DEPARTMENT OF ELECTRICAL ENGINEERING

LECTURE NOTES ON

UTILIZATION OF ELECTRICAL ENERGY AND TRACTION

(5th Semester)

Department of Electrical Engineering

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CHAPTER-1
ELECTROLYSIS

Definition and Basic principle of Electro Deposition.

The process of depositing metal over another metal or non-metal by electrolysis is known as electrodeposition. It is done to achieve the desire electrical and corrosion resistance, reduce wear &friction, improve heat tolerance and for decoration.

Important terms regarding Electrolysis

1. **Electrolyte** – The solution of salt when used for electrolytic process is called an electrolyte.
2. **Electrodes** – The plates or rods immersed in an electrolyte and connected to d.c supply are called electrodes.
3. **Anode** – The electrode connected to the positive terminal of the supply is called anode.
4. **Cathode**- The electrode connected to the negative terminal of the supply is called cathode.
5. **Ions** – When a direct current is passed through an electrolyte, it gets chemically decomposed into two parts known as positive and negative ions.
6. **Cations** – These are positively charged ions and they move towards the cathode.
7. **Anions** – These are negatively charged ions and they move towards the anode.
8. **Chemical equivalent weight** – it's the ratio of atomic weight and valency of a substance.
9. **Electrochemical equivalent(ece)-** It is the amount deposited on passing a steady current of one ampere for one second through its solution.
10. **Atomic weight-** It is the ratio of weight of an atom of the element to the weight of an atom of hydrogen.
11. **Valency** – The valency of an atom or group of atoms is the number of hydrogen atoms with which it will react chemically.

Electroplating Basics

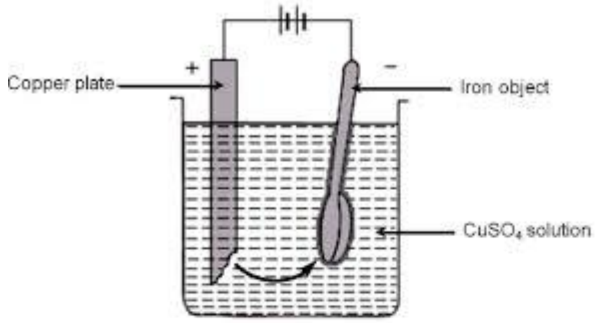

Fig-1. Process of Electrodeposit/ Electroplating

Figure- 1, illustrates a simple electroplating process. The electrolyte used in the given process is a solution of copper sulphate. The sulphate solution readily breaks into positive ions Cu++, which are deficit in two electrons per ion and SO4-- negative ions, having two surplus electrons per ion.

When the two electrodes get a dc supply from the busbars, the negative ions move towards the anode made of copper. Each SO4—ion after transfer of two electrons to the anode becomes SO4 radical. It attacks the copper anode to form CuSO4 molecule, which dissolves once again in water to maintain the electrolyte density at original level.

The positive copper ions reach the negative electrode i.e. the cathode and receive two electrons reach from supply circuit to become Cu atoms. These get deposited on the cathode surface. The cathode as shown in the figure is the job or article to be copper plated. The copper deposited on the cathode surface is practically having the same mass as lost by the anode, in maintaining the electrolyte strength.

The whole process described above is called electrolysis, but its effect is that the copper is also deposited on the cathode at the same time and there is no accumulation of charge at any point in the circuit. In the electrolyte, the ions move from one electrolyte to the other but in the outside circuit, electrons flow from cathode to anode.

Faraday's Laws of Electrolysis

From his experiments, Faraday deduced two fundamental laws which govern the phenomenon of electrolysis. These are:

(i) **First Law.** The mass of ions liberated at an electrode is directly proportional to the quantity of electricity i.e. charge which passes through the electrolyte.

Or

The weight of a substance liberated from an electrolyte in a given time is proportional to the quantity of electricity passing through the electrolyte.

$W \propto Q$

$W \propto IT$

$W = ZIT$

Where Q is the quantity of electricity passed

I is the current

T is the time

Z is a constant called electro-chemical equivalent

.If I = 1 ampere and T= one second then,

Z = W , which gives a definition of Z.

The electro-chemical equivalent of a substance is the amount of that substance by weight liberated in unit time by unit current.

(ii) **Second Law.** The masses of ions of different substances liberated by the samequantity of electricity are proportional to their chemical equivalent weights.

or,

If the same current flows through several electrolytes, the weights of ions liberated are proportional to their chemical equivalents.

The chemical equivalent of a substance is the weight of the substance which can displace or combine with unit weight of hydrogen .Obviously, the chemical equivalent of hydrogen is 1 by definition.

DEFINITIONS

1. **Current Efficiency**

   On account of the impurities which cause secondary reactions, the quantity of a substance liberated is less than that calculated from faraday's Law.

Current efficiency is the ratio of the actual mass of a substance liberated from an electrolyte by the passage of current to the theoretical mass liberated according to Faraday's law. Currentefficiency can be used in measuring electro deposition thickness on materials in electrolysis. Current efficiency is also known as faradic efficiency, faradic yield and columbic efficiency.

2. Energy Efficiency

On account of secondary reactions, the voltage actually required for the deposition or liberation of metal is higher than the theoretical value which increases the actual energy required.

Energy efficiency is defined as $\frac{\text{theoretical energy}}{\text{actual energy required}}$

Factors affecting the amount of electrodeposition:

(1) Time

Time is directly proportional to the quantity of electrodeposition.

(2) Efficiency

Greater the efficiency, greater the quantity of metal deposited for a given time.

(3) Current

The value of current is also directly proportional to the mass of metal deposited. Greater the current, greater is the quantity of metal deposited, while other conditions remaining the same.

(4) Strength of solution

If the solution is more, then the mass of metal deposited will be more as compared to the dilute solution of electrolyte, if other conditions remain same.

Factors governing better electrodeposition:

(i) Current Density

(ii) Electrolyte concentration

(iii) Temperature

(iv) Addition agents

(v) Nature of electrolyte

(vi) Nature of the metal on which the deposit is to be made

(vii) Throwing power of the electrolyte

Current density

At low values of current density, the ions are released at a slow rate and the rate of growth of nuclei is more than the rate at which the new nuclei form themselves. Electro-deposition depends upon the rate at which crystals grow and the rate at which fresh nuclei are formed. Therefore, at low current densities the deposit will be coarse and crystalline in nature. At higher values of current density the quality of deposit becomes more uniform and fine-grained on account of the greater rate of formation of nuclei. If the current density is so high that it exceeds the limiting value for the electrolyte hydrogen is released and spongy and porous deposit is obtained.

Electrolytic Concentration

This is more or less complementary to the first factor, i.e. current density, since by increasing the concentration of the electrolyte higher current density can be achieved. Increase of concentration tends to give better deposits .

Temperature

The temperature of the electrolyte has two contradictory effects. One, at comparatively high temperature there is more diffusion and even at relatively high current density smooth deposits may be produced. Two, the rate of crystal growth increases the possibility of coarse deposits. At moderate temperatures the deposits are good. In chromium plating the temperature is maintained at 35^0 C, and in nickel between 50^0C to 60^0C .

Addition Agents

the quality of a deposit is improved by the presence of an addition agent which may be colloidal matter or an organic compound, otherwise the metal deposits in the form of large crystals and the surface becomes rough. Materials used asaddition agents are gelatin, agar, glue, gums, rubber, alkaloids, sugar etc. The addition agents are supposed to be absorbed by crystal nuclei and prevent their growth into large crystals. The discharged ions start to build up new nuclei and thedeposit of metal is fine-grained.

Nature of electrolyte

Smooth deposits are obtained from solutions having complex ions, e.g.,cyanides. Silver from nitrate solution forms a coarse deposit while from cyanide solution it forms a smooth deposit. Therefore, the formation of smooth deposit largely depends upon the nature of electrolyte used.

Nature of the metal on which deposit is to be made

This factor influences the growth of crystals since it is believed that the operation of crystals is in continuation of these in the base metal.

Throwing Power

The throwing power of an electrolyte may be regarded as the quality which produces a uniform deposit on a cathode having an irregular shape.Since the shape is irregular, The distance of the various parts of the cathode from the anode is not the same and therefore the conductance of the electrolyte is not the same for all parts of the cathode. The phenomenon of throwing power has not been clearly understood so far. In an electrolyte of low conductance, the current will concentrate on the parts of the cathode which are nearer the cathode resulting in poor throwing power. If the electrolyte has good conductance, the throwing power will also be good. One way to improve the throwing power is to keep a good distance between the cathode and the anode thereby providing more or less the same conductance for all parts of cathode. Presence of colloidal matter improves the throwing power but increase of temperature may produce the opposite effect.

Extraction of Metals

This is done in two ways:

1. The ore is treated with a strong acid to obtain a salt and the solution of such a salt iselectrolyzed to liberate the metal.
2. When the ore in molten state is available it is electrolyzed in a furnace.

Extraction of Zinc

The ore consisting of zinc is treated with concentrated sulphuric acid, roasted and passed through other processes to get rid of impurities by precipitation. The zinc-sulphate solution is then electrolysed. The cells consist of large lead-lined wooden boxes having aluminum cathodes and lead anodes. The current density is about 1000 amperes per square meter. Zinc is deposited on cathodes.

Extraction of Aluminium

Ores of aluminium are bauxite cryolite.Bauxite is treated chemically and reduced to aluminium oxide and then dissolved in fused cryolite and electrolysed.The furnce is lined with carbon.The temperature of the furnace is about 1000^0 C to keep the electrolyte in a fused state. Aluminium deposits at the cathode.

Refining of Metals

Electrolytic extraction gives about 98 to 99 percent pure metal. Further refining is done by electrolysis. The anodes are made of the impure metal extracted from its ores and the electrolyte is a solution of the salt of the metal. Pure metal is deposited on the cathode.

Example : 1

A 20 cm long portion of a circular shaft 10 cm diameter is to be coated with a layer of 1.5 mm nickel. Determine the quantity of electricity in Ah and the time taken for the process. Assume a current density of 195 A/sq.m and a current efficiency of 92percent. Specific gravity of nickel is 8.9.

Solution :

Wt. of nickel = 8.9 gm/cm^3

Wt of nickel to be deposited

$$= \pi \times 10 \times \frac{1.5}{10} \times 8.9 \times 10^{-3} \text{ kg}$$

Electro-chemical equivalent of nickel is 1.0954 kg per 1,000Ah.

Quantity of electricity required

$$= \frac{838.4\times10^{-3}\times1{,}000}{1.0954\times0.92} = 833 \text{ Ahr}$$

Current density =195 A/m^2 .

$$\text{Time taken} = \frac{833}{\pi\times10\times20\times10^{-4}\times195} = 68 \text{ hours.}$$

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CHAPTER-2
ELECTRICAL HEATING

When current I is made to flow through any circuit having a resistance of R ohms, power is dissipated in that circuit in I^2R Watts. If the current flows for 1 second, energy consumed is i2rt joules/watt-sec. This energy is converted into heat.

Electric heating is extensively used both for domestic and industrial applications. Domestic applications include (1) room heaters **(ii)** immersion heaters for water heating **(iii)** hot plates for cooking **(iv)** electric kettles **(v)** electric irons **(vi)** pop-corn plants **(vii)** electric ovens for bakeries and **(viii)** electric toasters etc. Industrial applications of electric heating include **(i)** melting of metals **(ii)** heat treatment of metals like annealing, tempering, soldering and brazing etc. **(iii)** moulding of glass **(iv)**Baking of insulators **(v)** enameling of copper wires etc.

Advantage of electrical heating:

As compared to other methods of heating using gas, coal and fire etc., electric heating is far superior for the following reasons:

(i) Cleanliness. Since neither dust nor ash is produced in electric heating, it is a clean system of heating requiring minimum cost of cleaning.
(ii) No Pollution. Since no flue gases are produced in electric heating, no provision has to be made for their exit.
(iii) Economical. Electric heating is economical because electric furnaces are cheaper in their initial cost as well as maintenance cost since they do not require big space for installation or for storage of coal and wood. Moreover, there is no need to construct any chimney or to provide extra heat installation.
(iv)Ease of Control. It is easy to control and regulate the temperature of an electric furnace with the help of manual or automatic devices. Temperature can be controlled within ± 5°C which is not possible in any other form of heating.
(v) Special Heating Requirement. Special heating requirements such as uniform heating of a material or heating one particular portion of the job without affecting its other parts or heating with no oxidation can be met only by electric heating.
(vi) Higher Efficiency. Heat produced electrically does not go away waste through the chimney and other by products. Consequently, most of the heat produced is utilised for heating the material itself. Hence, electric heating has higher efficiency as compared to other types of heating.
(vii) Better Working Conditions. Since electric heating produces no irritating noises and also the radiation losses are low, it results in low ambient temperature. Hence, working with electric furnaces is convenient and cool.
(viii) Heating of Bad Conductors. Bad conductors of heat and electricity like wood, plastic and bakery items can be uniformly and suitably heated with dielectric heating process.
(ix) Safety. Electric heating is quite safe because it responds quickly to the controlled signals.

(x) Lower Attention and Maintenance Cost. Electric heating equipment generally will not require much attention and supervision and their maintenance cost is almost negligible. Hence, labour charges are negligibly small as compared to other forms of heating.

Different Methods of Heat Transfer

The different methods by which heat is transferred from a hot body to a cold body are as under:

I. Conduction
II. Convection
III. Radiation

I. Conduction

In this mode of heat transfer, one molecule of the body gets heated and transfers some of the heat to the adjacent molecule and so on. There is a temperature gradient between the two ends of the body being heated.

Consider a solid material of cross-section Asq.m. and thickness x metre as shown in Fig.1.

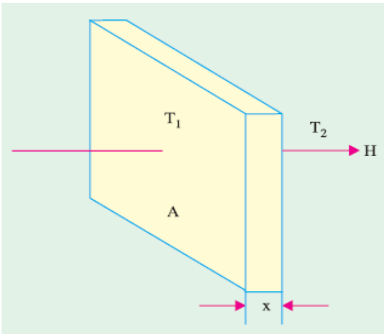


Fig-1

If T1 and T2 are the temperatures of the two sides of the slab in °K, then heat conducted between the two opposite faces in time t seconds is given by:

$$H = \frac{KA\,(T_1 - T_2)t}{x} \quad \ldots\ldots(1)$$

Where, K is thermal conductivity of the material.

II. Convection

In this process, heat is transferred by the flow of hot and cold air currents. This process is applied in the heating of water by immersion heater or heating of buildings. The quantity of heat absorbed by the body by convection process depends mainly on the temperature of the heating element above the surroundings and upon the size of the surface of the heater. It also depends, to some extent, on the position of the heater. The amount of heat dissipated is given by H = a (T1 – T2), where a is constant and T1 and T2 are the temperatures of the heating surface and the fluid in °K respectively. In electric furnaces, heat transferred by convection isnegligible.

III. Radiation

It is the transfer of heat from a hot body to a cold body in a straight line without affecting the intervening medium. The rate of heat emission is given by Stefan's law, according to which heat dissipated is given by equation—2.

$$H = 5.72\, eK \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \quad W/m^2 \quad \ldots\ldots(2)$$

Where, K is radiating efficiency and e is known as emissivity of the heating element. If d is the diameter of the heating wire and $l$its total length, then its surface area from which heat is radiated,

S = πdl...... (3)

If H is the power radiated per m^2 of the heating surface, then,

Total power radiated as heat = $H\pi dl$ ... (4)

If P is the electrical power input to the heating element, then

$$P = \pi dl \times H \quad \ldots..(5)$$

Resistance Heating.

It is based on the I^2R effect. When current is passed through a resistance element, I^2R loss takes place which produces heat. There are two methods of resistance heating.

(a) Direct Resistance Heating.

In this method the material (or charge) to be heated is treated as a resistance and current is passed through it. The charge may be in the form of powder, small solid pieces or liquid. The two electrodes are inserted in the charge and connected to either a.c. or d.c.supply (Fig. 2). Obviously, two electrodes will be required in the case of d.c. or single-phase

a.c. supply but there would be three electrodes in the case of 3-phase supply. When the charge is in the form of small pieces, a powder of high resistivity material is sprinkled over the surface of the charge to avoid direct short circuit. Heat is produced when current passes through it. This method of heating has high efficiency because the heat is produced in the charge itself.

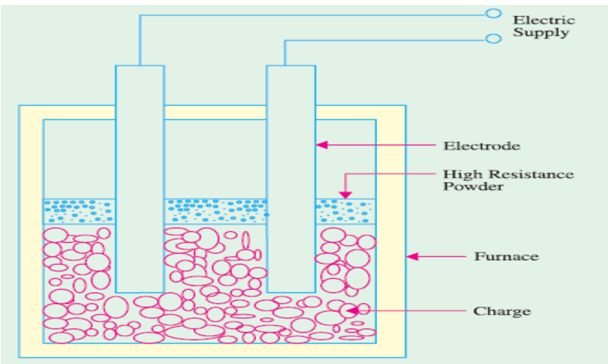


Fig:2 Direct Resistance heating

(b) In-Direct Resistance heating.

In this method of heating, electric current is passed through a resistance element which is placed in an electric oven. Heat produced is proportional to I^2R losses in the heating element. The heat so produced is delivered to the charge either by radiation or convection or by a combination of the two. Sometimes, resistance is placed in a cylinder which is surrounded by the charge placed in the jacket as shown in the Fig.3. This arrangement provides uniform temperature. Moreover, automatic temperature control can also be provided.

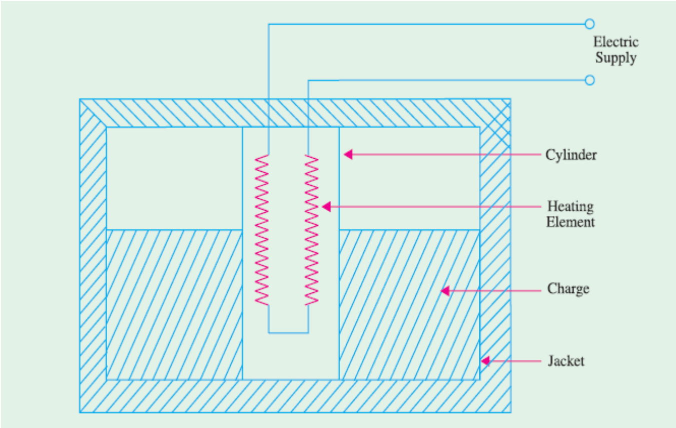


Fig-3 Indirect Resistance heating

Principle of Resistance furnace.

These are suitably-insulated closed chambers with a provision for ventilation and are used for a wide variety of purposes including heat treatment of metals like annealing and hardening etc., staving of enamelled wares, drying and baking of potteries, vulcanizing and hardening of synthetic materials and for commercial and domestic heating. Temperatures up to 1000°C can be obtained by using heating elements made of nickel, chromium and iron. Ovens using heating elements made of graphite can produce temperatures up to 3000°C.

Heating elements may consist of circular wires or rectangular ribbons. The ovens are usually made of a metal framework having an internal lining of fire bricks. The heating element may be located on the top, bottom or sides of the oven. The nature of the insulating material is determined by the maximum temperature required in the oven. An enclosure for charge which is heated by radiation or convection or both is called a **heating chamber**.

Electric resistance furnace

Fig. 4

Temperature Control of Resistance Furnaces

The temperature of a resistance furnace can be changed by controlling the I^2R or V^2/R losses.

Following different methods are used for the above purpose:

(1) Intermittent Switching.

In this case, the furnace voltage is switched ON and OFF intermittently. When the voltage supply is switched off, heat production within the surface is stalled and hence its temperature is reduced.

When the supply is restored, heat production starts and the furnace temperature begin to increase. Hence, by this simple method, the furnace temperature can be limited between two limits.

(2) By Changing the Number of Heating Elements.

In this case, the number of heating elements is changed without cutting off the supply to the entire furnace. Smaller the number of heating elements, lesser the heat produced. In the case of a 3-phase circuit, equal number of heating elements is switched off from each phase in order to maintain a balanced load condition.

(3) Variation in Circuit Configuration.

In the case of 3-phase secondary load, the heating elements give less heat when connected in a star than when connected in delta because in the two cases, voltages across the elements is different (Fig.5). In single-phase circuits, series and parallel grouping of the heating elements causes change in power dissipation resulting in change of furnace temperature. As shown in Fig.6 heat produced is more when all these elements are connected in parallel than when they are connected in series or series-parallel.

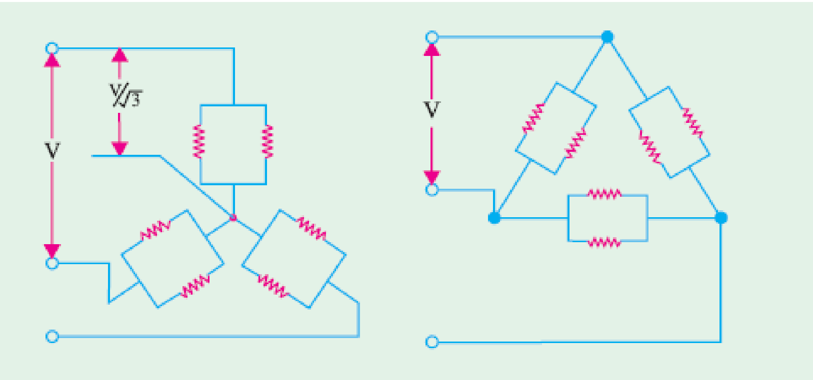


Fig-5

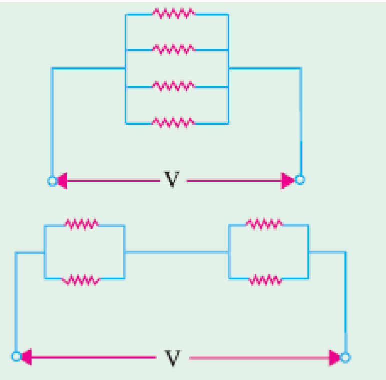


Fig-6

(4) Change of Applied Voltage.

(a) In the case of a furnace transformer having high voltage primary, the tapping control is kept in the primary winding because the magnitude of the primary current is less. Consider the multi-tap step-down transformer shown in Fig.7.

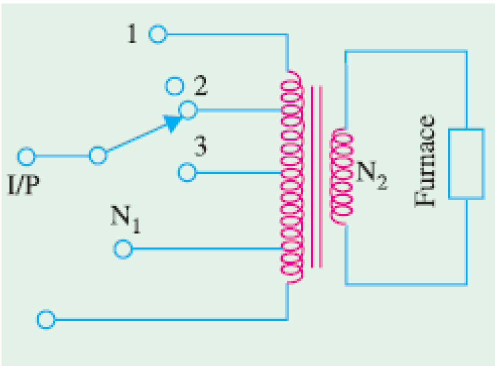


Fig-7

Let the four tapings on the primary winding have 100%, 80%, 60% and 50%. When 100% primary turns are used, secondary voltage is given by $V_2 = (N_2/N_1)V_i$, where Vi is the input voltage. When 50% tapping is used, the number of primary turns involved is N1/2. Hence, available secondary voltage $V_2 = (2N_2/N_1)Vi$. By selecting a suitable primary tapping, secondary voltage can be increased or decreased causing a change of temperature in the furnace.

(a)Bucking-Boosting the Secondary Voltage.

In this method, the transformer secondary is wound in two sections having unequal number of turns. If the two sections are connected in series aiding, the secondary voltage is boosted i.e., increased to (E2 + E3) as shown in Fig.8 (a). When the two sections are connected in series-opposing [Fig.8(b)] the secondary voltage is reduced i.e., there is bucking effect. Consequently, furnace voltage becomes (E2 – E3) and, hence, furnace temperature is reduced.

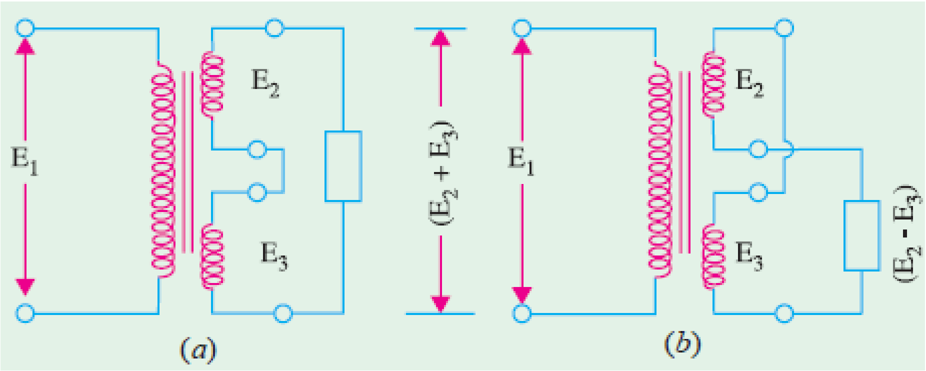


Fig-8

(b) Autotransformer Control.

Fig.9 shows the use of tapped autotransformer used for decreasing the furnace voltage and, hence, temperature of small electric furnaces. The required voltage can be selected with the help of a voltage selector.

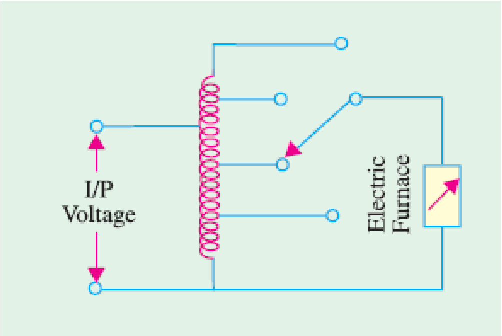


Fig-9

(c) Series Reactor Voltage.

In this case, a heavy-duty core-wounded coil is placed in series with the furnace as and when desired. Due to drop in voltage across the impedance of the coil, the voltage available across the furnace is reduced. With the help of D.P.D.T. switch, high/low, two mode temperature control can be obtained as shown in the Fig.10. Since the addition of series coil reduces the power factor, a power capacitor is simultaneously introduced in the circuit for keeping the p.f. nearly unity. As seen, the inductor is connected in series, whereas the capacitor is in parallel with the furnace.

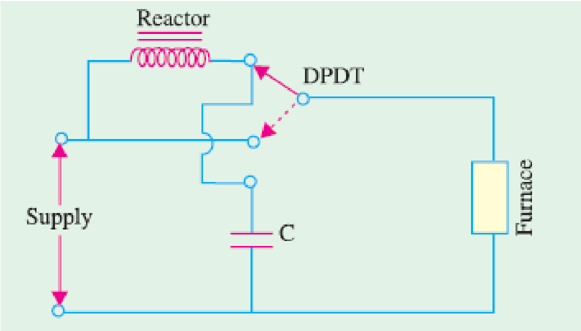


Fig-10

Arc Furnaces

If a sufficiently high voltage is applied across an air-gap, the air becomes ionized and starts conducting in the form of a continuous spark or arc thereby producing intense heat. When electrodes are made of carbon/graphite, the temperature obtained is in the range of 3000°C-3500C. The high voltage required for striking the arc can be obtained by using a step-up transformer fed from a variable a.c. supply as shown in Fig. 11 (a).

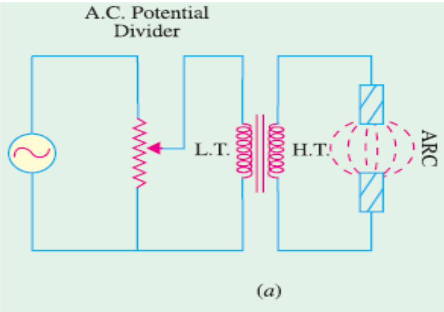
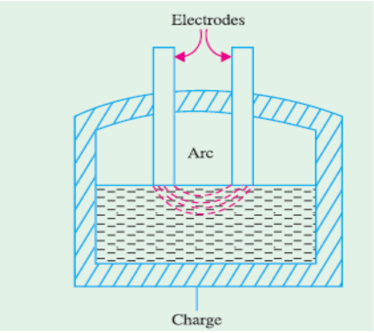


Fig-11

Indirect Arc Furnace

In this case, arc is formed between the two electrodes and the charge in such a way that electric current passes through the body of the charge as shown in Fig.11(a) . Such furnaces produce very high temperatures. In this case, arc is formed between the two electrodes andthe heat thus produced is passed on to the charge by radiation as shown in Fig. 47.11 (b).



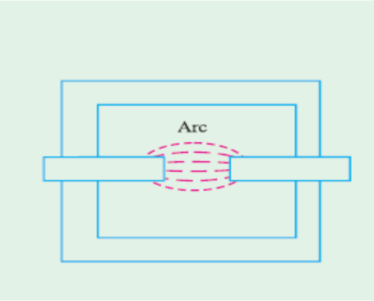


Fig-11(a)

Fig-11(b)

Direct Arc Furnace

It could be either of conducting-bottom type [Fig.12 (a)] or non-conducting bottom type [Fig.12 (b)]. As seen from Fig.12 (a), bottom of the furnace forms part of the electric circuit so that current passes through the body of the charge which offers very low resistance. Hence, it is possible to obtain high temperatures in such furnaces. Moreover, it produces uniform heating of charge without stirring it mechanically. In Fig.12 (b), no current passes through the body of the furnace. Most common application of these furnaces is in the production of steel because of the ease with which the composition of the final product can becontrolled during refining. Most of the furnaces in general use are of non-conducting bottom type due to insulation problem faced in case of conducting bottom.

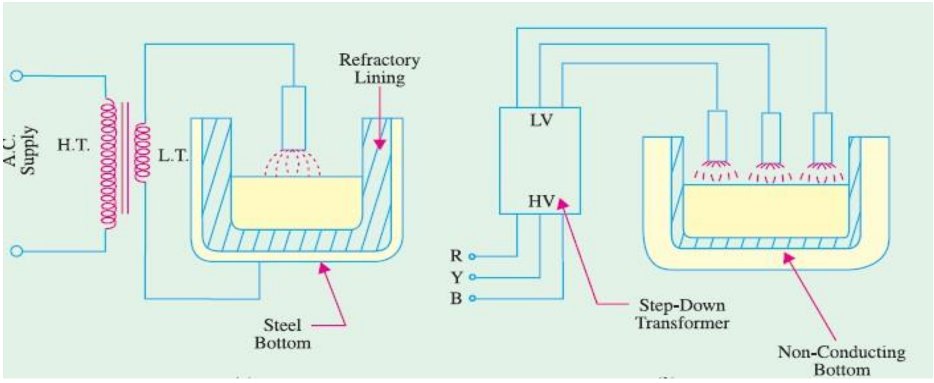


Fig-12(a) Fig-12(b)

Indirect Arc Furnace

Fig.13 shows a single-phase indirect arc furnace which is cylindrical in shape. The arc is struck by short circuiting the electrodes manually or automatically for a moment and then, withdrawing them apart. The heat from the arc and the hot refractory lining is transferred to the top layer of the charge by radiation. The heat from the hot top layer of the charge is further transferred to other parts of the charge by conduction. Since no current passes through the body of the charge, there is no inherent stirring action due to electro-magnetic forces set up by the current. Hence, such furnaces have to be rocked continuously in order to distribute heat uniformly by exposing different layers of the charge to the heat of the arc. An electric motor is used to operate suitable grinders and rollers to impart rocking motion to the furnace. Rocking action provides not only thorough mixing of the charge, it also increases the furnace efficiency in addition to increasing the life of the refractory lining material. Since in this furnace, charge is heated by radiation only, its temperature is lower than that obtainable in a direct arc furnace. Such furnaces are mainly used for melting nonferrous metals although they can be used in iron foundries where small quantities of iron are required frequently.

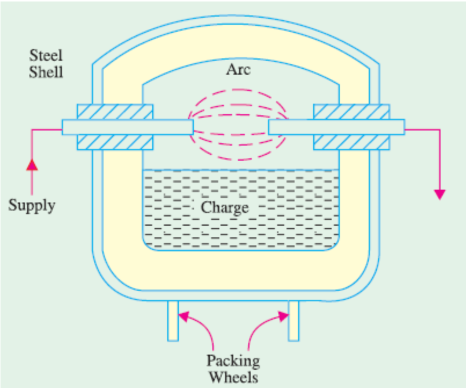


Fig-13

Induction Heating

This heating process makes use of the currents induced by the electro-magnetic action in the charge to be heated. In fact, induction heating is based on the principle of transformer working. The primary winding which is supplied from an a.c. source is magnetically coupled to the charge which acts as a short circuited secondary of single turn. When an a.c. voltage is applied to the primary, it induces voltage in the secondary i.e. charge. The secondary current heats up the charge in the same way, as any electric current does while passing through a resistance. If V is the voltage induced in the charge and R is the charge resistance, then heat produced = V 2/R. The value of current induced in the charge depends on **(i)** magnitude of the primary current **(ii)** turn ratio of the transformer **(iii)** co-efficient of magnetic coupling. Low-frequency induction furnaces are used for melting and refining of different metals. However, for other processes like case hardening and soldering etc., high frequency eddy- current heating is employed. Low frequency induction furnaces employed for the melting of metals are of the following two types:

(a) Core-type Furnaces — It operates just like a two-winding transformer. These can be further sub-divided into **(i)** Direct core-type furnaces **(ii)** Vertical core-type furnaces and **(iii)** Indirect core-type furnaces.

(b) Coreless-type Furnaces — in which an inductively-heated element is made to transfer heat to the charge by radiation.

Core Type Induction Furnace

It is shown in Fig.14 and is essentially a transformer in which the charge to be heated forms asingle-turn short-circuited secondary and is magnetically coupled to the primary by an iron core. The furnace consists of a circular hearth which contains the charge to be melted in the form of an annular ring. When there is no molten metal in the ring, the secondary becomes open-circuited there-by cutting off the secondary current. Hence, to start the furnace, molten metal has to be poured in the annular hearth. Since, magnetic coupling between the primary and secondary is very poor, it results in high leakage and low power factor. In order to nullifythe effect of increased leakage reactance, low primary frequency of the order of 10 Hz is used. If the transformer secondary current density exceeds 500 A/cm2 then, due to the interaction of secondary current with the alternating magnetic field, the molten metal is squeezed to the extent that secondary circuit is interrupted. This effect is known as –pinch effect‖.

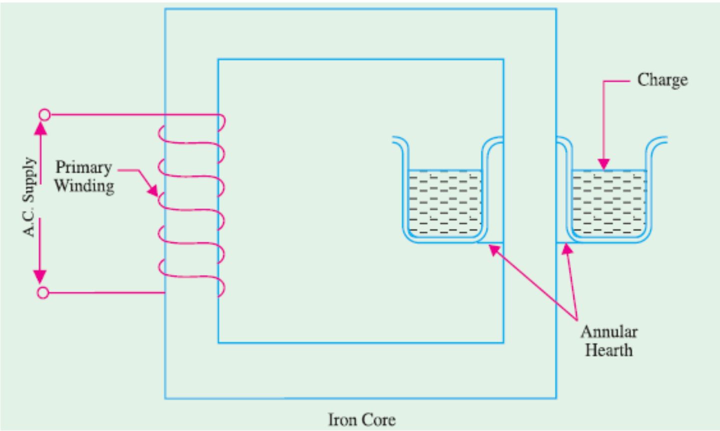


Fig-14

This furnace suffers from the following drawbacks:

1. It has to be run on low-frequency supply which entails extra expenditure on motor-generator set or frequency convertor.
2. It suffers from pinching effect.
3. The crucible for charge is of odd shape and is very inconvenient for tapping the molten charge.
4. It does not function if there is no molten metal in the hearth i.e. when the secondary is open. Every time molten metal has to be poured to start the furnace.
5. It is not suitable for intermittent service. However, in this furnace, melting is rapid and clean and temperature can be controlled easily. Moreover, inherent stirring action of the charge by electro-magnetic forces ensures greater uniformity of the end product.

Vertical Core-Type Induction Furnace

It is also known as Ajax-Wyatt furnace and represents an improvement over the core-type furnace discussed above. As shown in Fig.15, it has vertical channel (instead of a horizontal one) for the charge, so that the crucible used is also vertical which is convenient from metallurgical point of view. In this furnace, magnetic coupling is comparatively better and power factor is high. Hence, it can be operated from normal frequency supply. The circulation of the molten metal is kept up round the Vee portion by convection currents as shown in Fig.15. As Vee channel is narrow, even a small quantity of charge is sufficient to keep the secondary circuit closed. However, Vee channel must be kept full of charge in order to maintain continuity of secondary circuit. This fact makes this furnace suitable for continuous operation. The tendency of the secondary circuit to rupture due to pinch-effect is counteracted by the weight of the charge in the crucible. The choice of material for inner lining of the furnace depends on the type of charge used. Clay lining is used for yellow brass. For red brass and bronze, an alloy of magnetia and alumina or corundum is used. The top of the furnace is covered with an insulated cover which can be removed for charging. The furnace can be tilted by the suitable hydraulic arrangement for taking out the molten metal. This furnace is widely used for melting and refining of brass and other non-ferrous metals. Assaid earlier, it is suitable for continuous operation. It has a p.f. of 0.8-0.85. With normal supply frequency, its efficiency is about 75% and its standard size varies from 60-300 kW, allsingle phase.

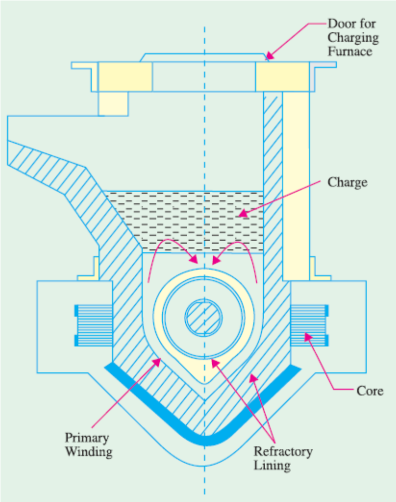


Fig-15 Core type Induction furnace

Indirect Core-Type Induction Furnace

In this furnace, a suitable element is heated by induction which, in turn, transfers the heat to the charge by radiation. So far as the charge is concerned, the conditions are similar to those in a resistance oven. As shown in Fig.16, the secondary consists of a metal container which forms the walls of the furnace proper. The primary winding is magnetically coupled to this secondary by an iron core. When primary winding is connected to a.c. supply, secondary current is induced in the metal container by transformer action which heats up the container.

The metal container transfers this heat to the charge. A special advantage of this furnace is that its temperature can be automatically controlled without the use of an external equipment. The part AB of the magnetic circuit situated inside the oven chamber consists of a special alloy which loses its magnetic properties at a particular temperature but regains them when cooled back to the same temperature. As soon as the chamber attains the critical temperature, reluctance of the magnetic circuit increases manifold thereby cutting off the heat supply. The bar AB is detachable and can be replaced by other bars having different critical temperatures.

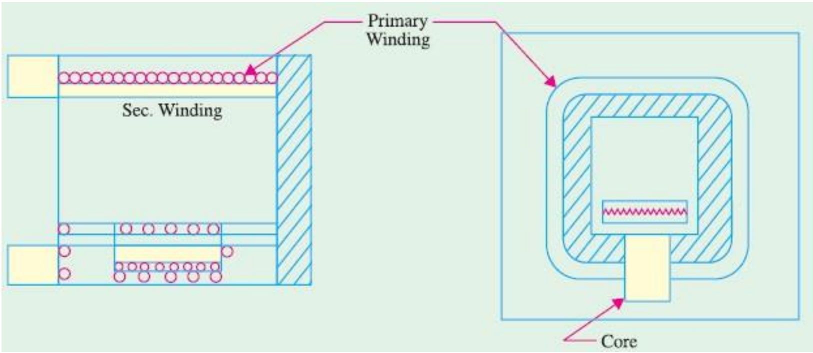


Fig-16

Coreless Induction Furnace

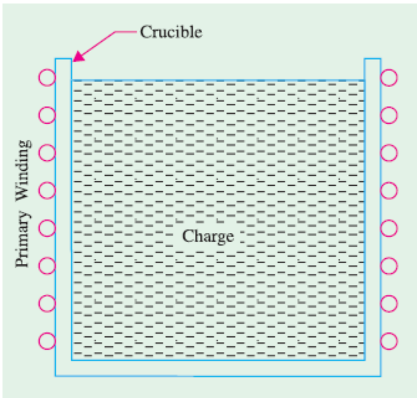


Fig-17

As shown in Fig.17, the three main parts of the furnace are **(i)** primary coil **(ii)** a ceramic crucible containing charge which forms the secondary and **(iii)** the frame which includes supports and tilting mechanism. The distinctive feature of this furnace is that it contains no heavy iron core with the result that there is no continuous path for the magnetic flux. The crucible and the coil are relatively light in construction and can be conveniently tilted for pouring. The charge is put into the crucible and primary winding is connected to a high-frequency a.c. supply. The flux produce by the primary sets up eddy-currents in the charge and heats it up to the melting point. The charge need not be in the molten state at the start as was required by core-type furnaces. The eddy- currents also set up electromotive forces which produce stirring action which is essential for obtaining uniforms quality of metal. Since flux density is low (due to the absence of the magnetic core) high frequency supply has to be used because eddy-current loss $W_e \propto B^2_{max} f^2$. However, this high frequency increasesthe resistance of the primary winding due to skin effect, thereby increasing primary Cu losses. Hence, the primary winding is not made of Cu wire but consists of hollow Cu tubes which are cooled by water circulating through them. Since magnetic coupling between the primary and secondary windings is low, the furnace p.f. lies between 0.1 and 0.3. Hence,static capacitors are invariably used in parallel with the furnace to improve its p.f. Such furnaces are commonly used for steel production and for melting of non-ferrous metals like brass, bronze, copper and aluminium etc., along with various alloys of these elements. Special application of these furnaces include vacuum melting, melting in a controlled atmosphere and melting for precision casting where high frequency induction heating is used.It also finds wide use in electronic industry and in other industrial activities like soldering, brazing hardening and annealing and sterilizing surgical instruments etc. Some of the advantages of coreless induction furnaces are as follows:

1. They are fast in operation.
2. They produce most uniform quality of product.
3. They can be operated intermittently.
4. Their operation is free from smoke, dirt, dust and noises.
5. They can be used for all industrial applications requiring heating and melting.
6. They have low erection and operating costs.
7. Their charging and pouring is simple.

Dielectric Heating

It is also called high-frequency capacitive heating and is used for heating insulators like wood, plastics and ceramics etc. which cannot be heated easily and uniformly by other methods. The supply frequency required for dielectric heating is between 10-50 MHz and the applied voltage is up to 20 kV. The overall efficiency of dielectric heating is about 50%.

Dielectric Loss

When a practical capacitor is connected across an a.c. supply, it draws a current which leads the voltage by an angle φ, which is a little less than 90° or falls short of 90° by an angle δ. It means that there is a certain component of the current which is in phase with the voltage and hence produces some loss called dielectric loss. At the normal supply frequency of 50 Hz, this loss is negligibly small but at higher frequencies of 50 MHz or so, this loss becomes so large that it is sufficient to heat the dielectric in which it takes place. The insulating material to be heated is placed between two conducting plates in order to form a parallel-platecapacitor as shown in Fig.19 (a). Fig.19 (b) shows the equivalent circuit of the capacitor and Fig.19 (c) gives its vector diagram.

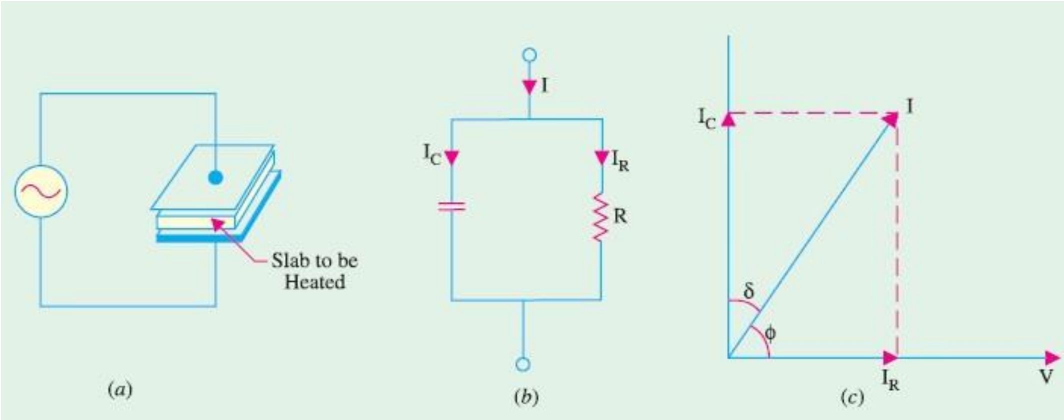


Fig-19

Power drawn from supply = VI cos φ

Now, Ic= I =V/Xc= 2πf CV

∴P = V(2πfCV) cos φ = $2\pi fCV^2$ cos φ

Now, φ = (90^0 – δ), cos φ = cos (90^0 –δ) = sin δ = tan δ = δ

where δ is very small and is expressed in radians.

P = $2\pi fCV^2\delta$ watts

Here,

$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$

Where, d is the thickness and A is the surface area of the dielectric slab.

This power is converted into heat. Since for a given insulator material, C and δ are constant, the dielectric loss is directly proportional to V 2 f. That is why high-frequency voltage is used in dielectric heating. Generally, a.c. voltage of about 20 kV at a frequency of 10-30 MHz is used.

Advantages of Dielectric Heating

1. Since heat is generated within the dielectric medium itself, it results in uniformheating.
2. Heating becomes faster with increasing frequency.
3. It is the only method for heating bad conductors of heat.
4. Heating is fastest in this method of heating.
5. Since no naked flame appears in the process, inflammable articles like plastics andwooden products etc. can be heated safely.
6. Heating can be stopped immediately as and when desired.

MICROWAVE HEATING AND ITS APPLICATION

In this system electricity is converted into electromagnetic waves which generates energy and this energy is used to cook food. These waves are nothing but high frequency radio waves whose wavelength is very short of high frequency known as microwave.

In the oven microwaves are confined inside the oven cavity and reflected off to its walls and doors. Once the door is opened all microwaves are automatically switched off.

When a microwave energy come into contact with some substance it is reflected, transmitted or absorbed. These waves are reflected by metals, transmitted through paper, glass and absorbed by water or moisture present in the food. When this energy is absorbed heat is produced and cooking takes place.

This microwave heating is used in microwave for baking purposes.

Applications of Microwave Heating

1 Baking and manufacture of bread, toast, etc.

2 Food processing or kitchen work

3 Drying of paper and textiles

4 Treatment of diseases like cancer

5 Manufacture of plastics.

6 Processing of cement and timber, etc.

CHAPTER - 3

WELDING

Definition

It is the process of joining two pieces of metal or non-metal at faces rendered plastic or liquid by the application of heat or pressure or both. Filler material may be used to effect the union.

Welding Processes

All welding processes fall into two distinct categories:

1. Fusion Welding—it involves melting of the parent metal. Examples are:

(i) Carbon arc welding, metal arc welding, electron beam welding, electro-slag welding andelectro-gas welding which utilize electric energy and
(ii) Gas welding and thermal welding which utilize chemical energy for the melting purpose.

2. Non-fusion Welding—It does not involve melting of the parent metal. Examples are:

(i) Forge welding and gas non-fusion welding which use chemical energy.

(ii) Explosive welding, friction welding and ultrasonic welding etc., which use mechanical energy.
(iii) Resistance welding which uses electrical energy.

Proper selection of the welding process depends on the **(a)** kind of metals to be joined **(b)** cost involved **(c)** nature of products to be fabricated and **(d)** production techniques adopted.

Use of Electricity in Welding

Electricity is used in welding for generating heat at the point of welding in order to melt the material which will subsequently fuse and form the actual weld joint. There are many ways of producing this localised heat but the two most common methods are as follows:

1. Resistance welding—here current is passed through the inherent resistance of the joint to be welded thereby generating the heat as per the equation I^2Rt/J kilocalories.

2. Arc welding—here electricity is conducted in the form of an arc which is established between the two metallic surfaces

Principle of arc welding

Formation and Characteristics of Electric Arc:

An electric arc is formed whenever electric current is passed between two metallic electrodes which are separated by a short distance from each other. The arc is started by momentarily touching the positive electrode (anode) to the negative metal (or plate) and then withdrawing it to about 3 to 6 mm from the plate. When electrode first touches the plate, a large short-circuits current flows and as it is later withdrawn from the plate, current continuesto flow in the form of a spark across the air gap so formed. Due to this spark (or discharge), the air in the gap becomes ionized i.e. is split into negative electrons and positive ions. Consequently, air becomes conducting and current is able to flow across the gap in the form of an arc. As shown in Fig. 48.2, the arc consists of **lighter** electrons which flow from cathode to anode and **heavier** positive ions which flow from anode to cathode. Intense heat isgenerated when high velocity electrons strike the anode. Heat generated at the cathode is much less because of the low velocity of the impinging ions. It is found that nearly **two-third**of the heat is developed at the anode which burns into the form of a crater where temperature rises to a value of 3500-4000°C. The remaining one-third of the heat is developed near the cathode. The above statement is true in all d.c. systems of welding where positive side of the circuit is the hottest side. As a result, an electrode connected to the positive end of the d.c. supply circuit will burn 50% faster than if connected to the negative end. This fact can beused for obtaining desired penetration of the base metal during welding.

Four Positions of Arc Welding

There are four basic positions in which manual arc welding is done.

1. Flat position. It is shown in Fig.20 (a). Of all the positions, flat position is the easiest, most economical and the most used for all shielded arc welding. It provides the strongest weld joints. Weld beads are exceedingly smooth and free of slag spots. This position is most adaptable for welding of both ferrous and non-ferrous metals particularly for cast iron.

2. Horizontal Position. It is the second most popular position and is shown in Fig.20(b). It also requires a short arc length because it helps in preventing the molten puddle of the metal from sagging. However, major errors that occur while welding in horizontal position are under-cutting and over-lapping of the weld zone .

3. Vertical Position. It is shown in Fig.20(c). In this case, the welder can deposit the bead either in the uphill or downhill direction. Downhill welding is preferred for thin metals because it is faster than the uphill welding. Uphill welding is suited for thick metals becauseit produces stronger welds.

4. Overhead Position. It is shown in Fig.20(d). Here, the welder has to be very cautious otherwise he may get burnt by drops of falling metal. This position is thought to be the most hazardous but not the most difficult one.

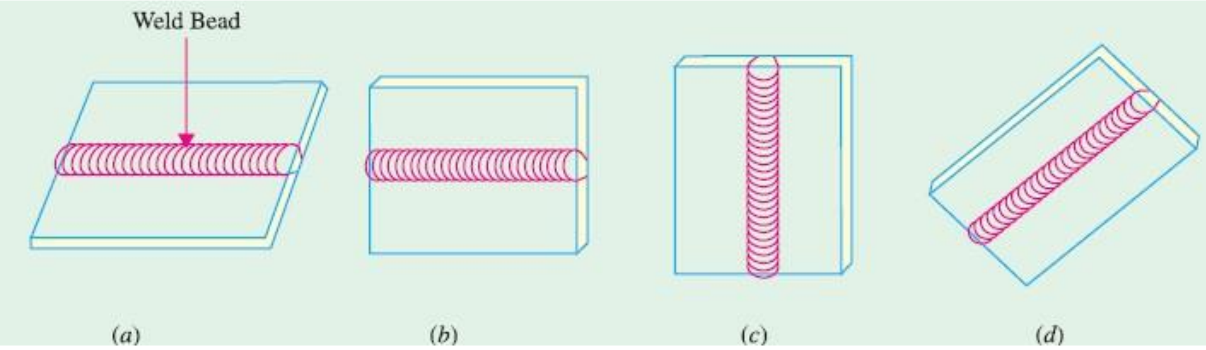


Fig-1

Electrodes for Metal Arc Welding

An electrode is a filler metal in the form of a wire or rod which is either bare or coated uniformly with flux. As per IS : 814-1970, the contact end of the electrode is left bare and clean to a length of 20-30 mm. for inserting it into electrode holder (Fig.21).

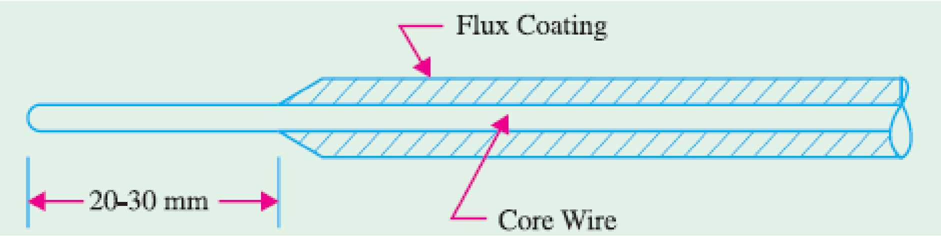


Fig-2

Metal arc welding was originally done with bare electrodes which consisted of a piece of wire or rod of the same metal as the base metal. However, due to atmospheric contamination, they produced brittle and poor quality welds. Hence, bare wire is no longer used except for automatic welding in which case arrangement is made to protect the weld area from the atmosphere by either powdered flux or an inert gas. Since 1929, coated electrodes are being extensively used for shielded arc welding. They consist of a metal core wire surrounded by a thick flux coating applied by extrusion, winding or other processes. Depending on the thickness of the flux coating, coated electrodes may be classified into **(i)** lightly-dusted (or dipped) electrodes and **(ii)** semi-coated (or heavy coated) electrodes. Materials commonly used for coating are **(i)** titanium oxide **(ii)** ferromanganese **(iii)** silica flour **(iv)** asbestos clay

(iv) calcium carbonate and **(vi)** cellulose with sodium silicate often used to hold ingredients together. Electrode coating contributes a lot towards improving the quality of the weld. Part of the coating burns in the intense heat of the arc and provides a gaseous shield around the arc which prevents oxygen, nitrogen and other impurities in the atmosphere from combining withthe molten metal to cause a poor quality brittle and weak weld.

Another portion of the coatingflux melts and mixes with the impurities in the molten pool causing them to float to the top ofthe weld where they cool in the form of slag. This slag improves the bead quality by protecting it from the contaminating effects of the atmosphere and causing it to cool down more uniformly. It also helps in controlling the basic shape of the weld bead. The type of electrode used depends on the type of metal to be welded, the welding position, the type of electric supply whether a.c. or d.c. and the polarity of the welding machine.

Carbon Arc Welding

(a) General

Carbon arc welding was the first electric welding process developed by a French inventor Auguste de Meritens in 1881. In this process, fusion of metal is accomplished by the heat of an electric arc. No pressure is used and generally, no shielding atmosphere is utilized. Filler rod is used only when necessary. Although not used extensively these days, it has, nevertheless, certain useful fields of application. Carbon arc welding differs from the more common shield metal arc welding in that **it uses non-consumablecarbon or graphic electrodes** instead of the consumable flux-coated electrodes.

(b) Welding Circuit

The basic circuit is shown in Fig.22 and can be used with d.c. as well as a.c. supply. When direct current is used, the electrode is mostly negative (DCSP). The process is started by adjusting the amperage on the d.c.welder, turning welder ON and bringing the electrode into contact with the work piece. After the arc column starts, electrode is withdrawn 25 – 40 mm away and the arc is maintained at this distance. The arc can be extinguished by simply removing the electrode from the work piece completely. The only function of the carbon arcis to supply heat to the base metal. This heat is used to melt the base metal or filler rod for obtaining fusion weld Depending on the type and size of electrodes, maximum current values range from 15 A to 600 A for single-electrode carbon arc welding.

(c) Electrodes

These are made of either carbon or graphite, are usually 300 mm long and 2.5 – 12 mm in diameter. Graphite electrodes are harder, more brittle and last longer than carbon electrodes. They can withstand higher current densities but their arc column is harder to control. Though considered non-consumable, they do disintegrate gradually due to vaporisation and oxidisation.

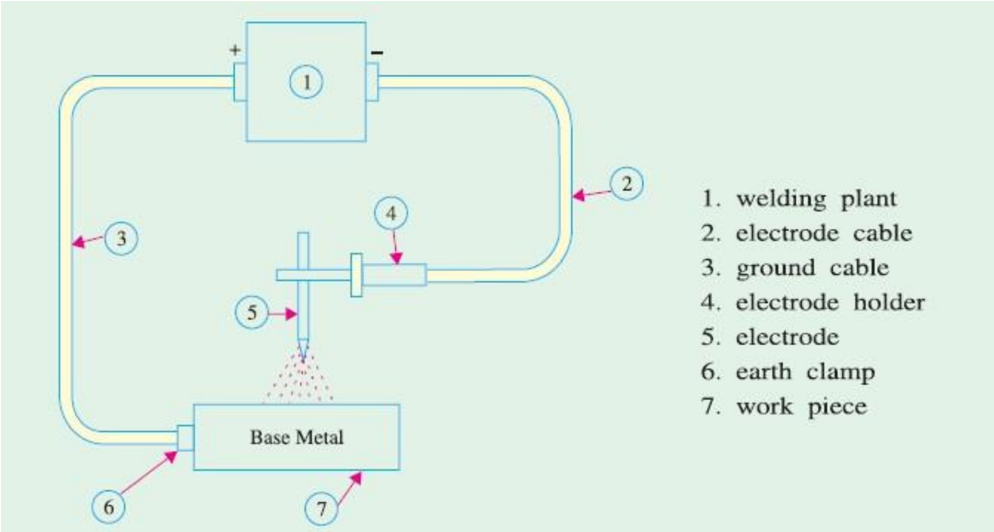


Figure. 3

(d) Applications

1. The joint designs that can be used with carbon arc welding are butt joints, bevel joints,flange joints, lap joints and fillet joints.
2. This process is easily adaptable for automation particularly where amount of weld depositis large and materials to be fabricated are of simple geometrical shapes such as water tanks.
3. It is suitable for welding galvanised sheets using copper-silicon-manganese alloy filler metal.
4. It is useful for welding thin high-nickel alloys.

5. Monel metal can be easily welded with this process by using a suitable coated filler rod.

6. Stainless steel of thinner gauges is often welded by the carbon-arc process with excellentresults.

(e) Advantages and Disadvantages

1. The main advantage of this process is that the temperature of the molten pool can beeasily controlled by simply varying the arc length.
2. It is easily adaptable to automation.
3. It can be easily adapted to inert gas shielding of the weld and
4. It can be used as an excellent heat source for brazing, braze welding and soldering

etc.Its disadvantages are as under:

1. A separate filler rod has to be used if any filler material is required.
2. Since arc serves only as a heat source, it does not transfer any metal to help reinforcethe weld joint.
3. The major disadvantage of the carbon-arc process is that blow holes occur due tomagnetic arc blow especially when welding near edges of the work piece.

Submerged Arc Welding

In this **fusion** process, welding is done under a blanket of granulated flux which shields the weld from all bad effects of atmospheric gases while a consumable electrode is continuously and mechanically fed into the arc. The arc, the end of the bare metal electrode and the molten weld pool are all submerged under a thick mound of finely-divided granulated powder that contains deoxidisers, cleansers and other fluxing agents. The fluxing powder is fed from a hopper that is carried on the welding head itself (Fig.23). This hopper spread the powder in a continuous mound ahead of the electrode in the direction of welding. Since arc column is completely submerged under the powder, there is no splatter or smoke and, at the same time, weld is completely protected from atmospheric contamination. Because of this protection, weld beads are extremely smooth. The flux adjacent to the arc column melts and floats to the top of the molten pool where it solidifies to form slag. This slag is easy to remove. Often it cracks off by itself as it cools. The unused flux is removed and is reused again and again.

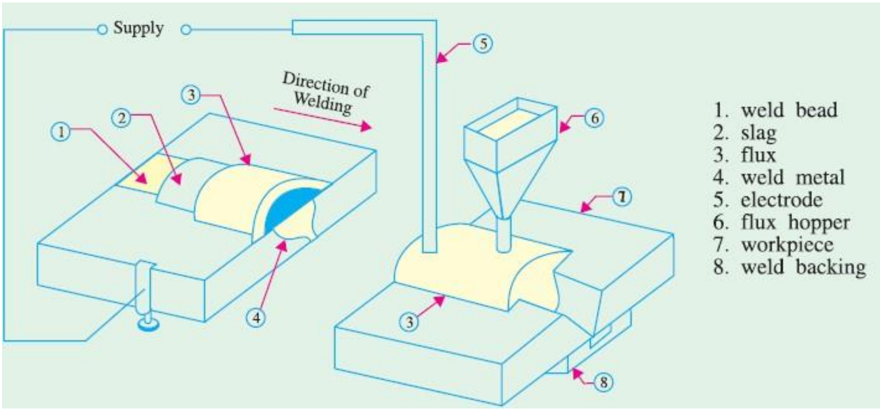


Fig-4

The electrode is either a bare wire or has a slight mist of copper coated over it to prevent oxidation. In automatic or semi-automatic submerged arc welding, wire electrode is fed mechanically through an electrically contacting collect. Though a.c. power supply may be used, yet d.c. supply is more popular because it assures a simplified and positive control of the welding process. This process requires high current densities about 5 to 6 times of those used in ordinary manual stick electrode welding. As a result, melting rate of the electrode as well as welding speed become much higher. Faster welding speed minimizes distortion and war page. The submerged arc process is suitable for

1. Welding low-alloy, high-tensile steels.

2. Welding mild, low-carbon steels.

3. Joining medium-carbon steel, heat-resistant steels and corrosion-resistant steels etc.

4. Welding nickel, and other non-ferrous metals like copper. This process has many industrial applications such as fabrication of pipes, boiler pressure vessels, railroad tank cars, structural shapes etc. which demand welding in a straight line. Welds made by this process have high strength and ductility. A major advantage of this process is that fairly thick sections can be welded in a single pass without edge preparation. Submerged arc welding can be done manually where automatic process is not possible such as on curved lines and irregular joints.Such a welding gun is shown in Fig-24. Both manual and automatic submerged arc processes are most suited for flat and slightly downhill welding positions.

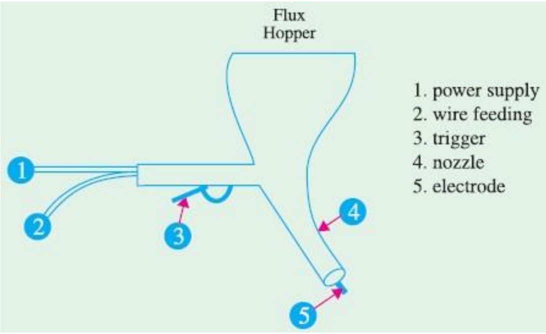


Fig-5

Twin Submerged Arc Welding

As shown in Fig.25, in this case, two electrodes are used simultaneously instead of one. Hence, weld deposit size is increased considerably. Moreover, due to increase in welding current (upto 1500 A), much deeper penetration of base metal is achieved.

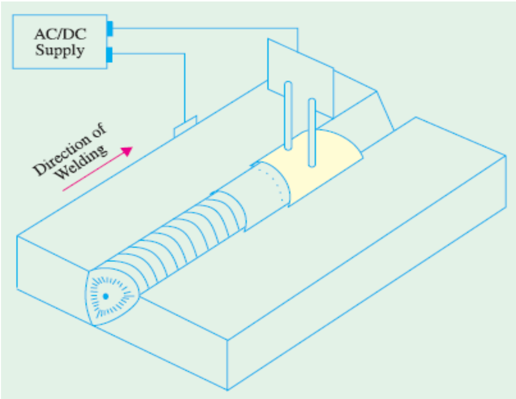


Fig-6

Gas Shield Arc Welding

In this fusion process, welding is done with bare electrodes but weld zone is shielded from the atmosphere by a gas which is piped to the arc column. Shielding gases used are carbon dioxide, argon, helium, hydrogen and oxygen. No flux is required. Different processes using shielding gas are as follows.

(a) Tungsten inert-gas (TIG) Process

In this process, non-consumable tungsten electrode is used and filler wire is fed separately. The weld zone is shielded from the atmosphere by the inert gas (argon or helium) which is ducted directly to the weld zone where it surrounds the tungsten and the arc column.

(b) Metal inert-gas (MIG) Process

It is a refinement of the TIG process. It uses a bare consumable (i.e. fusible) wire electrode which acts as the source for the arc column as well as the supply for the filler material. The weld zone is shielded by argon gas which is ducted directly to the electrode point.

Resistance Welding

It is fundamentally a heat and squeeze process. The term **'resistance welding'** denotes a group of processes in which welding heat is produced by the resistance offered to the passage of electric current through the two metal pieces being welded. These processes differ from the fusion processes in the sense that no extra metal is added to the joint by means of a filler wire or electrode. According to Joule's law, heat produced electrically is given by H = I2Rt/J. Obviously, amount of heat produced depends on. **(i)** square of the current **(ii)** the time of current and **(iii)** the resistance offered. As seen, in simple resistance welding, high-amperage current is necessary for adequate weld. Usually, R is the contact resistance between the two metals being welded together. The current is

passed for a suitable length of time controlled by a timer. The various types of resistance welding processes may be divided into the following four main groups :

(i) spot welding **(ii)** seam welding **(iii)** projection welding and **(iv)** butt welding which could be further subdivided into flash welding, upset welding and stud welding etc.

Advantages

Some of the advantages of resistance welding are as under :

1. Heat is localized where required
2. Welding action is rapid
3. No filler material is needed
4. Requires comparatively lesser skill
5. Is suitable for large quantity production
6. Both similar and dissimilar metals can be welded
7. Parent metal is not harmed

8. Difficult shapes and sections can be welded.

Only disadvantages are with regard to high initial as well as maintenance cost. It is a form of resistance welding in which the two surfaces are joined by spots of fused metal caused by fused metal between suitable electrodes under pressure.

Spot Welding

The process depends on two factors:

1. Resistance heating of small portions of the two work pieces to plastic state and

2. Application of forging pressure for welding the two work pieces. Heat produced is H = I2 Rt/J. The resistance R is made up of **(i)** resistance of the electrodes and metals themselves **(ii)** contact resistance between electrodes and work pieces and **(iii)** contact resistance between the two work pieces. Generally, contact resistance between the two work pieces is the greatest.

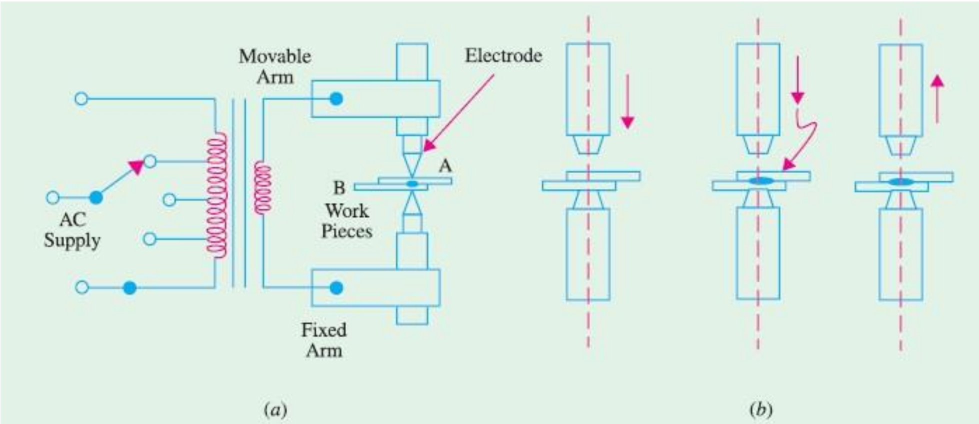


Fig-7

As shown in Fig-26 (b), mechanical pressure is applied by the tips of the two electrodes. In fact, these electrodes not only provide the forging pressure but also carry the welding current and concentrate the welding heat on the weld spot directly below them. Fig.26 (a) shows diagrammatically the basic parts of a modern spot welding. It consists of a step-down transformer which can supply huge currents (up to 5,000 A) for short duration of time. The lower arm is fixed whereas the upper one is movable. The electrodes are made of low-resistance, hard copper alloy and are either air cooled or butt-cooled by water circulating through the rifled drillings in the electrode. Pointed electrodes [Fig.27 (a)] are used for ferrous materials whereas domed electrodes are used for non-ferrous materials. Flat domesare used when spot-welding deformation is not desired. The weld size is determined by the diameter of the electrode.

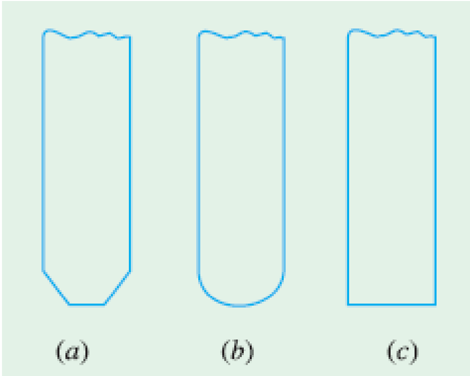


Fig-8

The welding machine is cycled in order to produce the required heat timed to coincide with the pressure exerted by the electrodes as shown in Fig.26 (a). As the movable electrodecomes down and presses the two work pieces A and B together, current is passed through the assembly. The metals under the pressure zone get heated up to about 950°C and fuse together. As they fuse, their resistance is reduced to zero, hence there is a surge of current. This surge is made to switch off the welding current automatically. In motor-driven machines, speeds of 300strokes/minute are common. Spot welders are of two different types. One is a station arc welder which is available in different sizes. The other has a stationary transformer but the electrodes are in a gun form. Electric resistance spot welding is probably the best known and most widely-used because of its low cost, speed and dependability. It can be easily performed by even a semi-skilled operator. This process has a fast welding rate and quick set-up time apart from having low unit cost per weld. Spot welding is used forgalvanized, tinned and lead coated sheets and mild steel sheet work. This technique is also applied to non-ferrous materials such as brass, aluminium, nickel and bronze etc.

Seam Welding

The seam welder differs from ordinary spot welder only in respect of its electrodes which are of disc or roller shape as shown in Fig.28(a). These copper wheels are power driven and rotate whilst gripping the work. The current is so applied through the wheels that the weld spots either overlap as in Fig.28 (b) or are made at regular intervals as in Fig.28 (c). The continuous or overlapped seam weld is also called **stitch weld** whereas the other is called rollweld.

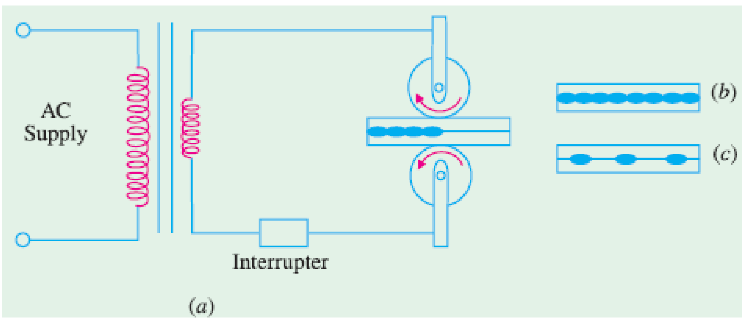


Fig-9

Seam welding is confined to welding of thin materials ranging in thickness from 2 mm to 5 mm. It is also restricted to metals having low harden ability rating such as hot-rolled gradesof low alloy steels. Stitch welding is commonly used for long water-tight and gas-tight joints. Roll welding is used for simple joints which are not water-tight or gas-tight. Seam welds are usually tested by pillow test.

Projection Welding

It can be regarded as a mass-production form of spot welding. Technically, it is a cross between spot welding and butt welding. It uses the same equipment as spot welding. However, in this process, large-diameter flat electrodes (also called platens) are used. This welding process derives its name from the fact that, prior to welding, projections are raisedon the surfaces to be welded [Fig.29 (a)].

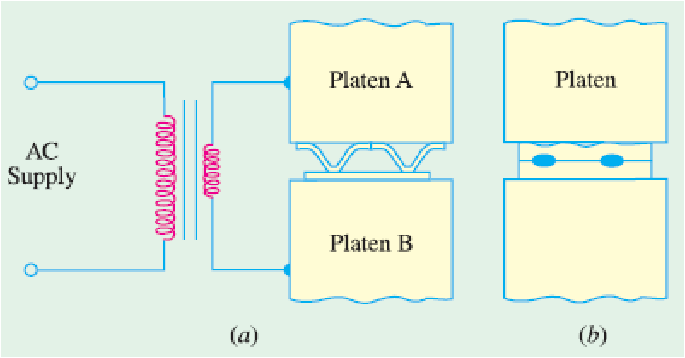


Fig-10

As seen, the upper and lower platens are connected across the secondary of a step-down transformer and are large enough to cover all the projections to be welded at one stroke of the machine. When platen A touches the work piece, welding current flows **through each projection**. The welding process is started by first lowering the upper platen A on to the work-piece and then applying mechanical pressure to ensure correctly-forged welds. Soon after, welding current is switched on as in spot welding. As projection areas heat up, they collapse and union takes place at all projections simultaneously [Fig.29(b)]. Projection welding is used extensively by auto manufactures for joining nuts, bolts and studs to steel plates in car bodies. This process is especially suitable for metals like brass, aluminium and copper etc. mainly due to their high thermal conductivity. A variation of projection welding isthe metal fibre welding which uses a metal fibre rather than a projection point(Fig.30).

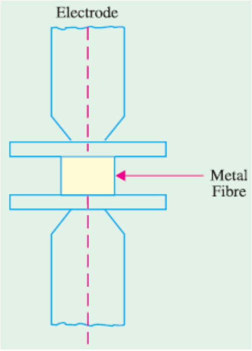


Fig-11

This metal fibre is generally a fill material. Instead of projections, tiny elements of this felt material are placed between the two metals which are then projection-welded in the usual way.

Butt Welding

In this case, the two work pieces are brought into contact end-to-end and the butted ends are heated by passing a heavy current through the joint. As in other forms of resistance welding, the weld heat is produced mainly by the electrical resistance of the joint faces. In this case, however, the electrodes are in the form of powerful vice clamps which hold the work-pieces and also convey the forging pressure to the joint [Fig.31].

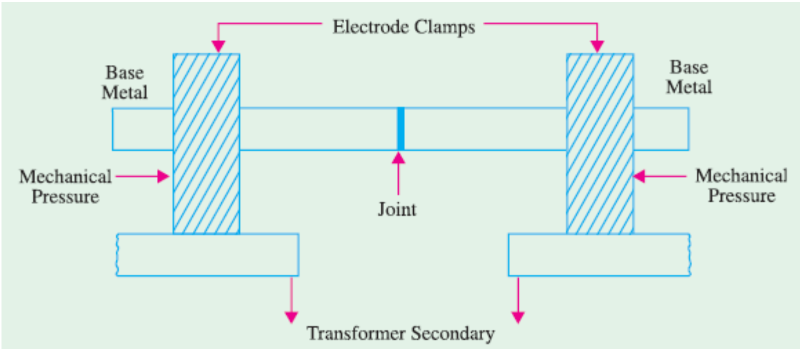


Fig-12

This process is useful where parts have to be joined end-to-end or edge-to-edge. i.e. for welding pipes, wires and rods. It is also employed for making continuous lengths of chain.

XXXXXXXXXX

CHAPTER 4
ILLUMINATION

Light is a form of radiant energy. Various form of incandescent bodies are the sources of light and light emitted by such bodies depend upon the temperature of bodies. Heat energy is radiated into the medium by a body which is hotter than the medium surrounding it.

When the temperature increases the body changes red-hot to white-hot state, the wave-length of the energy radiated becomes smaller and enters into the range of the wave- length of light.

The ratio of the energy emitted by the body in the form of light to the total energy emitted by the body is known as the –radiant efficiency‖ of the body, which depends upon the temperature. Higher the temperature of the body; lower the wave-length of radiant energy and higher the efficiency.

Terms used in illumination

Luminous Intensity: -Luminous intensity in any given direction is the luminous flux emitted by the source per unit solid angle, measured in the direction in which the intensity is required. It is denoted by symbol I and is measured in candela (cd) or lumens per steradian.

Lumen: - The lumen is the unit of luminous flux and is defined as the amount of luminous flux given out in a space represented by one unit of solid angle by a source having an intensity of one candle power in all directions.

i.e., Lumens= candle power × solid angle = $CP \times \omega$

Or, total lumens given out by source of one candela is 4π lumens

Illumination: - When the falls upon any surface, the phenomenon is called the illumination. Itis defined as the number of number of lumens, falling on the surface, per unit area. It is denoted by symbol E and is measured in lumens per square meter or lux or meter-candela.

If a flux of F lumens falls on a surface of area A , then the illumination of that surface is

$$E = \frac{F}{A} \text{ lumens per meter}$$

Mean Horizontal Candle Power (MHCP):- It is defined as the mean of candle powers in all directions in horizontal plane containing the source of light.

Mean Spherical Candle Power (MSCP):- It is defined as the mean of candle powers in all directions and in all planes from the source of light.

Mean Hemi-Spherical Candle Power (MHSCP):- It is defined as the mean of candle powers in all directions above or below the horizontal plane passing through the source of light.

Brightness or luminance: it is defined as the luminous intensity per unit projected area of either a surface source of light or a reflecting surface and is defined by L.

$$L= \frac{1}{A\cos\theta} \text{ candela/m}^2 \text{ or nits}$$

Solid Angle: Plane angle is subtended at a point in a plane by two converging straight lines and its magnitude is given by

$$\omega = \frac{Arc}{Radius} \, radians \, .$$

LAWS OF ILLUMINATION:

There are two laws of illumination (1) Law of inverse squares (2) Lambert‘s cosine law

1. LAW OF INVERSE SQUARES:

The law of inverse square states that –The illumination of a surface is inversely proportional to the square of the distance between the surface and the light source provided that the distance between the surface and the source is sufficiently large so that the source canbe regarded as a point of source.‖

If a source of light which emits light equally in all directions be placed at the centre of a hollow sphere, the light will fall uniformly on the inner surface of the sphere, that is to say each square mm of the surface will receive the same amount of light. If the sphere be replaced by one of the larger radius, the same total amount of light is spread over a larger area proportional to the square of the radius. The amount which falls upon any square mm of such a surface will, therefore, diminish as the radius increases, and will be inversely proportional to the square of the distance.

Mathematically it can be proved as follows:

Let us consider surface area A1 and surface area A2 at distances r1 and r2 respectively from the point source S of luminous intensity I and normal to the rays, as shown in fig.

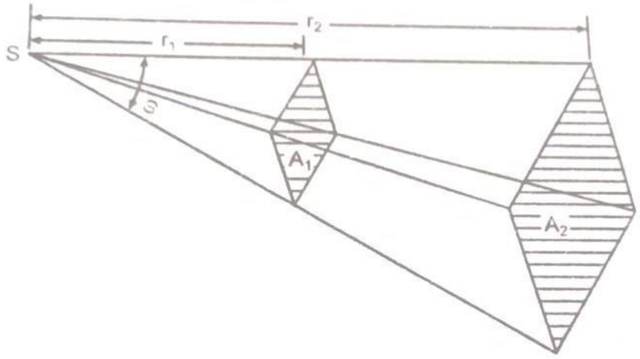


Fig. 1

Inverse Square Law:

Let the solid angle subtended be ω steradians

Luminous flux radiated per steradians = I

Total luminous flux radiated =Iω lumens

Illumination on the surface of area A1=Iω/A1 lumens per unit area

And area A1=ωr1

Illumination on the surface of area A1,

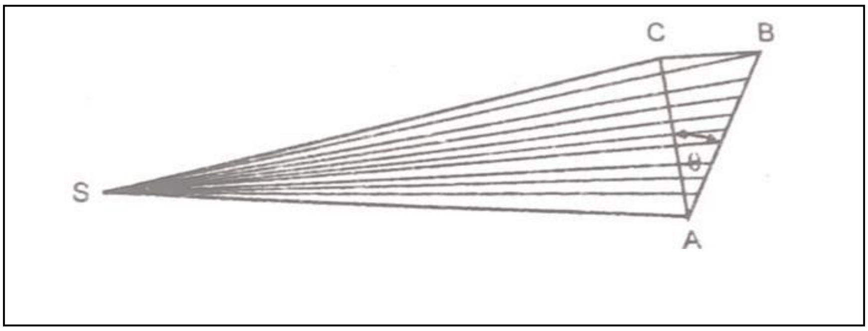
$E1=I\omega/\omega r1^2=I/r_1^2$ lumens per unit area

Similarly illumination on the surface of area A_2,

$E_2=I_w/A_2=I\ \omega/\omega r_2^2=I/r_2^2$ lumens per unit area.

2. Lambert's Cosine Law:

This law states that the illumination at any point on a surface is proportional to the cosine of the angle between the normal at that point and the direction of luminous flux.



Lambert's Cosine Law

The above figure shows that the area over which the is spread is then increased in the ratio

AB/AC=1/cosθ

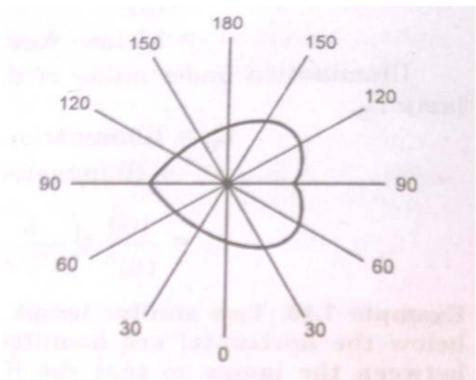
And the illumination decreases in the ratio cosθ/1

The expressions for the illumination then becomes

$$E=I\cos\theta / r^2.$$

POLAR CURVES:

The luminous intensity in all directions can be represented by polar curves. If theluminous intensity in a horizontal plane passing through the lamp is plotted against angular position then this curve is known as horizontal polar curve. If the luminous intensity in a vertical plane is plotted against the angular position, then curve is known as vertical polar curve. The vertical and horizontal polar curve is shown as fig.



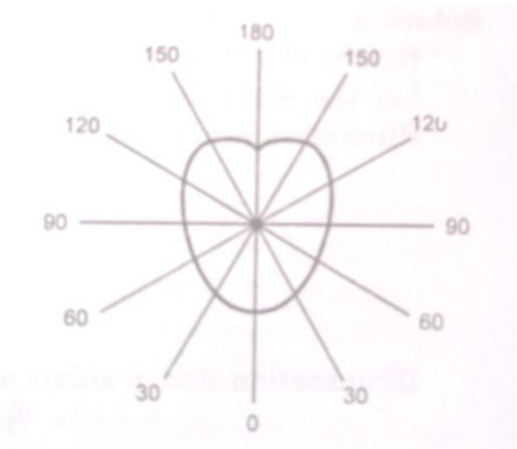


Fig.3a.Polar Curve for Horizontal plane

Fig 3.b. Polar Curve for Vertical Plane

The polar curves are used to determine the mean horizontal candle power and mean spherical candle power .These are used to determine the actual illumination of a surface by employing the candle power in that particular direction.

Maintenance Factor: The ratio of illumination under normal working conditions to the illumination when the things are perfectly clean is known as maintenance factor.

Illumination under normal working conditions / illumination when everything is perfectly clean.

Depreciation Factor: It is defined as the ratio of initial meter candles to the ultimate maintained meter candles on the working plane. It is also the inverse of the maintenance factor. Its value is more than 1.

TYPES OF LIGHTING SCHEMES:

The distribution of the light emitted by lamps is controlled by means of reflectors and translucent diffusing screens. The interior lighting schemes is classified as (a) direct lighting (b)semi-directing lighting (c) in directing lighting (d) general lighting.

Direct lighting: It is the most commonly used type of lighting scheme. In this scheme more than 90 percent of total light flux is made to fall directly on the working plane with the help of deep reflectors. It is mainly used for industrial and general outdoor lighting.

Semi-direct lighting: in this lighting scheme 60 to 90 percent of the total light flux is made to fall downwards directly with the help of semi direct reflectors, remaining light is used to illuminate the ceiling and walls. Such a lighting scheme is best suited to rooms with high ceilings where a high level of uniformly distributed illumination is desirable.

Semi-indirect lighting: In This lighting scheme 60 to 90 percent of total light flux is thrown upwards to the ceiling for diffuse reflection and the rest reaches the working plane directly except for some absorption by the bowl. This lighting scheme is with soft shadows and glare free. It is mainly used for indoor light decoration purposes.

Indirect Lighting: In this light scheme more than 90 percent of total light flux is thrown upwards to the ceiling for diffuse reflection by using inverted or bowl reflectors. in such a system the ceiling acts as the light source, and the glare is reduced to minimum. The resulting illumination is softer and more diffused, the shadows are more prominent and the appearance of room is more improved over which that results from direct lighting. it is used for decoration purposes in cinemas, theatres and hotel etc. and in workshops where large machines and other and obstructions would cause troublesome shadows if direct lighting is employed.

General Lighting: in this scheme lamps made of diffusing glass are used which give nearly equally illumination in all directions.

GAS DISCHARGE LAMP:

The basic principle of a gaseous discharge lamp as shown in fig. Gases are normally poor conductors at atmospheric and high pressures. When application of suitable voltage, known as ignition voltage across the two electrodes, as result in a discharge through the gas which is accompanied by electromagnetic radiation. The wave-length of this radiation depends upon the gas, its pressure and the metal vapour used in lamp.

Once the ionization has commenced in the gas, it has a tendency to increase continuously accompanied by a fall in the circuit resistance. In order to limit the current to a safe value of a choke or ballast is made. The choke performs the dual functions of providing the ignition voltage initially and limiting the current. Since due to use of choke the power factor becomes poor, i.e.0.3-0.4 .Therefore in order to improve the power factor of the gaseous discharge lamp use of a condenser. The colour of the light obtained depends upon thenature of the gas or vapour used.

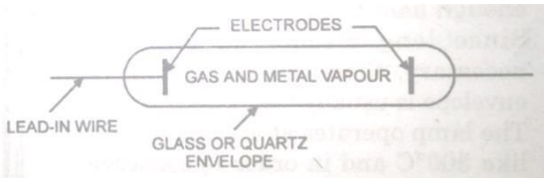


Fig. 4. Gaseous Discharge Lamp

The production of light by these lamps is based on the phenomenon of excitation andionization in a gas or vapour . We shall now briefly discuss this phenomenon with reference to the structure of an atom.An atom has a positive nucleus and one or more electronsrevolving around it in certain fixed orbits.in certain solids and gases here are what are known as free electrons which can escape from the influence of the nucleus of one atom and go over to another atom.There are thus a number of electrons which are mobile in nature.If a potentialdifference is applied to two electrodes placed in a gas having a large number of free electrons, these electrons will be attracted to the positive electrode and the velocity acquired by an electron will depend upon the potential gradient. During its motion towards the positive electrode, an electron will strike other atoms and one or more of the following results may be produced.

- ELASTIC COLLISION

The electron may be bounced off the atom it strikes and there may be no change in its velocity. This happens when the striking electron has a small amount of kinetic energy.

- EXCITATION

If the electron has acquired kinetic energy above a certain critical value in the process of passing through a certain potential which is termed as the excitation potential, the collision may cause one of the electrons to jump from its normal orbit into another one. This happens when the colliding electron has a kinetic energy of 2.1eV.The colliding electron imparts its kinetic energy to the atom that it strikes and this atom is said to be in an excited state.In this way the atoms can be placed in the 1^{st},2^{nd},3^{rd},4h or higher excited states depending upon the kinetic energy of the colliding electron.

- IONISATION BY COLLISION

If the kinetic energy of the colliding atom is large, it will completely knock out an electron from its orbit and this electron will now behave like a free electron and may produce more free electrons by collision. A large number of free electrons thus produced constitute a heavy current and an electric arc may result. This phenomenon is called *ionization*. Ionization potential is the potential difference through which an electron must travel to acquire energy for ionization by collision.

Neon Lamp

These belong to the cold-cathode category. The electrodes are in the form of iron shells and are coated on the inside. The colour of the light emitted is red and these lamps are mostly used for electrical advertising. High voltage is used for starting. If helium gas is used for in place of neon, pinkish white light is obtained. Helium and neon through coloured glass tubing produce a variety of effects. Figure below shows a circuit for a neon lamp. The transformer has a high leakage reactance, which stabilize the arc in the lamp. A capacitor is used for power factor improvement.

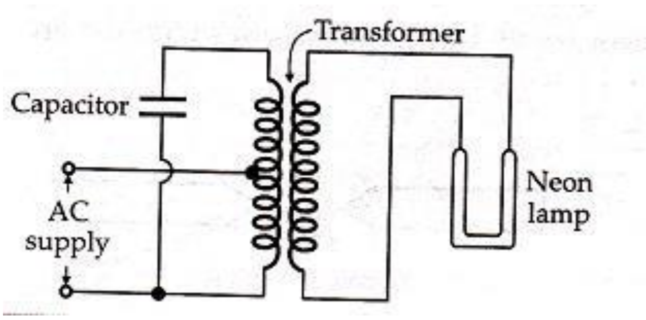


Fig. 5. Neon Lamp

Sodium Vapour lamp

Sodium vapour has the highest theoretical luminous efficiency and gives monochromatic orange-yellow light.The monochromatic light makes objects appear grey. Such lamps on account of this factor are used only for street and highway lighting.

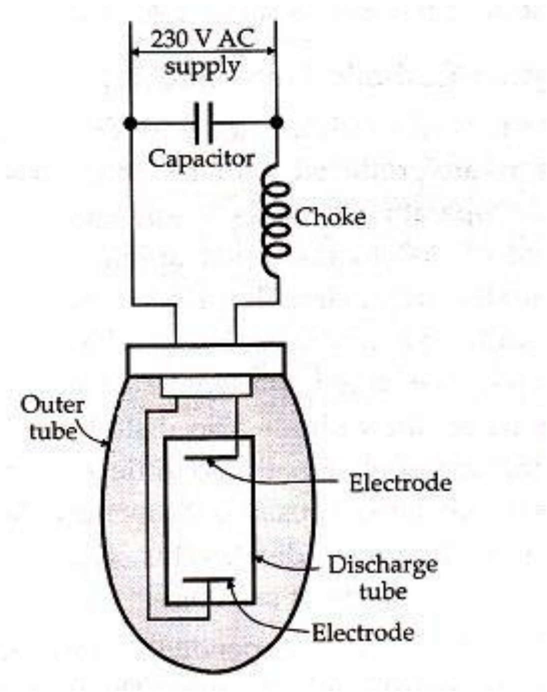


Fig. 6 Sodiun Vapour Lamp

The Lamp consists of a discharge tube having special composition of glass to withstand the high temperature of the electric discharge. The discharge tube is surrounded by an outer tube as shown below. For heating the cathode a transformer is included.Sodium below 60^0C is in solid state.For starting the lamp the electric discharge is allowed to take place in neon gas.The temperature inside the discharge tube rises and vapourises sodium.Operating temperature is around 230^0C .It takes about 10 minutes for the sodium vapour to displace the red colour of neon by its brown yellow colour. The lamp takes about half an hour to reach full output. A choke is providing for stabilizing the electric discharge and a capacitor for power factor improvement. The light output is about 40 to 50 lumens per watt.

Mercury Vapour Lamp

It is similar in construction to the sodium vapour lamp. The electrodes are tungsten coils containing an electron emitting material which may be a small piece of thorium or an oxide mixture. Argon is introduced to help start the lamp. The electric discharge first takes place through argon and this vaporizes the mercury inside the discharge tube. The electron emitting material supplies electrons to maintain the arc.

The space between the two bulbs is filled with an inert gas. The pressure inside the discharge tube may range from one to ten atmospheres in lamps used for lighting purposes as at these pressures the radiation is in the visible spectrum. If the pressure inside the discharge tube is low, most of the light is in the ultraviolet rgion.The efficiency is 30 to40 lumens per watt.

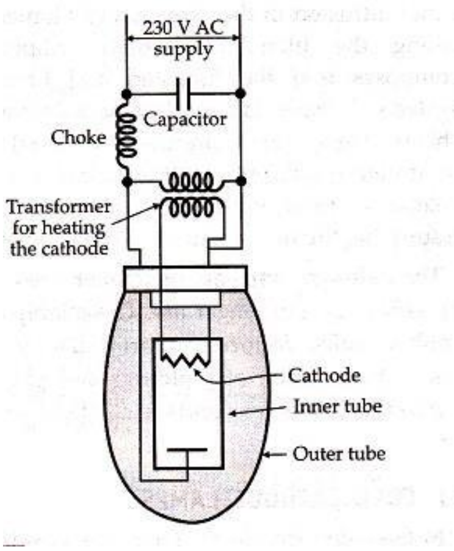


Fig.7 High pressure Mercury vapour Lamp

Fluorescent Lamp

In the mercury vapour lamp considerable amount of radiation is in the ultra violet range. By coating the inside of the tube by phosphor this ultra violet radiation is converted in visible light. Phosphors have definite characteristic colours but when mixed together they produce a large variety of colours. These phosphors are stable compounds and give a high output throughout the life of the lamp.

There are three types of fluorescent lamps:

1. Iron cathode or cold cathode type
2. Tungsten cathode, pre-heated type
3. Tungsten cathode, cold

In the cold cathode discharge tube under normal operating conditions which depend on the type and pressure of the gas and the type of electrodes,a glow discharge takes place which is discontinuous near the cathode where crockes and faraday dark space occur due to the formation of space charges in the gas.There is fairly large fall in voltage in this region.Then there is the positive column which provides useful illumination.The voltage dropalong the positive column is proportional to its length.The large voltage drop at the cathode isindependent of the tube length and depends only on the cathode material and the gas pressure.It may be between 100 and 200 volts. If, therefore , a cold cathode tube were to be operated from the mains,it would be very inefficient since most of the voltage will be utilized in overcoming the cathode voltage drop. It becomes necessary to use high voltage for the economic operation of this type of lamp.Also the lamp is not efficient unless its length is considerable.However, cold cathode tubes are of smaller diameter and can give any shape which makes them suitable for display and advertisement purpose.

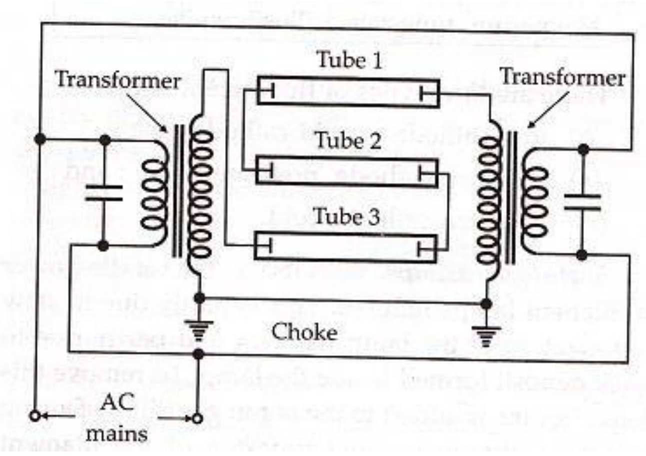


Fig. 8 Operation of the cold cathode lamps in series

Tungsten Cathode Preheated Type

In tungsten cathode preheated type electrons are produced by thermionic emission. Lower starting operating voltages are adequate. A transient voltage of 300 to 600 voltsapplied by the starter initiates the arc stream. The coating material decays in each starting of the lamp. The constant impact of electrons on the cathode also dislodges some of the emittingmaterial. Finally so little of the materials is left that it is not possible to emit any electronsand the lamp becomes dead. This type of lamp is unsuitable for frequent starting

Fluorescent lamps produce flicker or stroboscopic effect since on 50 cycle supply they are extinguished 100 times a second. Single lamp cannot be operated without flicker. Flicker correction can be applied to pairs of lamps.

Radio interference is another effect produced by fluorescent lamps and has to be removed by suitable filter circuits. The advantage of fluorescent lamp is that its efficiency and life under normal conditions are almost three times those for filament lamps. The quantity of light obtained is superior, glare is minimum and the fluorescent light source casts soft shadows. However, the initial cost of the lamp and filling is higher than the incandescent lamps.

Starters of automatic starting switches are of two types:

1. Thermal Type
2. Glow discharge Type

The thermal starter has a heater coil which heats a bimetallic switch. The heater coil remains energized to keep the bimetallic switch open throughout the operation .It therefore, consumes a small amount of power. Figure below shows the circuit diagram of fluorescent lamp started by a thermal starter. When the supply is switched on the contacts of the bimetallic switch are closed and the current passes though the electrodes and heats them up. But after an interval of a few seconds the heater coil heats up the bimetallic strip and the bimetallic switch contacts open. This starts a high voltage transient across the electrode due to the presence of the choke or ballast in the circuit. An arc is struck between the electrodes due to the high voltage transient. The identical circuit showing the use of a glow starter can also be used as shown. The glow starter is enclosed in a glass bulb filled with neon or argon. One of the electrodes is a bimetallic strip.

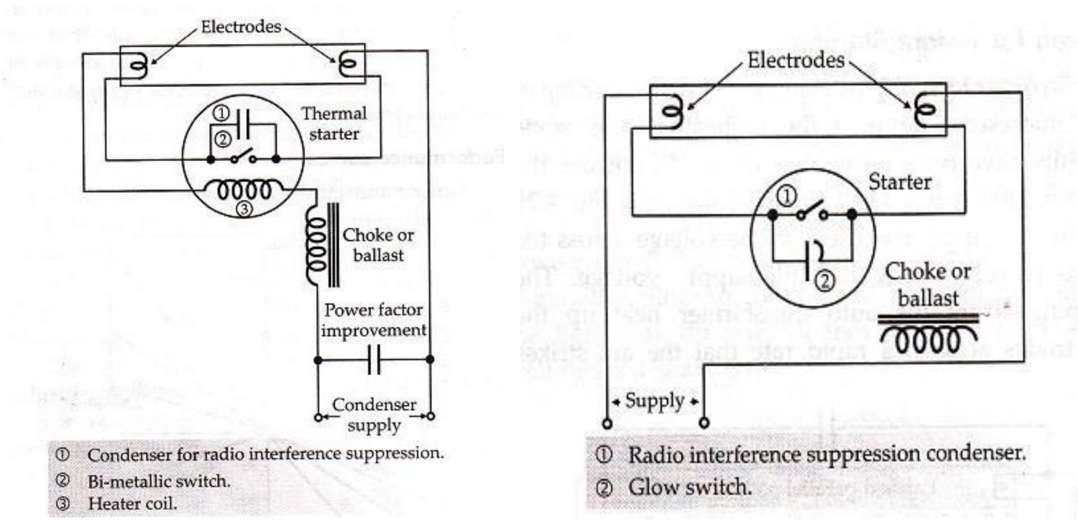


Fig.9 Fluorescent lamp

When the normal voltage is applied to the lamp, a glow discharge takes place across the glow switch and small current flows through the electrodes. The bimetallic strip expands due to the heating effect of the current in the glow discharge. The expansion of bimetallic strip causes the electrodes touch each other and the electrodes get pre heated due to flow of an appreciable amount of current. Mean while the bimetal cools. The glow switch opens and the resultant high voltage transient starts the arc discharge through the tube.

XXXXXXXXX

Introduction

Electrical energy is finding increasing application in industrial and commercial fields. Electric drive for industrial purposes is now almost universal. There are number of inherent advantages that the electric drive possesses over other forms of conventional drives. It is cleaner, more easily controllable and more flexible. With greater advancement in the development of Electric motors and control gear, the trend in the industry is towards an all-electric drive.

Both d.c. And a.c. is used for electric drives. Use of d.c. is limited on account of permissible voltage drop in feeders. But d.c. systems are still in use for many reasons.

The electric drive due to various inherent advantages has been universally adopted by the industry. Both A.C. and D.C. motors are used, however, A.C. system is preferred. The utilization of electrical energy is always advantageous as it is cheaper ,it can be easily transmitted at comparatively low line losses it is easy to maintain the voltage at consumer premises within the prescribed limits and it is possible to increase or decrease the voltage without appreciable loss of power.

In spite of the advantages of A.C. system, following are the applications of D.C. Industrial drives:

(i) For traction purposes, as in such application a very high staring torque is required. The starting torque can be obtained from D.C. series motor at low operating cost.

(ii) The speed of A.C. motors is almost constant, where as it can be varied easily in case of D.C. motor. Thus for variable speed applications such as lift and Ward Leonard system etc., the D.C. motors are preferred.

(iii) D.C. motors are also used in industry where very high accuracy of speed control is required.

(iv) The cost of change-over from d.c. to a.c. involves changes both in the power system and the consumer‘s equipment and is likely to be expensive.

(v) In some processes, Example: - electro-chemical, battery-charging etc. d.c. is the only type of power that is suitable.

Group Drive

Where a number of machines are driven through belts from a common shaft, it is known as *group drive*. Alternatively, each machine may have its own driving motor, in which case it is called individual *drive*.

In group drive case, one motor is used as a drive for two or more machines. The motor is connected to a long shaft. The machines are connected to this shaft through belt and pulleys. The use of this kind of drive is restricted due to the following reasons:

(i) If at certain instance all the machines are not in operation, then the motor will be working at low capacity.

(ii) In case of fault in the motor all the machines connected to this motor will cease to operate thereby paralyzing either complete or part of industry up till the time the fault is removed.

(iii) It is not possible to install any machine at a distant place.

(iv) The possibility of installation of additional machines in an existing industry is limited.

However, there are certain advantages of the group drive, which are detailed below:

i. Initial cost of installing the industry is low. For example , if the power requirement of each machine is 10 H.P. and there are 10 machines in the group, then thecost of ten numbers 10 H.P. motors will be much more than one 100 H.P. motor. Further, it is learnt from practical experience that the combined requirement of all these ten machinesat a time will be less than 100 H.P. This further reduces the initial cost.

ii. In certain industrial processes one process is connected to another process and will be advantageous if all these interconnected processes are stopped simultaneously.

Individual drive :

In this case there is a separate driving motor for each machines. Such a drive is very common in most of the industries. It has the following advantages :

i) If there is a fault in one motor, the effect on the production or output of theindustry will not be appreciable.

ii) Machines can be located at convenient places.

iii) Continuity in the production of the industry is ensured to a higher

degree.Following is the disadvantage:

i) Initial cost will be high.

Advantages of Electric Drives:

- Flexible control characteristics.
- Starting and braking is easy and simple
- Provides a wide range of torques over a wide range of speeds (both ac and dc motor)
- Availability of wide range of electric power
- Works to almost any type of environmental conditions

- No exhaust gases emitted
- Capable of operating in all 4 quadrants of torque –speed plane
- Can be started and accelerated at very short time

Choice of Electrical Drives:

The choice of an electrical drive depends on a number of factors. Some important factors are: ¬

Steady state operation requirements: (nature of speed-torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations, rating etc)

¬ Transient operation requirement(values of acceleration and deceleration, starting, braking, speed reversing)

¬ Requirement of sources:(types of source, its capacity, magnitude of voltage, power factor, harmonics etc)

¬ Capital and running cost, maintenance needs, life periods

¬ Space and weight restriction

STARTING and RUNNING CHARACTERISTICS OF DC AND AC MOTORS

DC MOTORCHARACTERISTICS

 Direct-Current Motors

DC motors are divided into three classes, designated according to the method of connecting the armature and the field windings as shunt-series and compound wound.

- Shunt-Wound Motors
- Series-Wound DC Motors
- Compound-Wound DC Motors

SHUNT-WOUNDMOTORCHARACTERISTICS

 Shunt-Wound Motors

- Runs practically constant speed, regardless of the load.
- Generally used in commercial practice
- Recommended where starting conditions are not usually severe.
- Speed of the shunt-wound motors may be regulated in two ways:
    - Inserting resistance in series with the armature, thus decreasing speed
    - Inserting resistance in the field circuit, the speed will vary with each change in load
        - the speed is practically constant for any setting of the controller.
        - Most generally used for adjustable-speed service, as in the case of machine tools.

SERIES-WOUNDMOTORCHARACTERISTICS

 Series-Wound DC Motors

- Speed varies automatically with the load, increasing as the load decreases.
- Generally limited to case where a heavy power demand is necessary to bring the machine up to speed, as in the case of certain elevator and hoist installations, etc.
- Series-wound motors should never be used where the motor cab be started without load, since they will race to a dangerous degree.

COMPOUND-WOUNDMOTORCHARACTERISTICS

 Compound-Wound DC Motors

- Combination of the shunt wound and series-wound types - combines the characteristics of both.
- Characteristics may be varied by varying the combination of the two windings.
- Generally used where severe starting conditions are met and constant speed is required at the same time.

Running Characteristics

The running characteristics of a motor include the speed-torque or the speed-current characteristics, losses, efficiency and power factor at various loads. Power factor consideration crops up in the case of a.c. motors only.

D.C. Motor

In the case of DC shunt motors speed is fairly constant with load; there is only a slight fall in speed as the load comes up. The speed torque characteristic is a slightly drooping straight line.

For the DC series motor the speed is normally high at low loads and decreases as the motor is loaded .The speed –Torque characteristics is a supply drooping curve.

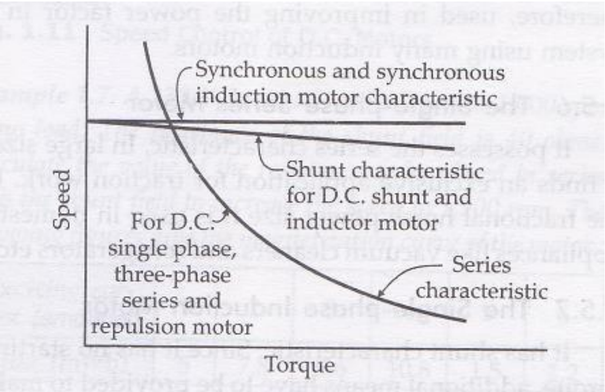


Fig..9 Torque speed relation of dc and ac motors

- In the compound motor, the speed-torque characteristics may be made to lie anywherebetween the pure shunt and the pure series by suitably adjusting the series and the windings

AC MOTOR BASICS

AC induction motors are one of the most common types of motors used in a variety of applications due to the fact that they run off of AC voltage which is readily available at every outlet. They also run quietly and have a long life.

All AC motors have the same basic components, a stator and rotor. The stator is the stationary coils in the motor where the current is produced to create the magnetic field. This magnetic field induces a current in the rotor bars causing the rotor to rotate.

KEY CHARACTERISTIC: RUNNING SPEED

Two important characteristics of AC motors that need to be considered for any application are running speed and starting torque. Running speed is dependent on the power supply frequency, the number of motor poles and the amount of slip. The frequency and number of poles define what the synchronous speed of the motor will be.

AC motors require slip to induce current in the rotor, and the amount of slip changes as the load on the motor changes. In order to change the speed of an AC motor, the frequency must be changed. This is accomplished by a motor control, and the most common is a Variable Frequency Drive (VFD)

KEY CHARACTERISTIC: STARTING TORQUE

Another key characteristic is the starting torque of the motor. In comparison to other motor types, starting torque is the chief limitation of an AC motor. A single phase motor will not start on and must have help. Single phase motors are defined by the methods they use to start. Some common types of single phase motors are the shaded pole motor, the split phase motor, the permanent split capacitor motor (also called the single value capacitor motor), and the two value capacitor motor. All these motor types either use an out of phase secondary coil or a capacitor to create a secondary phase to start the motor. Remember, if your application requires the motor to start with a load on it, consult your motor manufacturer to ensure the motor has enough torque to start at load and to ensure the correct motor type is specified for your application.

In comparison to single phase motors, three phase motors have a higher power density, a higher starting torque, and are more efficient than single phase motors. They start on their own, eliminating the need for a starting winding or capacitor. The same speed calculation applies to three phase motors as single phase, so a VFD is required to change the motor speed. Also, when a three-phase power source is unavailable, controls are capable of converting single phase power into three phase power, making the three-phase motor more versatile.

AC motors work great for a number of different applications such as pumps, conveyors, and commercial products.

Application of DC series motor

⇒ DC series motors are used where high starting torque required. These motors are only used where the variation of speed is possible. series motors are not suitable for constant speed applications.

⇒ DC series motor is used in a vacuum cleaner, traction systems, sewing machines, cranes, air compressors etc.

Application of DC shunt motor

⇒ DC shunt motors are used where constant speed is needed. So these motors are commonly used in fixed speed applications.

⇒ This type of motor is used in Lathe Machines, Centrifugal Pumps, Fans, Blowers, Conveyors, Lifts, Weaving Machine, Spinning machines, etc.

Application of DC Compound motor

⇒ By compound motor, we get high starting torque and nearly constant speed. Because of that Compound motors are used where we require high starting torque and constant speed.

⇒ A compound motor is used in Presses, Shears, Conveyors, Elevators, Rolling Mills, Heavy Planners, etc.

Application of 3 phase induction motor

Day to day life we can find the various **application of 3 phase induction motor**. Compare with a single-phase induction motor it has more advantages. That advantages help to used more applications of 3 phase induction motor than single-phase induction motor.

Applications of **3 phase induction motor** depend on their types, so now we need to get some idea about its types.

phase induction motors can be divided into two types depending on their rotor construction.

1. Squirrel cage induction motor.
2. Slip ring induction motor.

Squirrel cage induction motor widely used in industry than a slip ring induction motor. Because the squirrel cage induction motor has a simple and rugged construction.

Squirrel cage induction motor has not a very good speed control method, so it used for constant speed applications. Also, it's starting efficiency less compare with running efficiency.

- 3 phase squirrel cage induction motor is used for centrifugal pump, milling machines, lathe machines, woodworking machines, and large blowers and fans.

Application of slip ring induction motors.

Slip ring induction motor has a high starting torque and good speed control method, so it can operate a high load with less speed.

- So it is using for high load applications like elevators, food processing factory machines, tea processing factory machines, and printing machines.

Application of 3 phase synchronous motor

The important characteristics of the synchronous motor is its constant speed irrespective of the load conditions, and variable power factor operation. As seen earlier its power factor can be controlled by controlling its excitation. For overexcitation its power factor is leading in nature, which is very important from the power factor correction point of view.

Due to constant speed characteristics, it is used in machine tools, motor generator sets, synchronous clocks, stroboscopic devices, timing devices, belt driven reciprocating compressors, fans and blowers, centrifugal pumps, vacuum pumps, pulp grinders, textile mills, paper mills line shafts, rolling mills, cement mills etc.

The synchronous motors are often used as a power factor correction device, phase advancers and phase modifiers for voltage regulation of the transmission lines. This is possible because the excitation of the synchronous motor can be adjusted as per the requirement.

The disadvantages of synchronous motor are their higher cost, necessity of frequent maintenance and a need of d.c. excitation source, auxiliary device or additional winding provision to make it self starting. Overall their initial cost is very high.

Application of single phase induction motor

Single phase induction motors are used in smaller equipment where we require less horsepower (for example, one horsepower). Some of the examples of real life are

- Pumps
- Compressors
- Small fans
- Mixers
- Toys
- High-speed vacuum cleaners
- Electric Shavers

- Drilling Machines

Application of single phase series motor

There are numerous applications where single-phase ac series motors are used, such as hair dryers, grinders, table-fans, blowers, polishers, kitchen appliances etc. They are also used for many other purposes where speed control and high values of speed are necessary.

Application of universal motor

- Universal Motors are used in table fans, hairdryers and grinders.
- They are used in portable drill machines.
- They are used in polishers, blowers and kitchen appliances.

Application of repulsion motor

The applications are

- They are used where there is a need for starting torque with high-speed equipment's
- Coil Winders: Where we can adjust speed flexibly and easily and direction can also be changed by reversing the brush axis direction.
- Toys
- Lifts etc.

Introduction

The system of traction involving the use of electricity is known as the electric traction .

In the earlier stages of the development of Electric traction two systems have been in use –D.C. at 1500 volts or 3000 volts and single-phase a.c. at 11 to 16kV using low frequency. The reasons for the adoption of low frequency rather than the standard 50-cycle frequency was that the series wound commutator was developed for satisfactory operation only up to about 25 cycles and the low frequency was suitable for the hydro-generators of the railways which had to generate their own power in the absence of any national grids that existtoday. The d.c series motor has ideal characteristics for traction purpose. D.C. was already in use for tramways and in about 1905, on account of the better performance of d.c. series motordue to the introduction of the inter-poles and adoption of higher voltage with increased spacing of the substations the traction became economical. The two systems i.e. D.C. and

A.C. developed and grew side by side.

In India we have the single-phase A.C. at 25kV,50 cycles is supplied to the locomotives which carries transformers and rectifiers. A.C. is converted into D.C. in the locomotive and traction motors are D.C. motors. However, recently A.C. traction motors arebeing attempted.

SYSTEM OF TRACTION

There are various systems of traction are commonly used such as

1. Direct steam engine drive
2. Direct internal combustion engine drive
3. Steam electric drive
4. Petrol electric traction
5. Battery electric drive
6. Electric Drive
7. Internal combustion engine electric drive

Direct Steam Engine Drive :

The steam engine drive used to be widely employed for railway work. In this drive the reciprocating steam engine is invariably used for getting the necessary motive power because of its inherent simplicity, operational dependability, and simplified maintenance, the simplicity of connections between the cylinders and driving wheels and easy speed control. It causes no interference to the communication lines running along the track. It is cheap for low density traffic areas and initial stages of communication by rail.

Direct Internal Combustion Engine Drive:

Direct internal combustion engine drive is widely employed for road transport. The efficiency of internal combustion engine at its normal speed is about 25 percent. It is self contained unit and it is not tied to any route. Initially the cost of vehicle and garage is very low. Speed control and braking system employed is very simple. It is cheap drive for the outer suburbs and country districts.

Steam Electric Drive:

A few locomotives employing steam turbine for driving a generator used for supplying current to electric motors have been built for experimental purposes.

Internal Combustion Engine Electric Drive :

In this drive the reduction gear and gear box are eliminated as the diesel engine is to drive the dc generator coupled to it at a constant speed. This type of drive has found considerable favour for railway work and locomotives of this type are becoming widely used.

Petrol Electric Traction:

This system has been used in heavy lorries and buses. Due to electric conversion it provides a very fine and continuous control which makes the vehicle capable of moving slowly at an imperceptible speed and creeping up the steepest slope without throttling the engine.

Battery Electric Drive:

In this drive the locomotive carries the secondary batteries which supply power to dc motor employed for driving the vehicle .Such a drive well suited for frequently operated service such as local delivery of goods in large towns with maximum daily run of 50 to 60 km, shunting and traction in industrial works and mines. The major limitation of this type of drive is the small capacity of the batteries and the necessity for frequent charging, speedrange is also limited.

Electric Drive:

The drive of this type is mostly widely used. In this system of traction the vehicle draws electrical energy from the distribution system fed at suitable points from either a central power station or substations.

System of Electric Traction

Two types of vehicles are in use for electric traction. In one type they receive power from a distribution network while in the other type they generate their own power. The former type vehicles may use both a.c. or d.c. ; the latter type will be the diesel-electric car or train, petrol-electric truck, lorry and battery driven vehicles.

DC TRACTION MOTOR

Most suitable motors for dc system are the series and compound motors.

DC Series Motor:

The series motor used for traction purposes have following requirements

1. The dc series motor develops high torque at start which is essential for tractionservices.
2. The series motor is simple speed control method.

3. Power drawn from supply mains varies as the square root of the load torque.
4. Series motor is not suitable for regenerative braking as these are not electrically
5. In case of dc series motor commutation is excellent up to twice full load so stable

replacement of brushes in not required frequently.

6 In cases of dc series motors the flux varies as the armature current, torque corresponding to a given armature current, therefore is independent of line voltage.

7 In case of dc series motor up to magnetic saturation, torque developed is proportional to the square of the armature current. Thus dc series motor requires comparatively less increased power input with the increase in load torque.

8. The series motor when operated in parallel to drive a vehicle by means of different axles, share load almost equally even there is unequal wear of different driving wheels.

9. The dc series motor is simple and robust in

construction.

AC TRACTION MOTOR:

AC Series Motor: Many single phase ac motors have been developed for traction purposes but only compensated series type commutator motor is best for traction. The construction of an ac series motor is similar to a dc series motor except that some modification such as whole magnetic circuit laminated, series field with as few turns as possible, large no of armature conductors, use of carbon brushes, numerous poles with lesser flux per pole. Compensating windings are provided to neutralize armature reaction andcommutating or interpoles are provided for better performance in terms of higher efficiency and a greater output from a given size of armature core. The speed –Torque characteristics and the speed-current characteristics of compensated series type commutator motors are similar to those of D.C. series motor.Thea.c. Series motor is not suitable to suburban services where stops are frequent. It is being extensively employed on main line work on the continentand in America and provides good service.

If a d.c. series motor is worked on a.c. it would not operate in a satisfactory manner. Though the torque on the armature would be unidirectional, it would be at double the frequency since both the field current and the armature current reverse every half cycle.The alternating flux would cause heavy iron losses in the field and yoke.Heavy sparking would also take place at the brushes since the induced voltage and currents in the armature would beshort-circuited at the time of commutation. The overall performance of the motor would be poor.

The difference between d.c. and a.c. operation can be understood by a reference to figure shown below

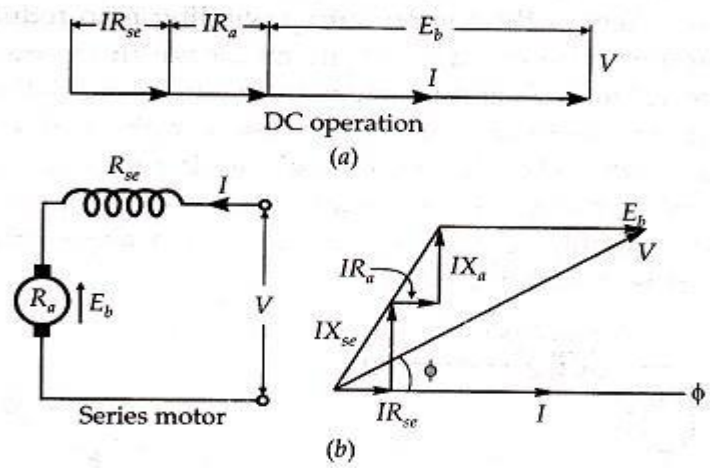


Fig. 1 Operation of series wound motor on dc and ac

Operation on d.c. is simple enough. I is the current drawn by the motor, $IR_{se}$and $I\,R_a$ are the drops in the series field and the armature respectively. E_b is the back emf developed and equals kØN.

Mathematically, we have

$$V = E_b + IR_{se} + IR_a$$

Since $I(R_{se} + R_a)$ drop is about 10 percent of the applied voltage , E_b is practically equal to V.

On the a.c. the magnetizing component of the current and the flux are in time phase and the back emfE_b which is due to rotation of the armature is also in phase with the flux. If we neglect the loss component of the current we can assume the whole current to be in phase with the flux. The drops IR_{se} and IR_a are in phase with the current while the drops due to reactance, i.e. IX_{se} and IX_a are leading the current by 90^0. The a.c. operation is shown by the phasor diagram below. In this case E_b will be much less as compared to the d.c. operation. N is proportional to E_b and torque depends upon the product of E_b and I. Since, E_b in d.c. is larger than in a.c., for the same torque the speed for d.c. operation is higher than for a.c. operation as shown below.

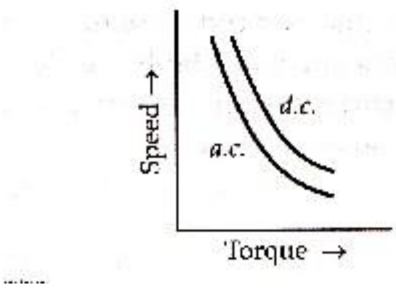


Fig.2 Speed – torque curves for d.c. and a.c. operation

In order to improve the performance of the motor on a.c., a compensating winding either in series with the armature or short-circuited in it be provided. The effect of the compensating winding is to reduce the armature reactance of the motor which increases the value of E_b and provides better speed regulation. The armature and field mmfs are at right angles to each other. The compensating winding provides an mmf opposite to the armature mmf and therefore considerably reduces the armature reactance drop. This is shown below

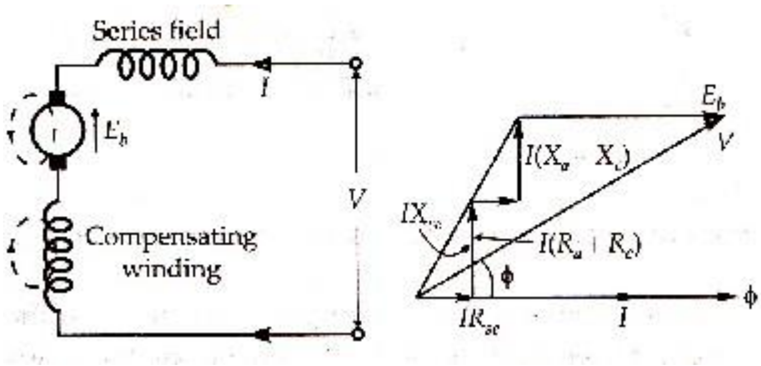


Fig. 3 Circuit diagram & phasor diagram of the series motor with compensating winding

$R_a + R_c$ represent the resistances of the armature and compensating winding.

$X_a + X_c$ represent the reactances of the armature and compensating winding.

Fig. below shows the case where the compensating winding is short-circuited on itself. It acts like the short-circuited secondary of a transformer and greatly reduces the effect of the armature reactance.In the phasor diagram R'_a and X'_a are the equivalent resistance and reactance of the armature and compensating winding referred to the armature circuit. It is also seen that by using the compensating winding ,the power factor of the motor improves as shown in the figure below.

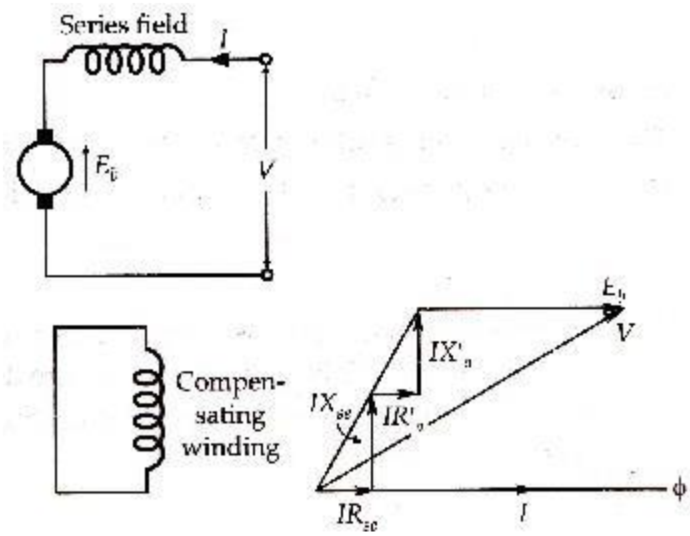


Fig.4. Circuit and phasor diagram for an inductively compensating series motor

THREE-PHASE INDUCTION MOTOR

Although it is robust and the simplest in construction, the difficulties in starting and speed control do not make it suitable for traction work. The speed torque curve is flat. It has been used in the Kando system in Hungary and some sections of Italian State Railways. It was not likely to find further application elsewhere though in recent years, with power electronic method of speed control, research is being undertaken to apply this drive in traction.

CONTROL OF MOTORS

CONTROL OF D.C.MOTORS

The starting current taken by a D.C. motor during its starting period is limited to a value approximately equal to the normal rated current by the resistance of the starter. There is a considerable loss of energy at the starting resistance. Consider the use of a single motor started by a resistance starter, the average value of the current during the starting period being limited to I, the normal full-load current.

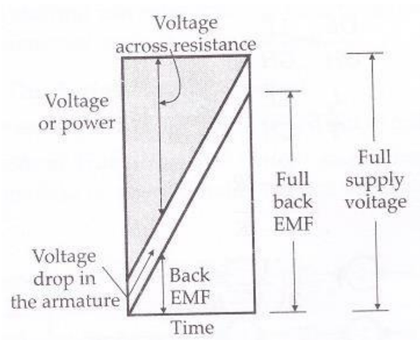


Fig.5. Voltage during the starting of a d.c. motor

The back emf of the motor starts to build up from zero magnitude. At the instant of switching on the supply, E_b=0, a current of I amperes is drawn from the supply and the supply voltage is the sum of the IR drop in the motor armature and the voltage drop across the starting resistance. At any other instant during starting, the supply voltage = (motor back emf)+(IR drop in the motor armature)+(voltage drop across starting resistance).

At the end of the accelerating period, the back emf has developed to a full value and the supply voltage =(back emf)+(IR drop).

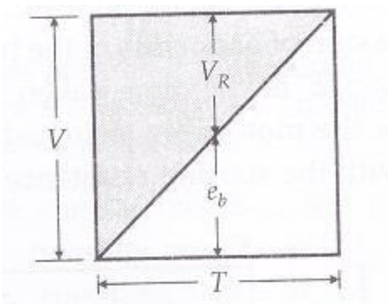


Fig 6. Starting of a dc motor by using a resistor in the armature circuit

T is the time in seconds for starting and further if we ignore the voltage drop due to the resistance of the motor armature circuit we have total energy supplied =VIT watt-sec. in fig. shown the back emf and V_r is the voltage drop across the starting resistance st any instant.

SERIES PARALLEL STARTING

In traction work, usually two or more similar motors are employed. Considerable saving energy can be affected by employing series-parallel starting. Consider the use of two series motors. They are started in series with the help of a starting resistance till each of them develops a back emf equal to half the supply voltage minus the IR drop. The motors give one running speed when they are in the full series position. The starting resistance is again re-inserted in the circuit and the motors are switched in parallel. The starting resistance is cutout in steps and the back emf of each motor develops from about half the value to the normal value. In the full parallel position the motors give another running speed which is obviously higher than that when the motors are in full series.

Let us consider the case of two similar motors started by the series parallel method as shown below.

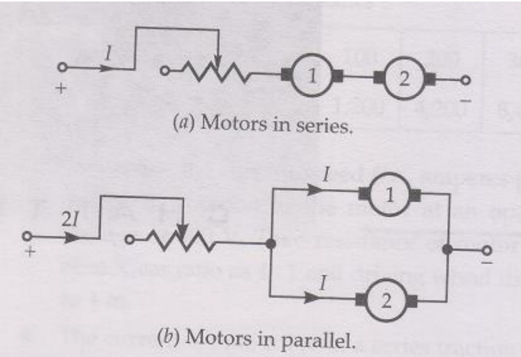


Fig.7. Series Parallel starting

Let the current during the starting interval be limited to the normal rated current I per motor. During the series period a current of I amperes is frawn from the supply while during the parallel period a current of 2I is drawn.

As shown in figure below, at the instant of starting OA =OB = IR drop in each motor,OK= supply voltage V. The back emf of the two motors jointly develops along the lineOM .The back emf of two motors at the point E plus IR drops equal to V. Any point on the line BC at any instant represents the sum of back emfs of two motors and the IR drops.OE is the time taken for the series running.Now the motors are switched on in parallel, at instant E with the starting resistance reinserted.

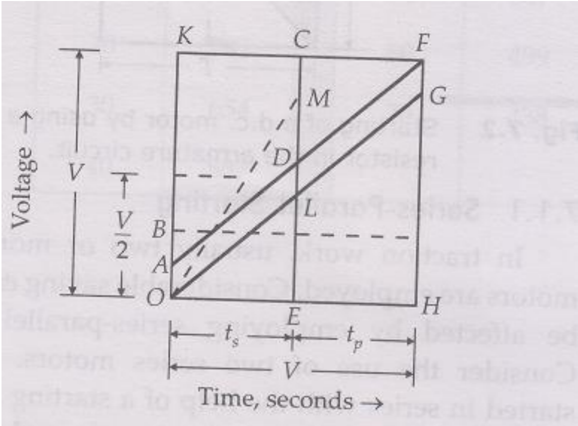


Fig.8 Voltage build-up in series-parallel starting

At the end of the series period each motor has developed a
Back-emf equal to (V- 2 IR)/2 = (V/2)-IR

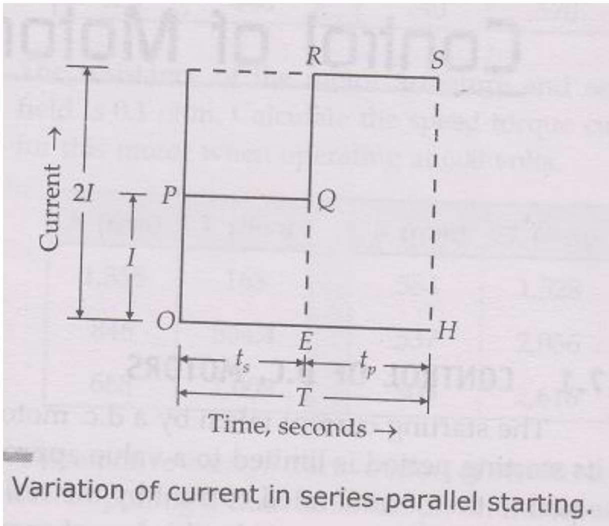


Fig.9 Variation of current in series –parallel

The back emf of each motor is represented by the ordinate EL = ED – LD =(((v/2)-IR)

The back emf of each motor is represented by the ordinate EL = ED-LD= $(\frac{V}{2}$ -IR)

The back emf of the combination now develops along LG and at H when the motors are in full parallel we have HF =supply voltage V,HG =normal back emf of each motor and GF =IR drop in each motor.

Figure below shows the current during the series and parallel starting periods.During the series period OE, the current is I while during the parallel period EH is 2I.

The value of the time t_s during which the motors remain in series and t_p , during which there are in parallel can be determined from figure shown below.Triangles OLE and OGH are similar.

Therefore

$$\frac{OE}{OH} = \frac{LE}{GH}$$

$$\frac{t_s}{T} = \frac{LE}{GH} = \frac{DE-DL}{FH-FG} = \frac{\frac{V}{2}-IR}{V-IR}$$

And $t_s = \frac{1}{2}\left(\frac{V-2IR}{V-IR}\right) T$

Hence $t_p = T - t_s = T - \frac{1}{2}\left(\frac{V-2IR}{V-IR}\right) T$

$= \left[1-\frac{1}{2}\left(\frac{V-2IR}{V-IR}\right)\right] T$

2 V−IR

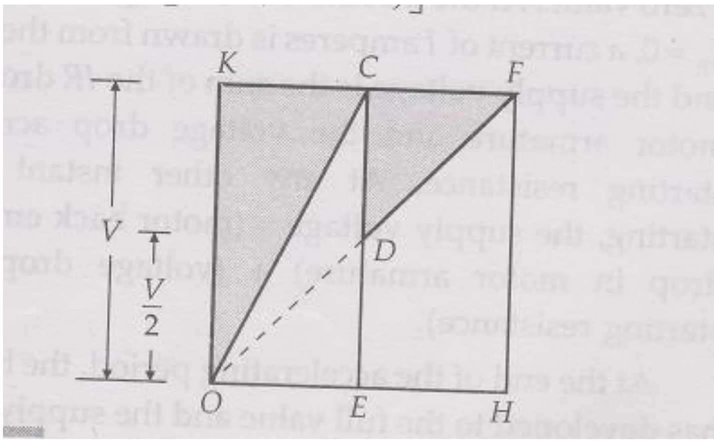


Fig.10 Efficiency of starting by series parallel method

Let us now calculate the efficiency of this method. For this purpose neglect the IR drop in the armature circuit as back emf developed practically equals the voltage impressed across the motor. This modifies the figure to as shown.

Since, D is the mid-point of CE and the back emf of the motor develops along DF in the parallel combination, KC = CF, i.e., time for series combination = the time for the parallel combination.

Let $t_s = t_p = t$ and the average starting current be I per motor, t_s =OE, t_p =EH.

The energy lost in starting resistance is proportional to the shading area. i.e.

$= I(\frac{1}{2}Vt) + (\frac{1}{2}\frac{V}{2}t)\,2I = IVt$

Total energy supplied =IVt + 2IVt =3IVt

Efficiency of starting = $\frac{(3-I)IVt}{3IVt}$ =2/3 or 66%

Thus the efficiency is increased by about 17 % .The series-parallel method enables a saving of about 15 to 20 % in the energy.

The Series-Parallel Control

The series-parallel control is carried out as follows:

(a) Shunt Transition: The various stages involved in this method of series- parallel Control are shown below.

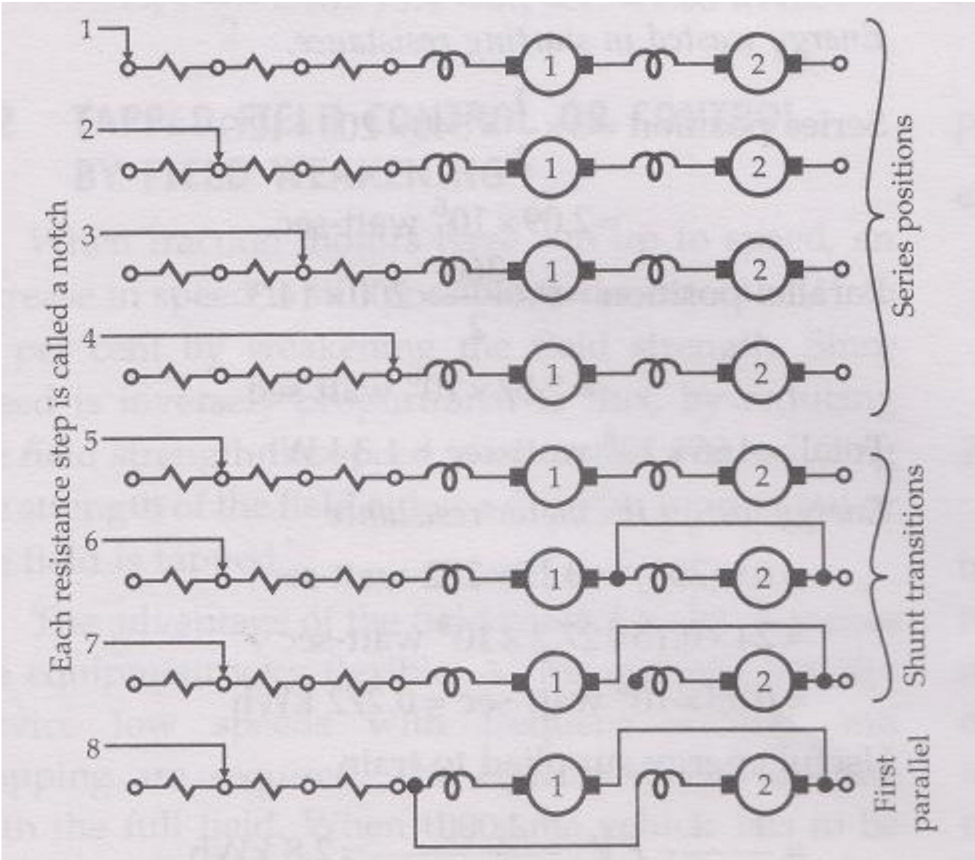


Fig..11 Series position

In steps 1,2,3,4 the motors are in series and are accelerated by cutting out the starting resistance in steps. In step 4 , the motors are in full series. During transition from series to parallel, the resistance is re-inserted in the motor circuit (step-5).One of the motors is by-passed (step-6) and disconnected from the main circuit (step-7).

It is then connected in parallel with the other motor (step-8) giving the first parallel position. The resistance is then cut out in steps completely and the motors are placed in parallel.

This method is known as the shunt-transition method.

(b)Bridge Transition: the motor and the starting rheostats are connectedin the form of a Wheatstone bridge as shown below.

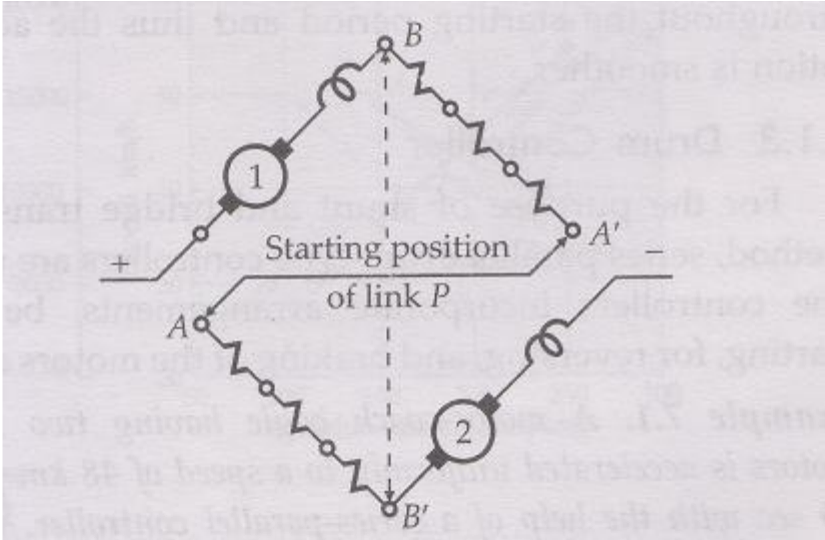


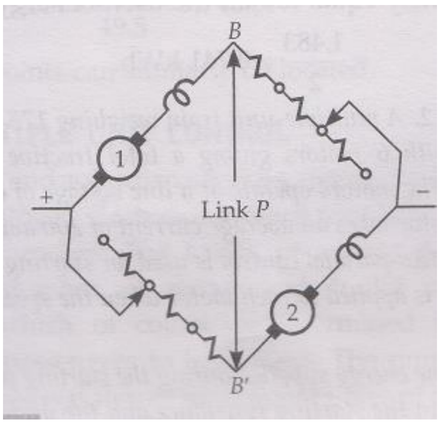
Fig.9. Series position.

(a) At starting, motors are in series with link P in position AA'

(b) Motors in full series with link P in position BB'

In the first starting position the motors are in series and the rheostats are completely in Circuit as indicated by the rheostats arm P at A A′. A and A′ are moved in the direction of the arrowheads and in position BB′ the motors are in full series.

In the transition step, the rheostats are reinserted by connecting to positive and negative of the supply as shown below.



In the first parallel step, the link P is removed and the motors are connected in parallel with the starting resistances in their circuit.

B

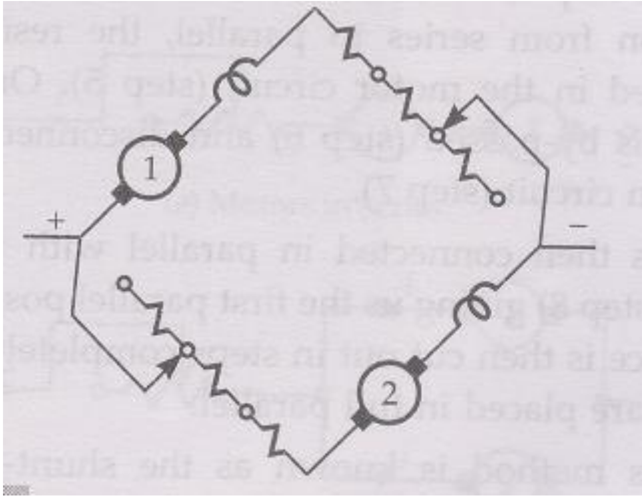


Fig.11 First Parallel position

The advantage of the bridge transition method over the shunt transition methid is that the normal accelerating torque is available from both the motors throughout the starting period and thus the acceleration is smoother.

DRUM CONTROLLER

For the purpose of shunt and bridge transition method, series parallel drum type controllers are used. The controllers incorporate arrangements, besides starting, for reversing, and braking of the motors also.

Tapped Field Control :As the speed of the motor is inversely proportional to the flux (assuming line voltage constant), therefore, the speed can be varied by varying the flux. In case of series motors the flux can be varied either (i) by connecting a variable resistance known as diverter in parallel with the series field winding or (ii) by cutting out some of the series field turns. Since in both the cases the flux can be only reduced, therefore, this method is known as field weakening method and speeds above normal can be obtained. By this method speed can be raised to the extent of 15 to 30 percent of normal speed owing to design difficulties arising with traction motors.

The field weakening method is of no use for starting purpose. This method is used for increasing the speed of traction motors upto the extent of 10 to 15 percent when they have attained maximum possible sped by series-parallel control system. The advantage of this system is that it increases the flexibility of the train utility.

THE METADYNE SYSTEM OF CONTROL FOR D.C. MOTORS

In the series-parallel control of D.C. traction motors,there is considerable loss of energy in the starting resistances. The metadyne system of control estimates the energy loss and achieves a very smooth control during the acceleration period.

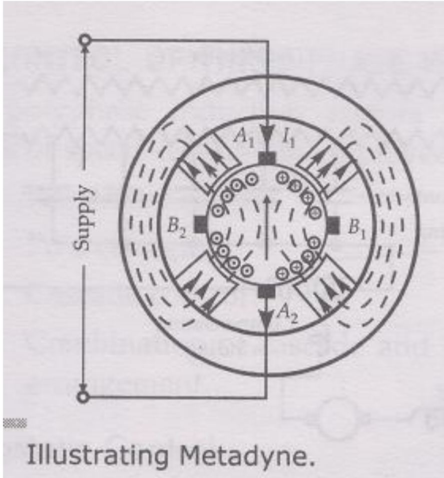


Fig.12 Illustrating Metadyne

Consider a D.C. armature with two brushes and two poles. If current is supplied to the two brushes A_1A_2 the armature cross-flux will be as shown anmd mainly confined to the poles as shown in Figure. If there are four brushes, current is supplied to brushes A_1A_2 and the armature cross-flux will take up the path as shown below.If now the current is supplied to brushes B_1B_2 as shown the armature cross-flux takes up path as indicated.If the armature is rotated at a constant speed and a current I is fed into the bushes A_1A_2 , an emf is induced in the winding betweenB_1B_2 due to the flux produced by I.No emf is induced between A_1A_2 and the voltage between A_1A_2 is on account of the voltage drop due to I_1 .

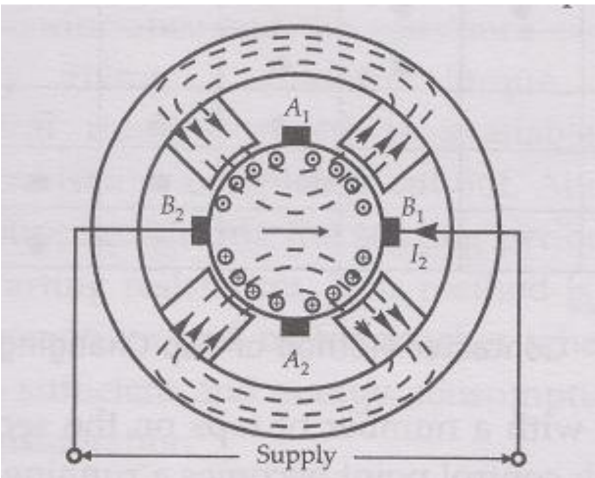


Fig.6.14

Since an emf is induced across B_1 ,B_2 a current I_2 will flow in a load connected between them. The resultant flux distribution on account of I_1 and I_2 is as shown below.

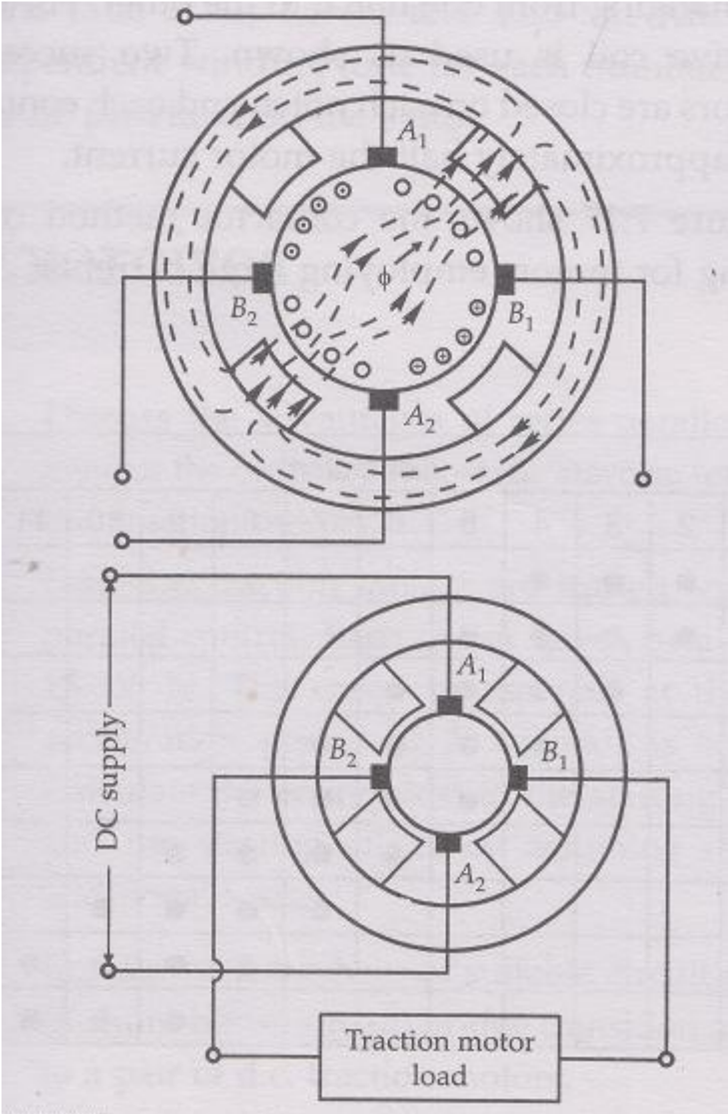


Fig.15

The total flux may be assumed to be made up of two components $Ø_1$ and $Ø_2$ at right angles and directed along A_2A_1 and B_2B_1 .The rotation of the armature in $Ø_2$ induces an emf E_1 between A_1 and A_2 which opposes the supply voltage.Since the current is to be kept at its original value of I_1 ,the supply voltage must be induced to overcome E_2 . Under steady conditions

E_1 a $Ø_2$ $=KI_2$

E_2 a $Ø_1$ $=KI_1$

$E_1I_1 = E_2I_2 = K\ I_1I_2$

This shows that the machine behaves like a D.C. transformer. Only the rotational losses of the machine need be supplied by the driving motor.

If the supply voltage E_1 remains constant , I_2 remains constant. The arrangement therefore is quite suitable for starting D.C.motors

RheostaticControl :A series motor can be started by connecting an external resistance (starter) in series with the main circuit of the motor. At the starting instant, since the back emfdeveloped by the motor is zero, therefore, the resistance connected in series with the motor is maximum and is of such a value that the voltage drop across it with full load rated current is equal to the line voltage. As the motor speeds up, the back emf developed by the motor increases, therefore, the external resistance is gradually reduced in order to maintain the current constant throughout the starting or accelerating period. Basic traction motor circuit with rheostatic starting is shown in figure. In this method there is a considerable loss of energy in the external circuit.

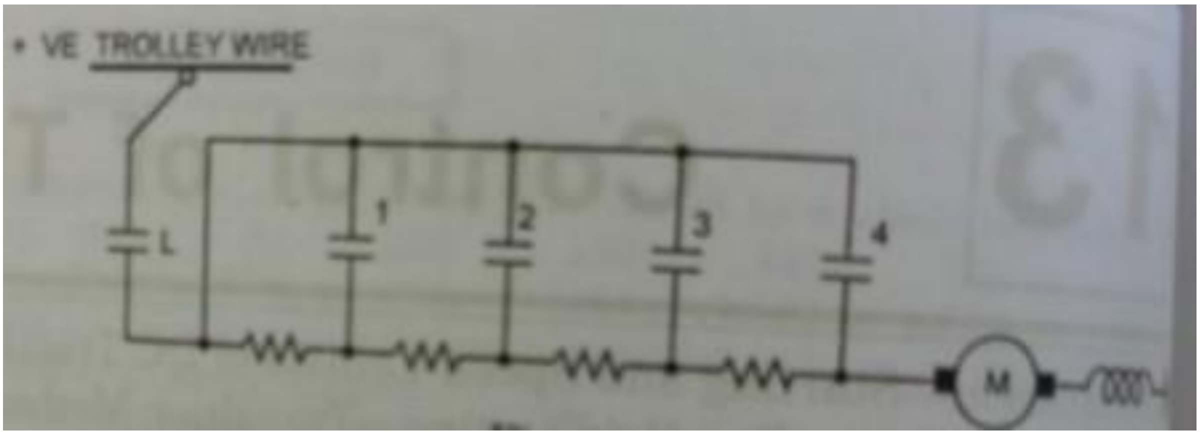


Fig.16 Rheostatic control method

BRAKING

Introduction

In traction work both electrical and mechanical braking are employed for bringing the vehicle to rest. Electrical braking cannot do away with the mechanical brakes since a vehicle cannot be held stationary by its use; it nevertheless forms a very important part of a traction system..The main advantage of using electric braking is that it reduces the wear on the mechanical brakes and gives a higher value of braking retardation thus bringing a avehiclequickly to rest and cutting down considerably on the running time.Where regenerative braking is employed , a part of the energy is returned to the supply thereby affecting a considerable saving in the running costs.

For D.C. motorsThere are three methods emp-loyed for electric braking:

(i) Plugging

(ii) Rheostatic braking

(iii)Regenerative braking

Plugging :

Elaborate discussions have already been made on this inprevious chapter and does need any more of it.

Rheostatic Braking

When two or three series motors are used for traction work,the motors are connected in parallel across a resistance.The kinetic energy of the vehicle is utilised in driving themotors as generators which dissipate this energy in the form of heat in the rheostats to which they are connected. The two machines in parallel amount to two series generators in parallel and in order that they may self-excite, an equalizer connection as shown has to be used. If theequalizer connection are not used,the machine that would build up first would send a current through the other in the opposite direction with the result that the second machine would excite withreversedvoltage.The two machiones would be short-circuited on themselves and might even burn out on account of large currents. The equalizer prevents such a condition.

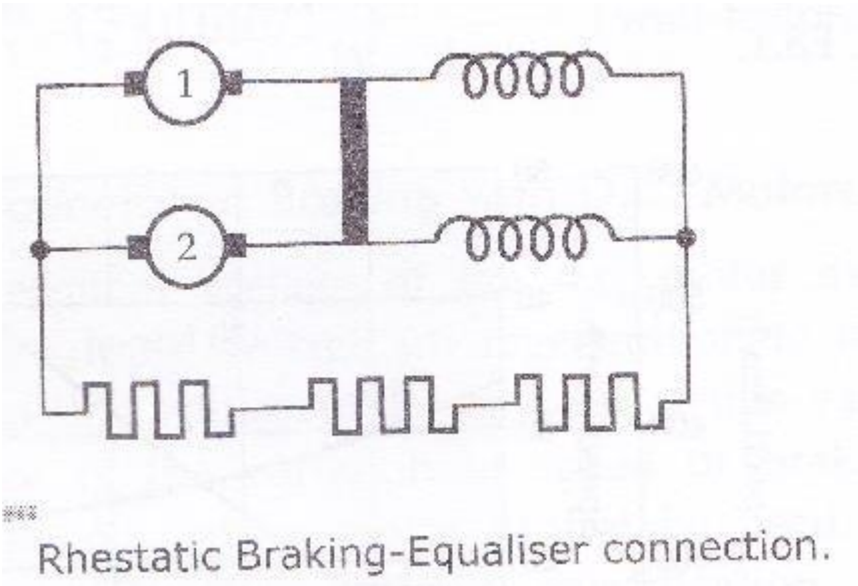


Fig.17

Another way to cross connect the fields of the machines is shown below.

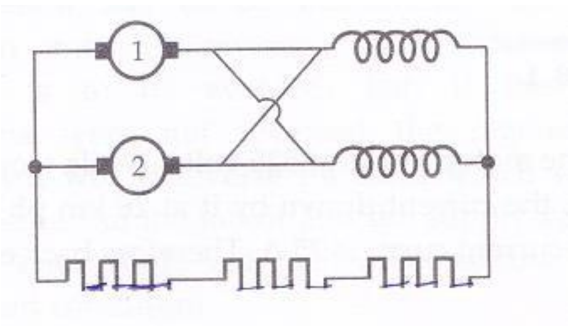


Fig.17 Rheostatic braking cross connection

Suppose the voltage of machine 1 is greater than that of 2.It will send a greater current through the field of machine 2 causing it to excite to a higher voltage and its own excitation will be kept down because of the lesser induced emf of 2.Thus automatic compensation is provide and the two machines operate satisfactorily.

The connections of the second case possess an advantage over that of the first. If the direction of rotation of the armature reverses, say, due to run-back, the machines fail to excite in the first case and no braking effect can be produced. However, with the cross-connected fields the machines build up in series and since they are short-circuited upon themselves, they provide emergency braking and would not allow the car to run-back on a gradient.

REGENERATIVE BRAKING

Mechanical Regenerative braking

When a train is accelerated up to a certain speed, it acquires kinetic energy corresponding to that speed. During the coasting period, a part of this kinetic energy is used up in overcoming the fractional resistance and some part is utilized in the propulsion of the train. The kinetic energy ,which is utilized in the propulsion ,does useful work and therefore coasting may be regarded as ― mechanical regenerative braking ― since the speed gradually decreases on account of the utilization of the kinetic energy stored in the train at the end of the accelerating period.

A system of track grading is employed in the case of the underground railway where the kinetic energy of a train may be used in doing useful work against gravity. Two types of graded tracks are shown in Figure below.

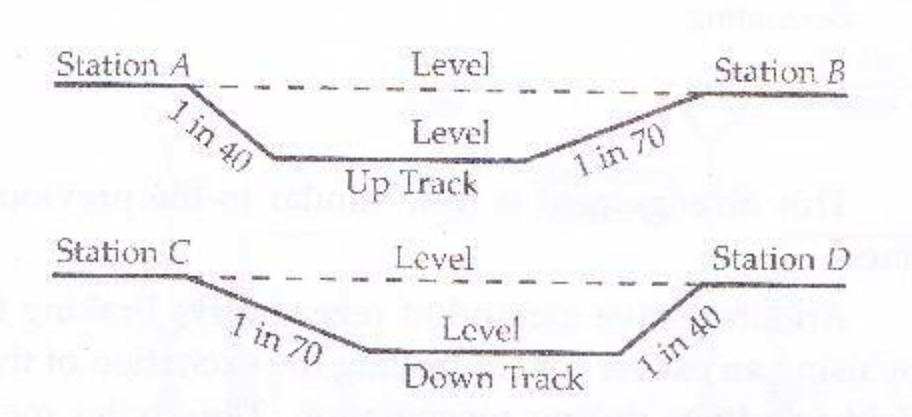


Fig.18 Track Grading

When the train is at a station, say A, it possess a certain potential energy which is utilized in its descent down the gradient till it reaches the level tracks. However, graded track construction is only possible in the case of the underground railway and is not practicable for surface railway.

Regenerative Braking with D.C. Motors

The terminal voltage of the D.C. motor must exceed the supply voltage for regeneration to take place. Also this voltage must kept at this value irrespective of the variation in speed or braking torque. The D.C. series motor cannot be used for regenerative braking without modification for the reasons to be stated presently. During regeneration the current through the armature reverses and since the excitation has to be maintained, the field connection must be reversed, if a short-circuit condition to be avoided. For, if the field connection were not reversed the regenerated current in it would reverse the field which would reverse the emf of the motor and the supply voltage and back emf would aid each other setting up a short-circuit condition.

One method of regenerative braking with series motors is the French method. If there is a single series motor as in the case of a trolley-bus it is equipped with a main series field auxiliary any field windings placed in parallel with the main series winding.

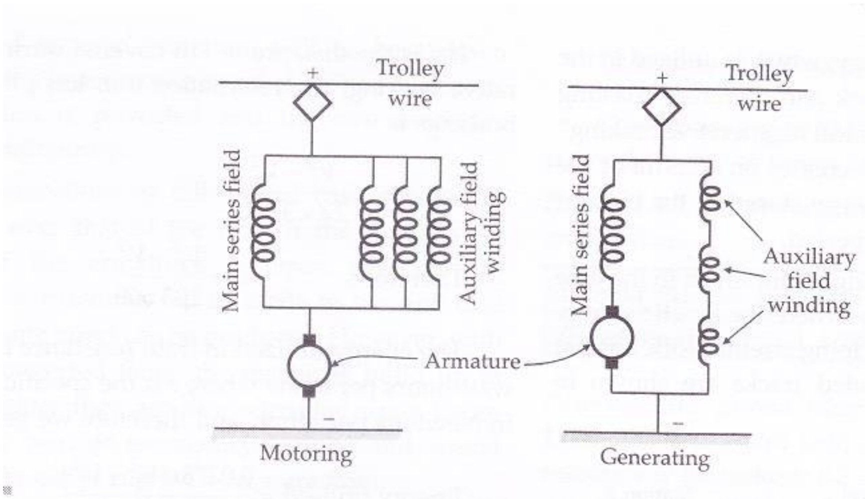


Fig. 20 Regenerative braking

During regenerative breaking the auxiliary field windings are placed in series with each other and switched over in parallel across the armature and the main series field. The machine acts as a compound generator with slight differential compounding. If there is a change in the line voltage, the shunt excitation being sensitive to such changes, immediately causes the emf of the generator to increase or decrease thus providing the necessary balance. Suppose the line voltage tends to increase beyond the emf of the generator. The increased voltage across the shunt circuit will send a large exciting current through it causing the emf ofthe generator to rise. The reverse of this happens when the line voltage tends to fall. The arrangement is, therefore, self-compensating.

In locomotives where four or six series motors are used, there neednot be any auxiliary windings. During normal working all the motors are in series within their respective field windings but during regeneration, the motor armature is in parallel with the field windings of all other motors except one.

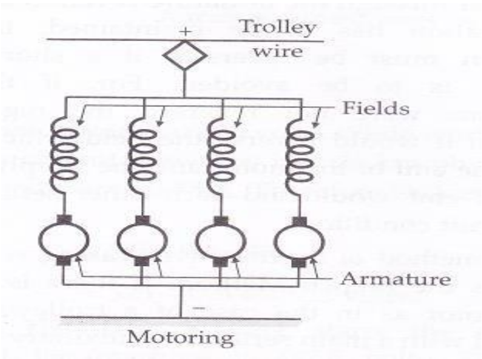


Fig.21 Regenerative Braking

This arrangement is now similar to the previous one. An alternative method of regenerative braking by using an exciter for controlling the excitation of the field winding during regeneration. The exciter may either be axle driven or noticed from an auxiliary supply.

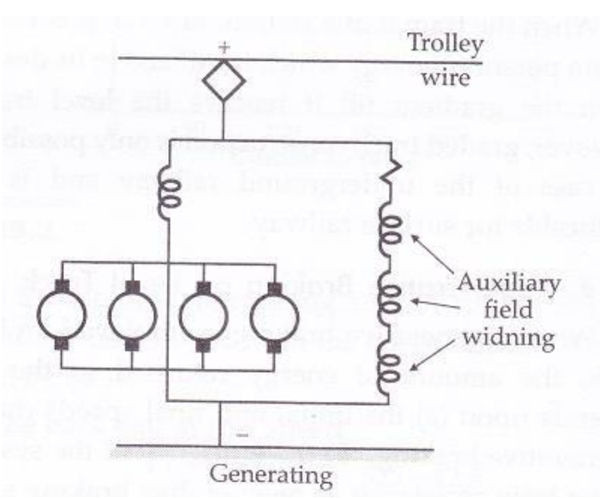


Fig. 22 Regenerative braking (alternative)

As shown in Figure the exciter E have separately excited winding whose excitation is controlled by the driver. The armature of the exciter is placed in the circuit of the series fields of motors 1 and 2. The exciter has other winding F_2 placed in series with the main motor circuit.F_2 and F_2 are arranged to oppose each other during regeneration.Suppose the line voltage decreases, it will try to increase the regeneent through the armayures 1 and 2.The excitation of F_2 therefore increase and since F_2 and F_2 each other, the emf of E falls on account of reduced excitation. As soon as the emf of the exciter falls , the current in the field current 1 and 2 decreases causing the emf of 1 and 2 to decrease. Compensation for a decrease in the line voltage is automatically provided, The arrangements shown below has theexciter connected in the circuit of the field windings and the stabilizing resistance. The balance of voltage available in the exciter armature circuit is reduced causing a reduction in the exciting current in the fields of 1 and 2.this decrease the induced emf of the generators, thus providing inherent compensation.

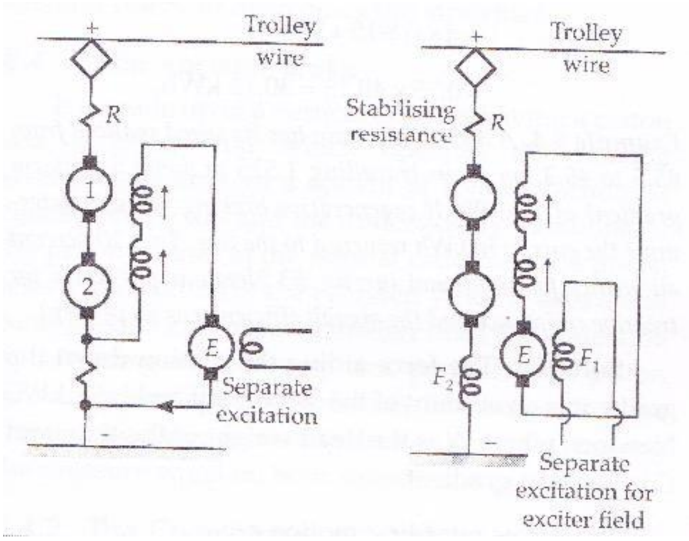


Fig. 23 Regenerative braking

The function of the stabilizing resistance is to prevent the current surges when the vehicle crosses one section of the supply to another and to compensate for variation in line voltage.

Limits of Braking

Regenerative braking is employed down to a speed of 16 km.ph. Then rheostatbraking to about 6.5 km.ph and then mechanical brakes are used to bring the vehicle to rest.

REGENERATIVE BRAKING WITH THREE-PHASE INDUCTION MOTORS

Regenerative braking with three-phase induction motor occurs automatically when themotor runs at a speed slightly above the synchronous. It then works as induction generator. The induction generator however is not self-starting and must be connected to a system supplied from synchronous generator.

The torque-curve of an induction motor is as shown below. With no extraresistance in the rotor circuit, there is only a slight variation of speed with torque. By adding extra resistance in the rotor circuit the speed increases for a particular braking torque.

Therefore while braking without any extra resistance in the rotor circuit; the speed will be kept almost constant independent of the gradient and the load of the train. This is a great advantage with the induction motor when used for traction.

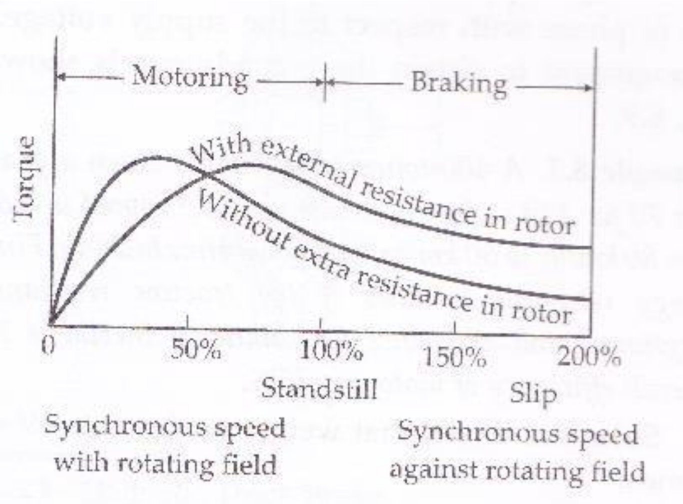


Fig.24 Torque speed curve of an Induction motor

BRAKING WITH SINGLE-PHASE SERIES MOTORS

In this case both rheostatic and regenerative braking are possible.

Rheostatic Braking: The motors are worked as separately excited generators supplying energy to resistance load. The fields are energized at low voltage from suitable tapings on the train transformer. The kinetic energy of the rotor is dissipated as electrical energy in the load resistance. Also, the fields of the motors may be excited from one of the motors acting as a series generator. In this case D.C. will be generated in the rotors of the motors and the kinetic energy of rotors will be dissipated as D.C. power in the loading resistors.

Regenerative Braking

For generative braking the regenerated power should be at the frequency of the main supply. This necessitates the energizing of the field winding from the main supply. Secondly, the regenerated current must be in phase opposition to the applied voltage and also the flux Ø so that the power may be feedback into the supply system.The voltage applied to the field winding must be 90^0 out of phase with respect to the supply voltage.An arrangement to obtain these conditions is shown below.

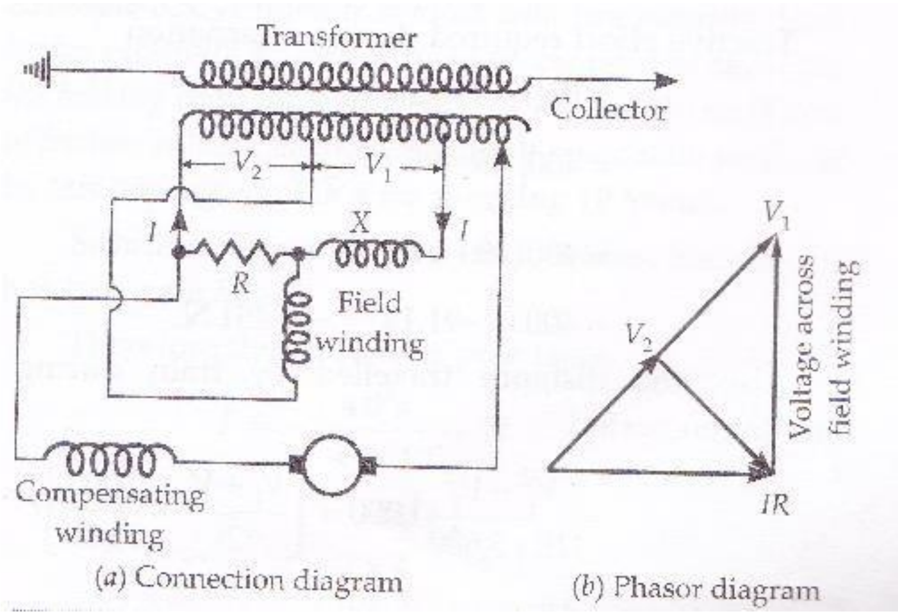


Fig.25 Regenerative braking with single phase series motor

MECHANICAL BRAKING

Mechanical brakes are essential feature on traction vehicles and are always operated by power. Two types of mechanical power brakes have been developed. (i) compresses air- brakes and (ii) vacuum brakes. The compressed air brake is extensively used on electrified railway and vacuum brakes on steam railway. The compressed air brake possess a little advantage over the other type since compressed air can conveniently be stored up andreleased for quick action where as the vacuum brake, a pump has to create the necessary vacuum. However, use of a vacuum reservoir overcomes this drawback.

THE VACUUM BRAKE

It is made up of a vertical cylinder having a piston and a piston rod which operates the braking arrangement through a system of levers. Vacuum is created on the top and the underside by admitting of the piston so that in the normal condition, the piston rests at the bottom of the cylinder. When brakes are to be applied, the vacuum is broken from the underside by admitting air at atmospheric pressure. The piston moves up applies the brakes. The brakes may be released by either creating the vacuum or by making the pressure equal onboth sides of the piston.

The Compressed Air Brake

It consists of a reservoir of compressed air, a brake cylinder, a valve and pipe. The brakes are kept in the: off‖ position by springs in the brake cylinder. When brakes are to be applied, compressed air is admitted into the cylinder. It presses the piston against the force of the spring. Clearly, the force with which the brakes are applied depends upon the quantity of the compressed air admitted. To release the brakes, compressed air is exhausted from the cylinder.

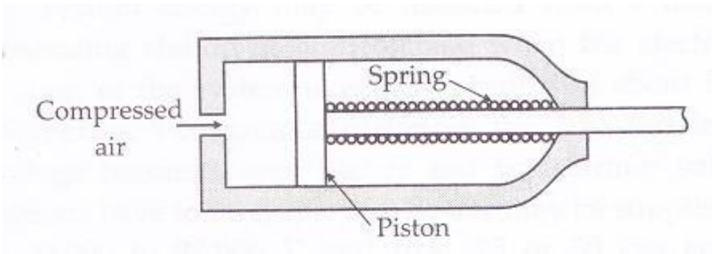


Fig.26 Action of compressed air brake

Magnetic Track Brake

It is used in tramcars. The electromagnet is bipolar. The body is made of cast steel and the pole faces are made of soft steel and can be renewed. The exciting coil is enclosed in a water-tight case. The magnetic flux is perpendicular to the pole faces and the track. The force of attraction between the magnet and the track is given by

$F = \frac{B^2 a}{2 \times \pi \times 10^{-7}}$ N, where B is the flux density in weber/m^2 and a is the area in the pole face in sq .m. The drag that it can produce on the car is given by micro farad, where t is the coefficient of friction.

Electro-Mechanical Drum Brakes

The brake drum is fitted to the motor shaft and brake shoes are applied by springs and released by a solenoid excited from a battery. They have replaced the hand applied wheel brake.