

FIG. 4

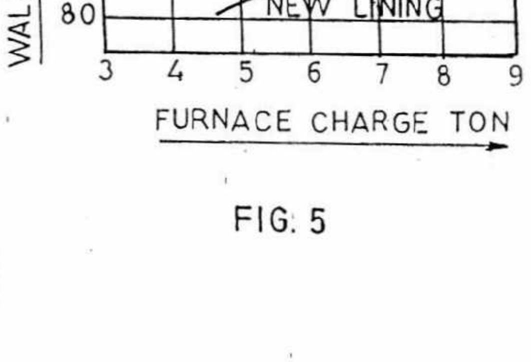

FIG. 5

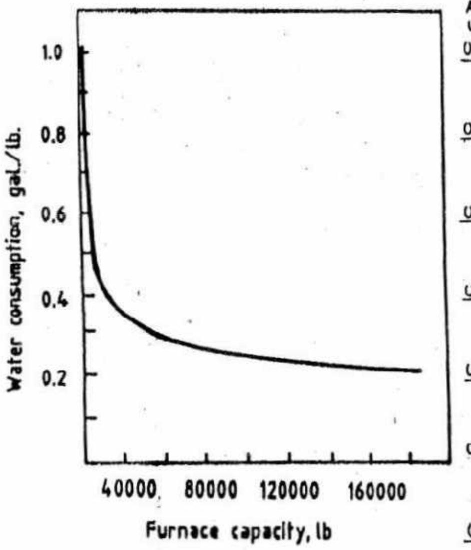

Fig. (6)

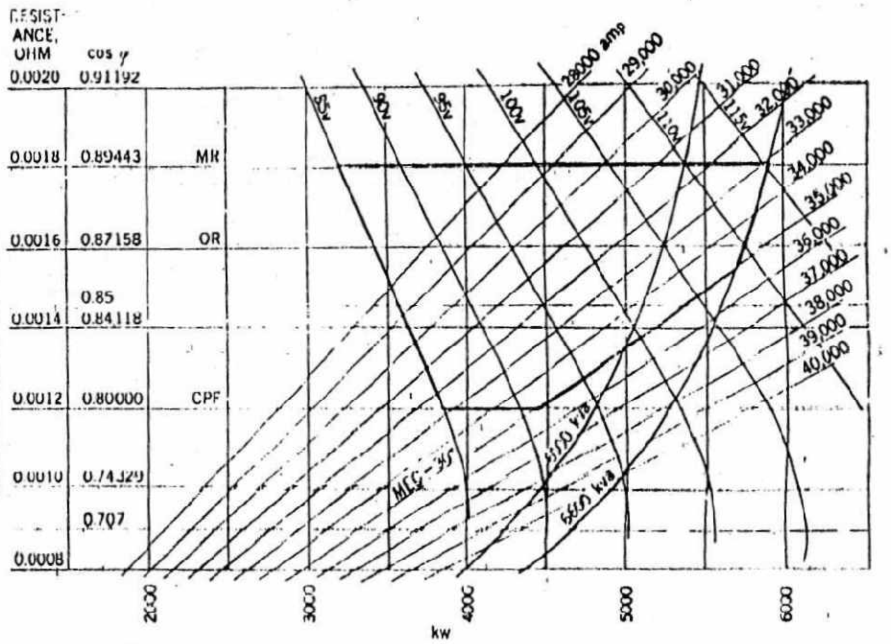

FIG. 7 — Example of operating diagram of a ferro-alloy furnace. *MR*, maximum operating resistance; *OR*, optimum operating resistance; *CPF*, contract power factor; *MEC*, maximum electrode current (30-in. electrode).

Table — 4

Conditions for Constant Power of 17,500 kw Delivered to Plant

Substation voltage	Current	Power factor	Plant voltage	Plant power factor	Plant resistance	Kw losses in furnace leads*	Useful power in furnace
13700	878.7	0.8540	13010	0.8830	7.556	800.7	16663
13600	874.1	0.8540	12884	0.8770	7.200	928.4	16672
13500	911.2	0.8308	12767	0.8691	7.026	964.2	16631
13400	930.4	0.8263	12626	0.8600	6.730	1005.1	16495
13300.6	950.3	0.8148	12500	0.8500	6.461	1018.6	16451[b]
13200	970.2	0.7987	12347	0.8357	6.084	1113.2	16387
13100	1014.2	0.7782	12190	0.8173	5.671	1194.3	16306
13000	1078.2	0.7306	11983	0.7821	5.010	1349.4	16151
12987.7	1132.1	0.7071	11870	0.7613	4.651	1488.1	16012
13000	1151.8	0.6933	11863	0.7381	4.371	1548.3	15952
13004.4	1207.9	0.6611	11820	0.7071	3.968	1691.1	15808
13100	1247.6	0.6107	11832	0.6656	3.871	1719.7	15780
13200	1271.6	0.6210	11860	0.6700	3.608	1877.3	15623
13300.6	1300.3	0.6026	11880	0.6382	3.403	1990.4	15519
13400	1338.1	0.5863	11953	0.6317	3.258	2079.0	15421
13500	1360.3	0.5709	11998	0.6168	3.125	2107.1	15333
13600	1392.4	0.5570	12007	0.6013	3.000	2250.9	15249
13700	1410.9	0.5442	12143	0.5872	2.906	2330.9	15169

* Including transformers, busses, and electrodes.
[b] Normal conditions.

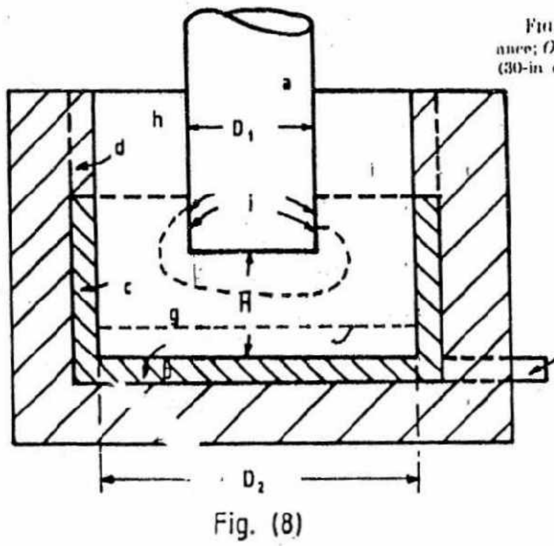

Fig. (8)

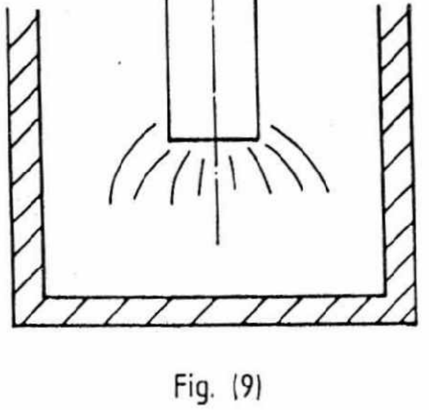

Fig. (9)

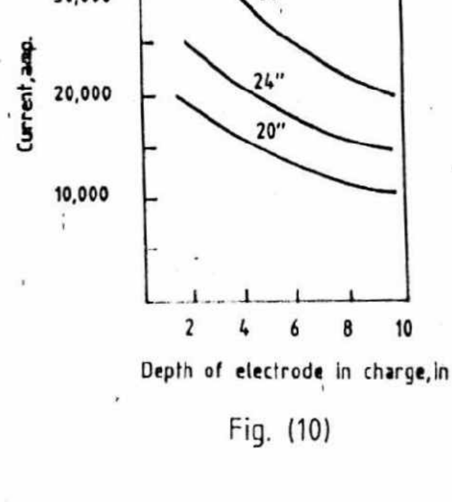

Fig. (10)

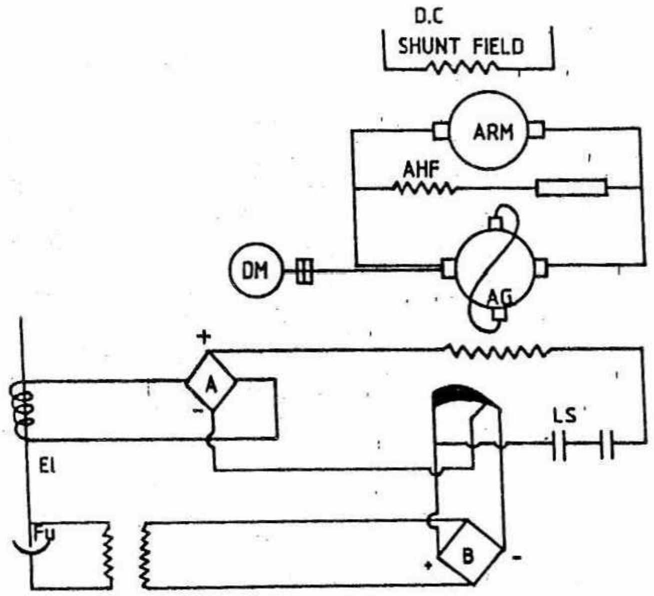

FIG. (11)

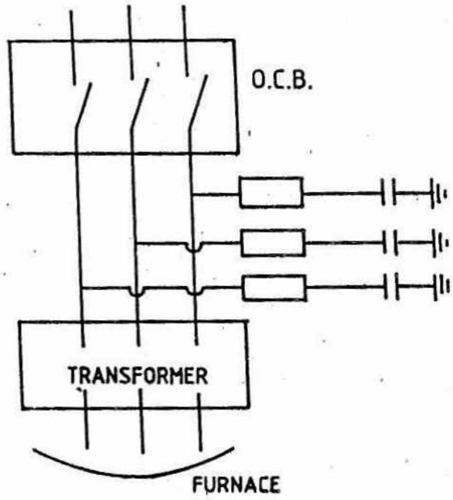

FIG. (12)

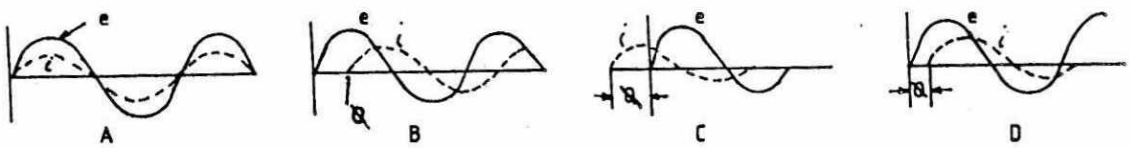

FIG. (13)

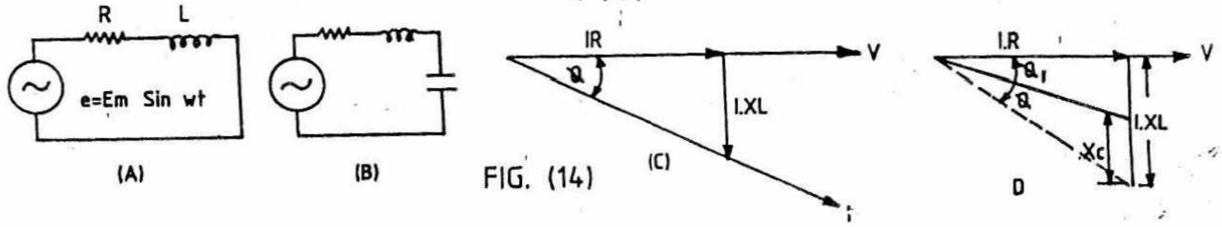

FIG. (14)

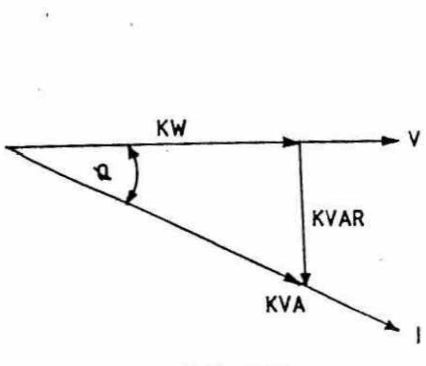

FIG. (15)