Electric heating is extensively used both for domestic and industrial applications.
Domestic applications include **(i)** 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)** enamelling 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.

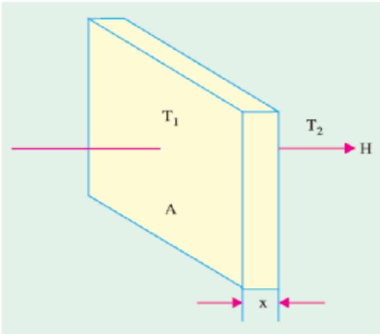

Fig-1

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:

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

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 is negligible.

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.

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

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.

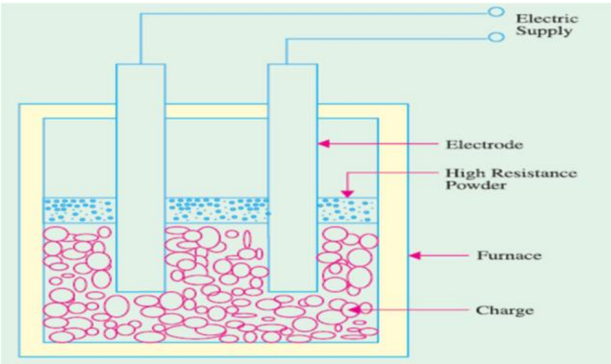

Fig:2 Direct Resistance heating

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.

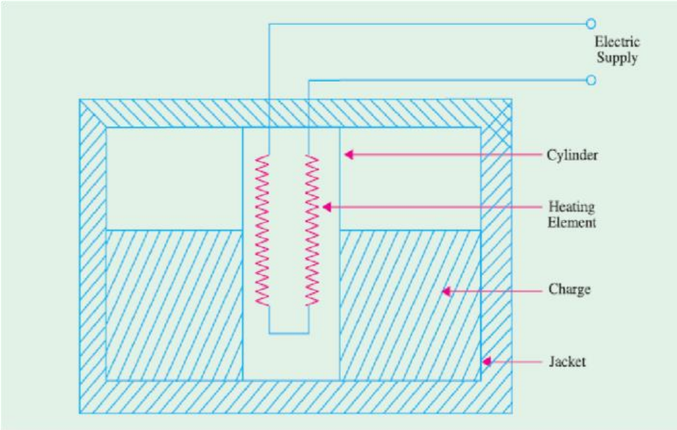

Fig-3 Indirect Resistance heating

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

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°C3500C. 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).

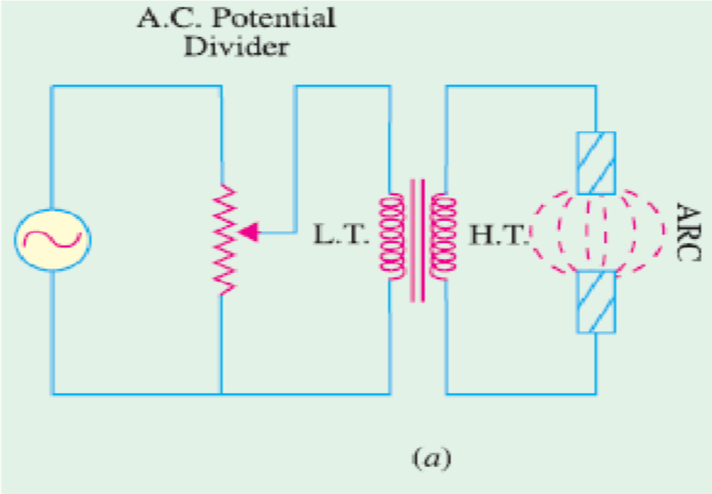

Fig-11

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 and the heat thus produced is passed on to the charge by radiation as shown in Fig. 47.11 (b).

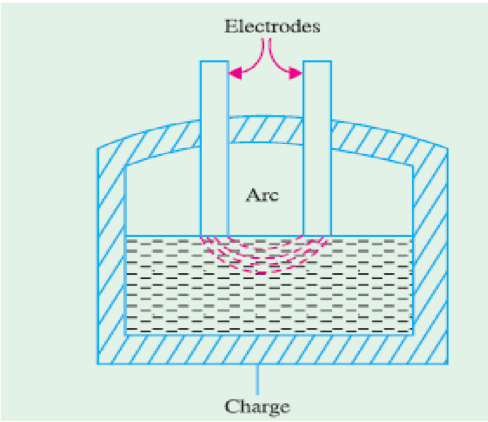

Fig-11(a)

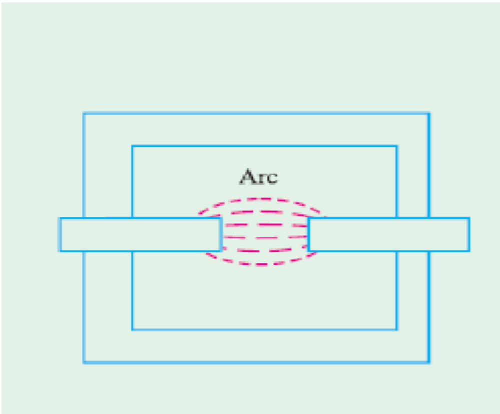

Fig-11(b)

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 be controlled 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.

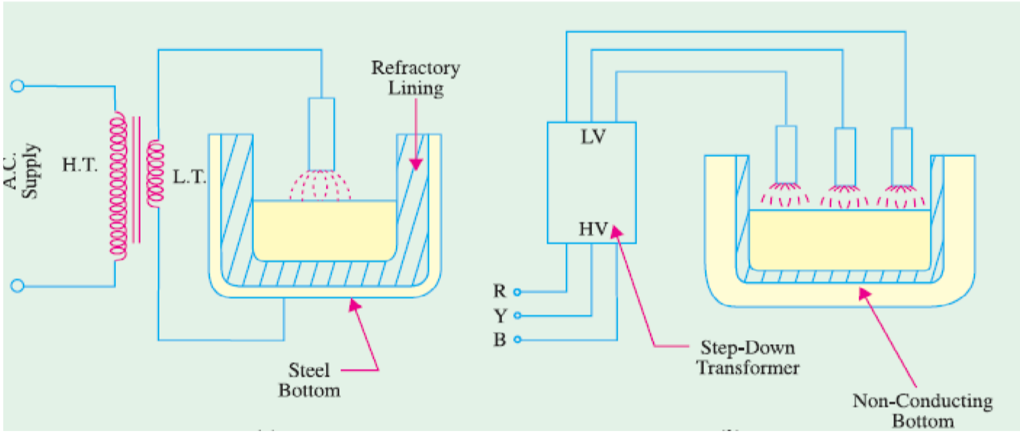

Fig-12(a) Fig-12(b)

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.

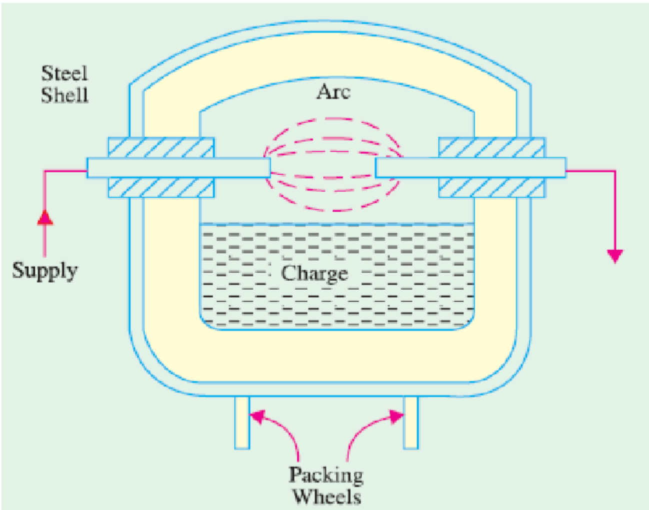

Fig-13

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 eddycurrent 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 a single-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 nullify the 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‖.

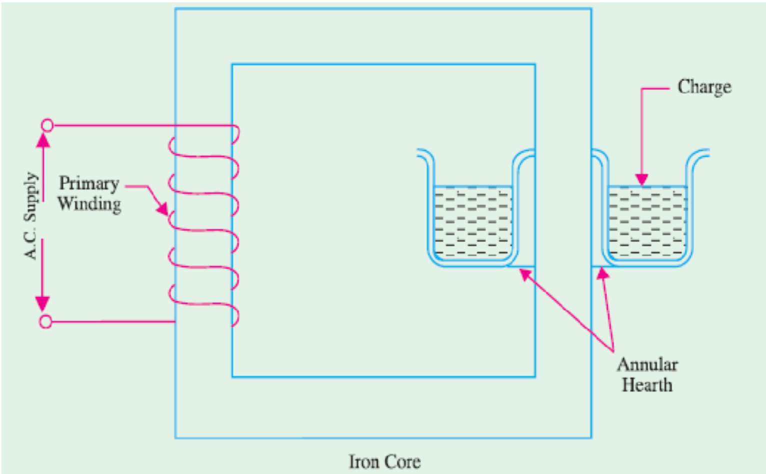

Fig-14

This furnace suffers from the following drawbacks:

1. It has to be run on low-frequency supply which entails extra expenditure on motorgenerator 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. As said 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, all single phase.

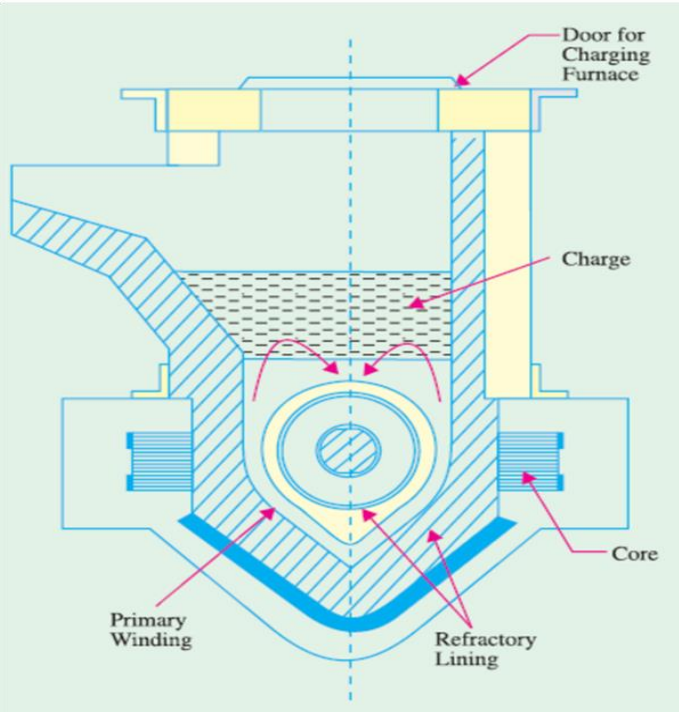

Fig-15 Core type Induction furnace

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.

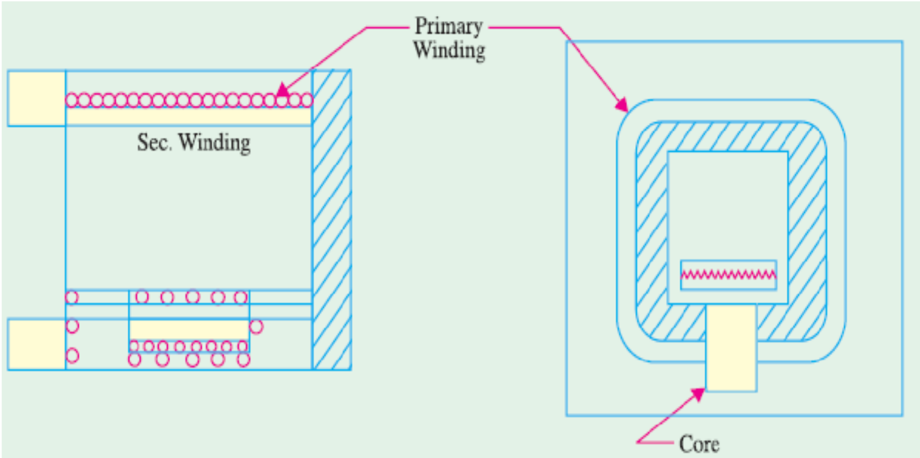

Fig-16

Coreless Induction Furnace

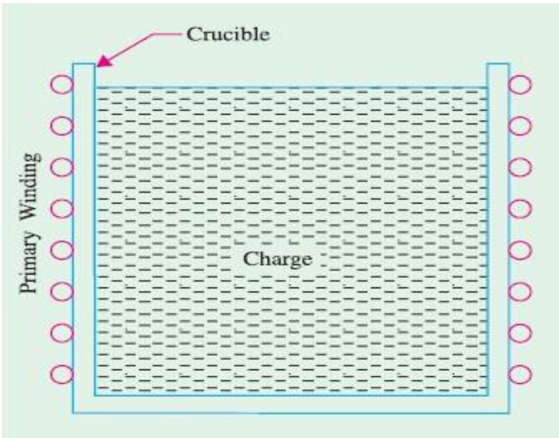

Fig-17

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 highfrequency 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 increases the 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-plate capacitor as shown in Fig.19 (a). Fig.19 (b) shows the equivalent circuit of the capacitor and Fig.19 (c) gives its vector diagram.

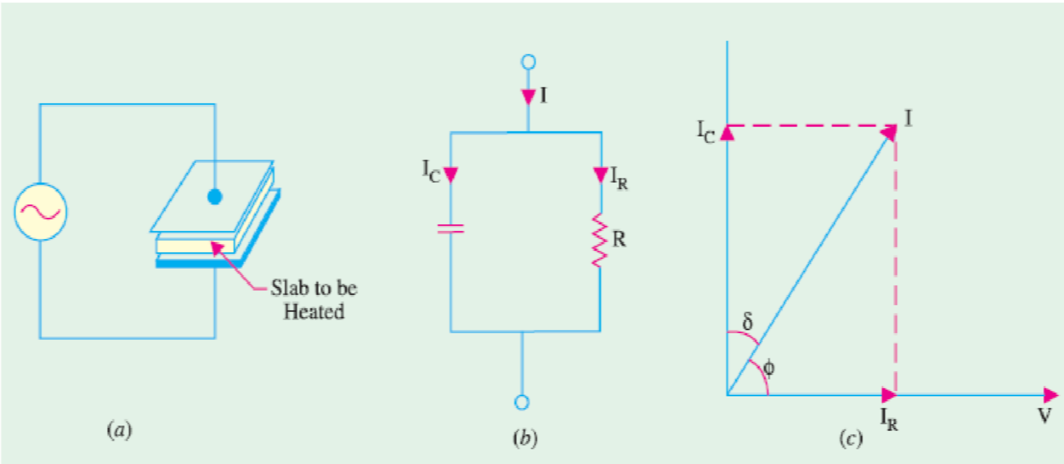

Fig-19

Power drawn from supply = VI cos ϕ

Now, Ic= I =V/Xc= 2 f CV

∴P = V(2 fCV) cos ϕ = 2 fCV^2 cos ϕ

Now, ϕ = (90^0 – δ), cos ϕ = cos (90^0 –δ) = sin δ = tan δ = δ whereδ is very small

and is expressed in radians.

P = 2 fCV^2δ 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 uniform heating.
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 and wooden products etc. can be heated safely.
6. Heating can be stopped immediately as and when desired.

CHAPTER-3
ELECTRIC 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 and electro-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 continues to 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 is generated 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 be used for obtaining desired penetration of the base metal during welding.

(e) Advantages and Disadvantages

1. The main advantage of this process is that the temperature of the molten pool can be easily 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 reinforce the weld joint.
3. The major disadvantage of the carbon-arc process is that blow holes occur due to magnetic arc blow especially when welding near edges of the work piece.

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.

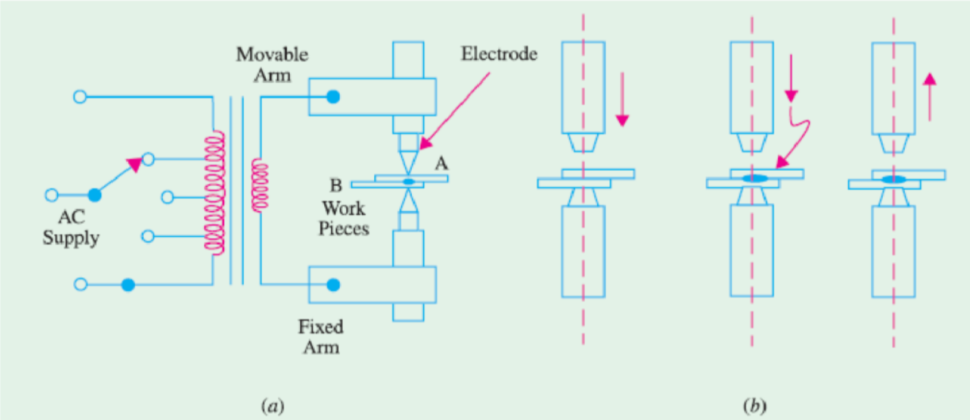

Fig-7

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 lowresistance, 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 domes are used when spot-welding deformation is not desired. The weld size is determined by the diameter of the electrode.

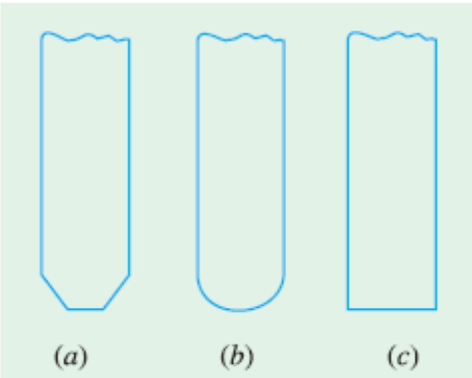

Fig-8

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 electrode comes 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 for galvanized, 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 roll weld.

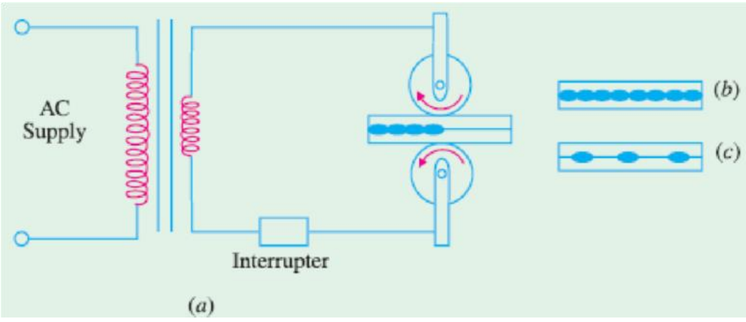

Fig-9

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 grades of 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 raised on the surfaces to be welded [Fig.29 (a)].

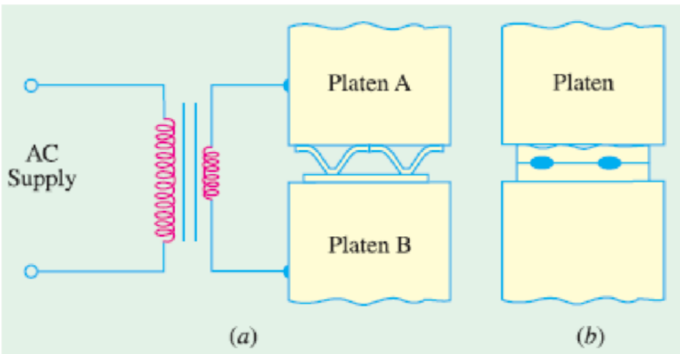

Fig-10

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 is the metal fibre welding which uses a metal fibre rather than a projection point(Fig.30).

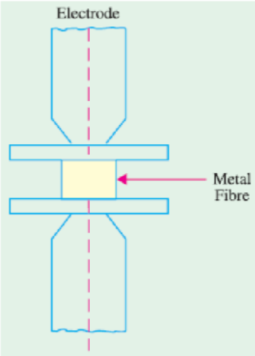

Fig-11

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].

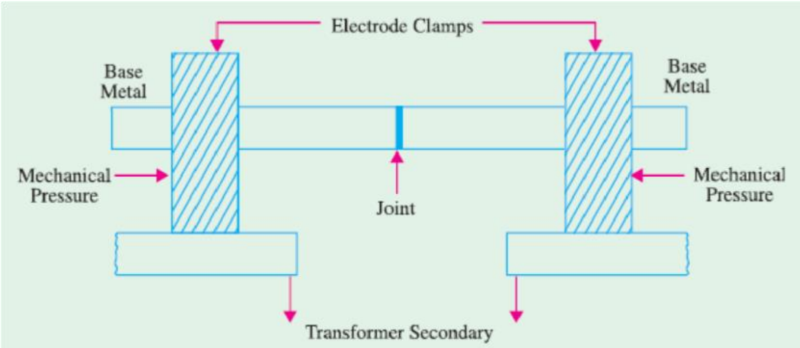

Fig-12

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.

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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 wavelength 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.

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×ω

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

Illumination:- When the falls upon any surface, the phenomenon is called the illumination. It is 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

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

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 can be 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.

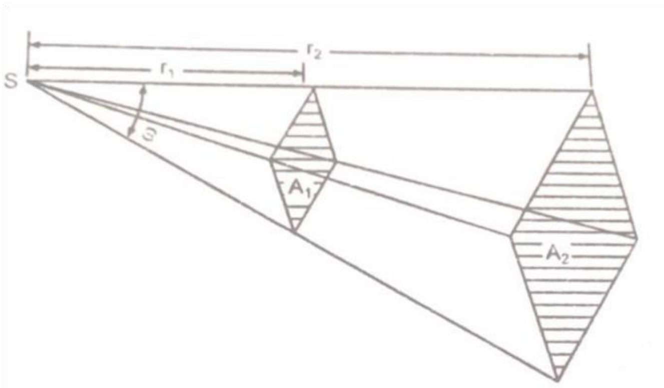


Fig. 1

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.

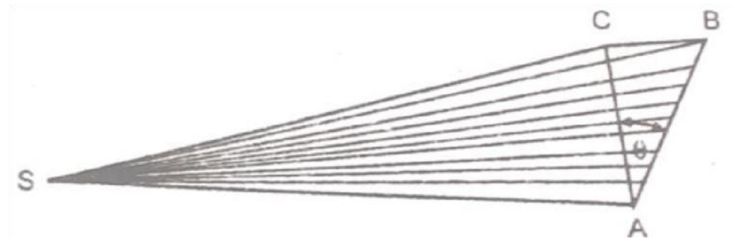


Fig. 2

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

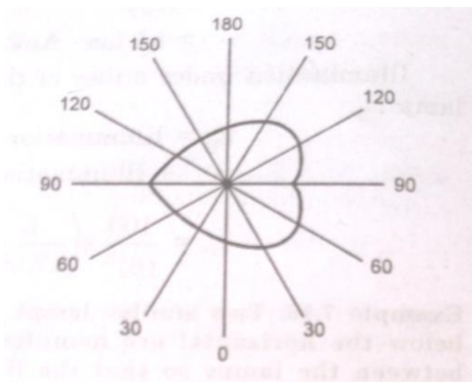
And the illumination decreases in the ratio cosθ/1 The expressions

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 the luminous 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.



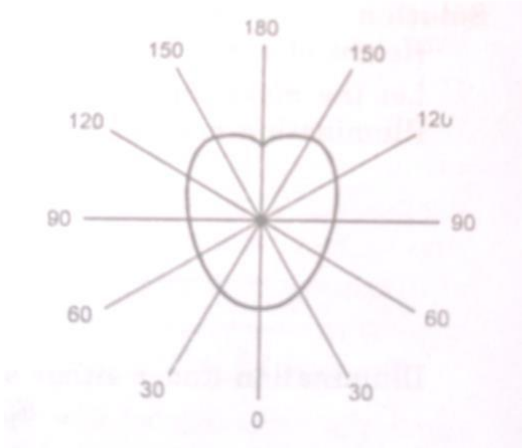


Fig.3a.Polar Curve for Horizontal plane

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.

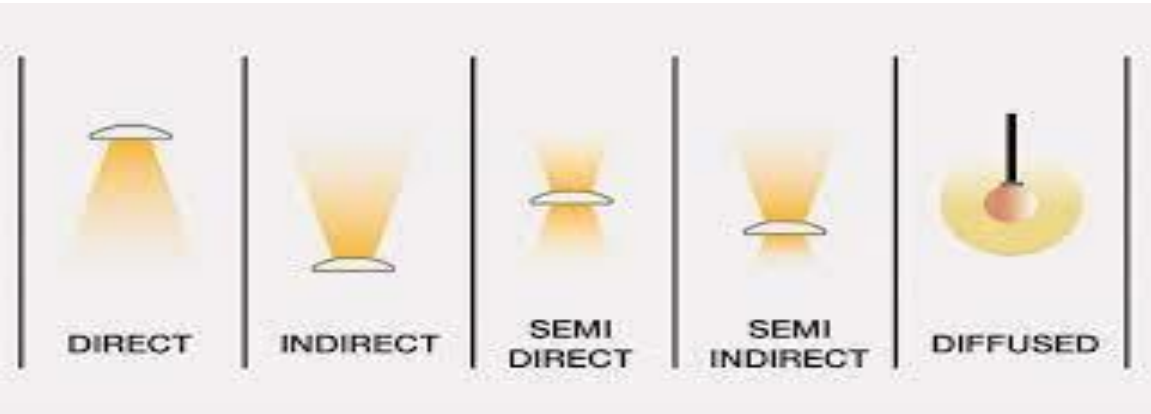
Direct lighting: It is the most commonly used type of lighting scheme. In this scheme more than 90 percent of total light flux is made to fall directly on the working plane with the help of deep reflectors. It is mainly used for industrial and general outdoor lighting.

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 the nature of the gas or vapour used.

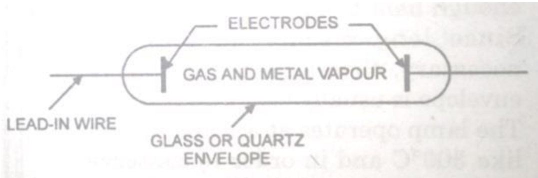


Fig. 4. Gaseous Discharge Lamp

The production of light by these lamps is based on the phenomenon of excitation and ionization 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 electrons revolving 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 potential difference 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.

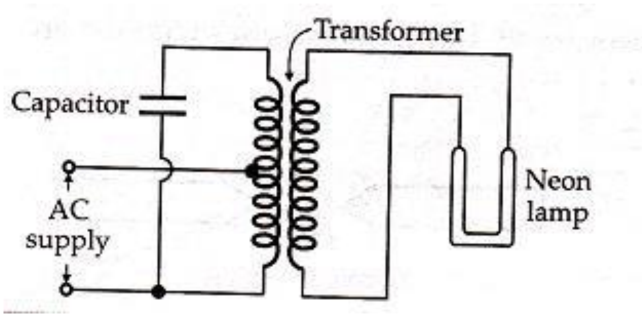


Fig. 5. Neon Lamp

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.

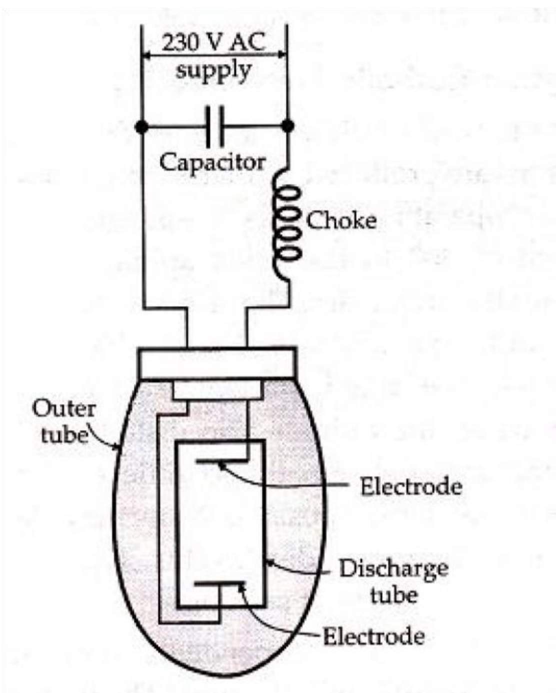


Fig. 6 Sodiun Vapour Lamp

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 $60^0\mathrm{C}$ 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 $230^0\mathrm{C}$ .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 to 40 lumens per watt.

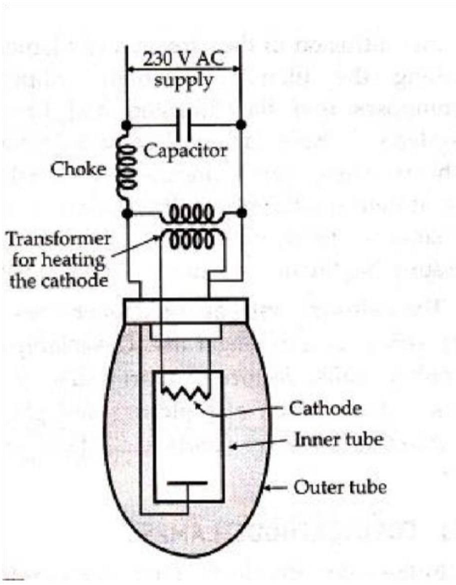


Fig.7 High pressure Mercury vapour Lamp

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 drop along the positive column is proportional to its length.The large voltage drop at the cathode is independent 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.

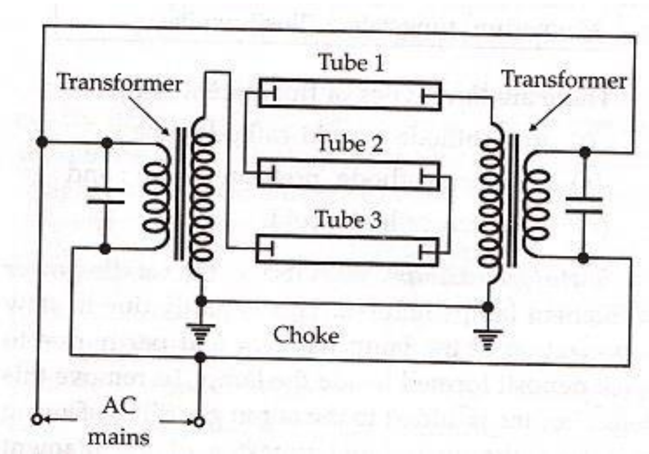


Fig. 8 Operation of the cold cathode lamps in series

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 volts applied 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 emitting material. Finally so little of the materials is left that it is not possible to emit any electrons and the lamp becomes dead. This type of lamp is unsuitable for frequent starting

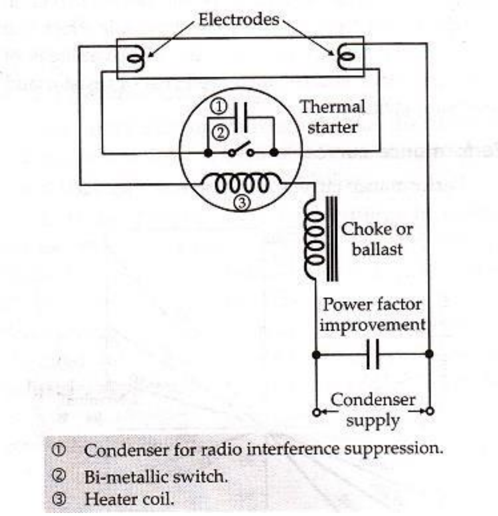
Fluorescent lamps produce flicker or stroboscopic effect since on 50 cycle supply they are extinguished 100 times a second. Single lamp cannot be operated without flicker. Flicker correction can be applied to pairs of lamps.

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.



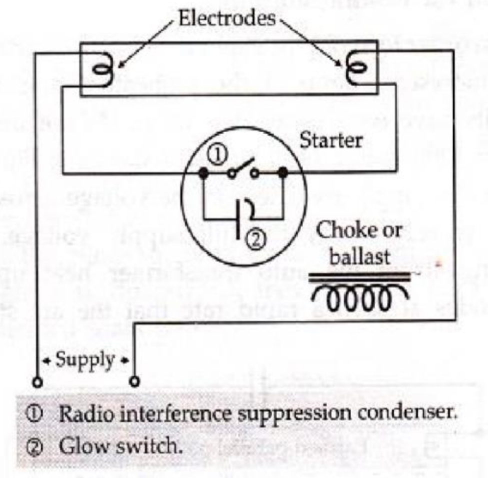


Fig.9 Fluorescent lamp

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.

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CHAPTER-5

INDUSTRIAL DRIVES

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 allelectric 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 the cost 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 machines at 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 the industry 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.

Selection of Motors :

Due to the universal adoption of electric drive, it has become necessary for the manufacturer to manufacture motors of various designs according to the suitability and use in various classes of industry. This has resulted into numerous types of motors. For this reason, the selection of motor itself has become an important and tedious process. Taking into account the conditions under which a motor is required to operate, following factors will decide the type of motor required. :

1. Electrical Characteristics: The following are the electrical characteristics:

   a. Starting characteristics
   b. Running characteristics
   c. Speed control
   d. Braking

2. Mechanical Characteristics. These are:

   a. Structural feature i.e. type of enclosure and bearing.
   b. Method employed for transmission of power.
   c. Noise.
   d. Type of cooling.

3. **Size and Rating of motors.**

Following are the sub-heads under these characteristics;

   a. Rating of the motor.
   b. Suitability of the motor for continuous intermittent or variable loads.
   c. Over load capacity.

4. Cost;

   a. Initial cost.
   b. Running cost.

In addition to the above factors, the type of current is also to be taken into consideration. From above it will be seen that the basic problem is to study carefully and thoroughly the load requirement, its surrounding and type of job it has to perform and then a motor which has the required characteristics and fulfil all the requirements is selected. The factors described above have been discussed in the following pages in detail.

Starting characteristics

The starting torque exerted by a motor should be large enough to accelerate the motor and its load to the rated speed in a reasonably short time. Some motors mat have to start against full load torque, Ex:- motors driving grinding mills or oil expellers. In the case of lifts and hoists, the motors have to start frequently with acceleration.

At the time of starting a motor two torques come into play: the torque required to overcome the static friction and the torque necessary to accelerate the motors and its load to the desired speed. The torques required for static friction cannot be easily determined. The torque for acceleration depends upon the load torque itself. The load torque may:

(i) Increase with speed i.e., may be proportional to $(\text{speed})^2$ as in the case of a fan or centrifugal pump OR

(ii) Remain constant with speed as in the case of a hoist.

The starting gear should, therefore be able to carry the starting current taken by a motor to a safe value consistent with the production of the necessary starting torque.

Starting Torque of DC Motors

Starting Torque in case of DC motors. Consider P poles motor producing flux Ø webers per pole and let, I_a be the total armature current.if the number of parallel paths are A, then the gross torque T_g is given as:

$$T_g = \frac{1}{2\pi} \times \frac{ØZPI_a}{A} \text{ m.Nw} = 0.159 \frac{ØZPI_a}{A} \text{m.Nw} = 0.0162 \frac{ØZPI_a}{A} \text{ m.Kg}$$

Now, whole of this torque developed will not be available at the pulley or is not available for doing useful work, since some of the power (Torque) developed is utilized in supplying friction and windage losses. The difference of gross Torque and the Torque lost in friction is called the shaft torque.

Let,ω be the angular speed of motor.

Power developed by the armature = $T_g\omega$ metre-Newtons or joules or watts

$$= \frac{2\pi NT_g}{60}$$

But 1 H.P.(metric) = 735.5 watt

∴ H.P.(metric) developed by the armature = $\frac{2\pi NT_g}{60 \times 735.5}$

The torque therefore, depends upon the product of flux and armature current and is independent of speed i.e. , T $\propto I_a$.

In the case of a shunt motor, both the armature and the field are connected in parallel across constant voltage mains. The current taken by the field is, therefore, constant and hence the flux will be maintained constant so long as the field current remains constant. Therefore the torque in a shunt motor varies as the armature current. The torque –armature current curve is a straight line passing through the origin. Full-load current will produce full-load torque and twice the full-load current will produce twice the full-load torque.

In the case of D.C. series motors, the current in the series winding and the armature is same. The flux is dependent directly on the value of the current the motor draws. Torque is, therefore, proportional to the square of the armature current i.e. $\propto I_a^2$ .The torque-current curve is ,therefore, a parabola.But the flux varies as the current only upto the limit of saturation of the magnetic circuit and the torque current curve is parabolic in shape only up to the limit of saturation.Beyond the saturation point since‖∅ —does not vary appreciably the torque current curve is almost a straight line. A d.c. series motor is,therefore suitable for drives starting with heavy loads,Ex- electric train ,hoists and lifts etc.

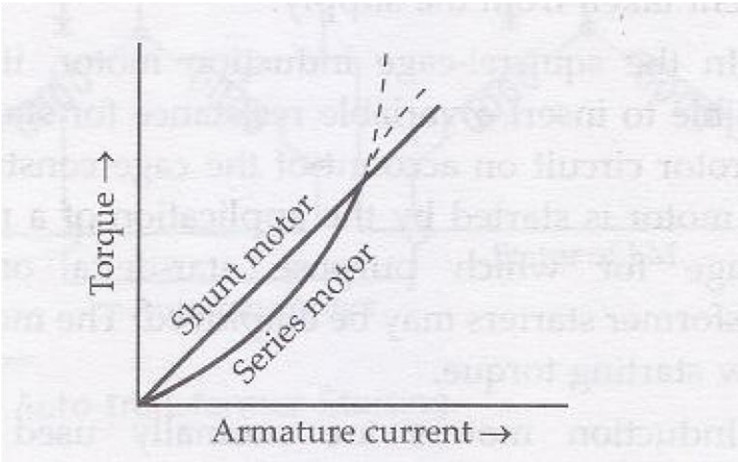


Fig..1 Torque Current characteristics of DC motor

Three-Phase Induction motors

In a three-phase induction motor, if

r_1 = stator resistance per phase

r_2 = rotor resistance per phase referred to the stator

x_1 = stator reactance per phase

x_2 = rotor reactance per phase referred to the stator s = slip

V = stator applied voltage per phase,

Then the torque, T, is given by

$$T = k \frac{V^2 r_2/s}{(r_1+\frac{r_2}{s})^2+(x_1+x_2')^2} \quad \text{and}$$

Stator current per phase is: $I = \frac{V}{\sqrt{(r_1+\frac{r_2'}{s})^2+(x_1+x_2')}}$

2

If k is made unity ,the torque is expressed in synchronous watts per phase. At starting, s = 1

Therefore, starting Torque, $T_s = \frac{V^2 r_2'}{(r_1+r_2')^2+(x_1+x_2')^2}$ synchronous watt per phase

and starting current per phase

$I_s = \frac{V}{\sqrt{(r_1+r_2')^2+(x_1+x_2')^2}}$ amperes.

The starting torque is a maximum if the rotor resistance per is made equal to its leakage reactance. It is, therefore, usual to start a slip ring induction motor with a variable resistance in its rotor circuit to have a good starting torque and to cut the resistance in steps as the motor speeds up. The resistance in the rotor circuit also serves the purpose of limiting the starting current taken from the supply.

In the squirrel cage induction motor, it is not possible to insert a variable resistance for starting in the rotor circuit on account of the cage construction. The motor is started by the application of a reduced voltage for which purpose star-delta or auto-transformer starters may be employed. The motor has a low starting torque

Induction motors are normally used where constant torque is required, ex- in paper machinery, textile machinery, compressors, conveyors etc. Squirrel cage motors are more reliable, cheaper and easier to use where as phase wound motors are expensive and maintenance is complicated. The former are used for low and medium H.P. while the latter are used for high H.P.

Motors with double cage have a high starting torque. The outer cage is made of highresistance metal bars and inner cage is made of copper bars. The inductance of the inner winding is higher than that of the outer high resistance winding. At the instant of starting, the motor induced currents are at the line frequency and the inner cage has a high reactance ($2\pi fL$) with the result that the rotor currents remain confined to the outer cage despite its high resistance. The starting torque is, therefore, high.During normal running, the reactance of the inner cage decreases ($2\pi sfL$), and the rotor currents are now confined to the inner cage which is a low resistance winding. This gives a high efficiency of the motor.

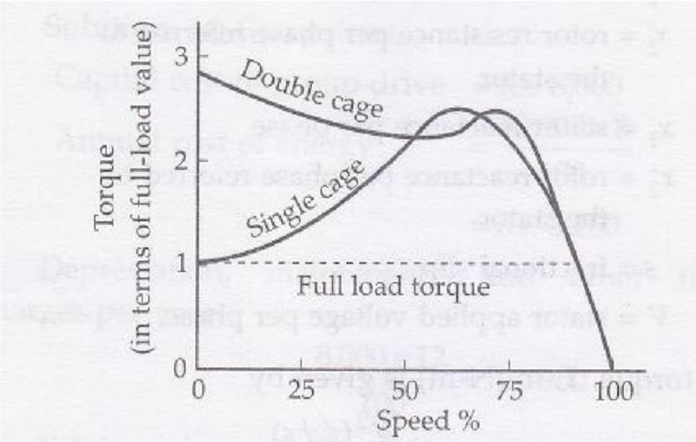


Fig.2 Torque speed characteristics of Induction motor

The Figure above shows the speed-torque curves of a single cage and double cage motor.

An important relation existing for three-phase induction motor, i. e.

$$\frac{\text{Starting Torque}}{\text{Full} - \text{Load torque}} = \left(\frac{Starting\ Current}{Full - Load\ Current}\right)^2 \times Full\ Load\ slip$$

$$i.e., \frac{T_s}{T_L} = \left(\frac{I_s}{I_L}\right)^2 \times s_{FL}$$

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.

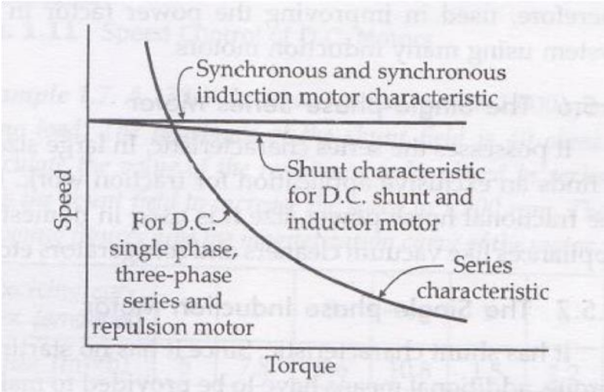


Fig..9 Torque speed relation of dc and ac motors

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

The Theree-phase Induction Motors

It possesses shunt characteristics. The power factor is very poor at low loads but improves as the load increases. The power factor, however, always remains less than unity.

The Synchronous and synchronous-Induction motor

The synchronous motor is a constant speed motor: The speed is fixed by the frequency of the supply. It is not, however, self starting. It is started by an auxiliary motor and synchronized to the supply .This disadvantage is eliminated in a synchronous-Induction Motor where the machine starts as plane Induction motor and when the speed is very near the synchronous speed the DC excitation to the rotor is switched on and the motor pull into synchronism.

By varying the field excitation of these types of motors the power factor may be made unity or even be made leading. An over-excited synchronous motor works as a leading power factor while an under-excited motor works as lagging power factor. It is, therefore used in improving the power factor in a system using many induction motors.

Single-phase series motor

It possesses the series characteristics. In large sizes it finds an exclusive application of Traction work .In fractional horse power size it is used in domestic appliances like vacuum cleaners and refrigerators etc.

Single-phase Induction motor

It has shunt characteristics. Since it has no starting torque, additional means have to be provided to make it starting. Repulsion start and the capacitor start motor are the common modifications of the single phase induction motor.

Repulsion motor

It has series characteri9stics and closely resembles the series motor in construction.The armature is short circuited in itself.

SPEED CONTROL :

Control of speed for an industrial drive depends upon the nature of work being carried out. A certain operation may require a continuously varying speed; another one may only require two fixed speeds.Some times creeping speed may be necessary to adjust the work.For most industrial drives ,however,a control speed within $\pm$20 per cent may be suitable

Speed control of D.C. motors :

The speed of D.C. motors is given by the expression

$N \propto \frac{V-I_a R}{\phi}$

Or, $N = K \frac{V-I_a R}{\phi}$

Where, N = speed in rpm

φ= flux/pole

V = supply voltage

R = resistance in the armature circuit

I_a =current drawn by the motor armature

Two methods of speed variations are possible:

1. Flux variation or field control
2. By changing resistance in the armature circuit

Field control in shunt motors

The flux per pole is varied by inserting an extra resistance in the field circuit. Variation of the flux per pole changes the speed of the motor.

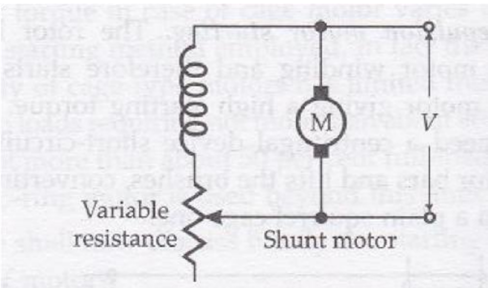


Fig.10 Shunt Field Control *Some limitations of this method are discussed below:*

i. With the regulating resistance in the field circuit zero, the flux per pole, is maximum which gives the lowest speed of the motor. Motors are usually designed to work at a speed slightly less than the rated speed when the regulating resistance is zero. It is obvious that any lower speed than this cannot be achieved by this method.

ii. The speed of the motor N is proportional to VI/Ø where as the full-load torque T is proportional to TN or VI_a which is constant. Therefore, this method can be utilized only where the horse power of the load remains constant.

iii. There is a limit to which the field can be weakened to obtain high speed. At such a speed the motor will tend to draw large current to develop the same torque. But this will result in the main field ampere-turns becoming much smaller than the armature mmf. The armature reaction will demagnetize and distort the main flux making the operation of the motor unstable. In motors where a wide speed-range is required, this difficulty is overcome by having a light series winding connected cumulatively to provide stable operation.

Sped variation by this method is limited to a ratio of 5:1.

Field control in series motors

Three methods are used for changing the flux per pole in series motors These are :

- Diverter field control
- Tapped field control
- Series-parallel field control

i. **Diverter Field control** :

A shunt is employed in parallel with the series field to divert a part of the current in the series field thus causing field weakening. Speeds higher than normal are attained when the diverter is used.

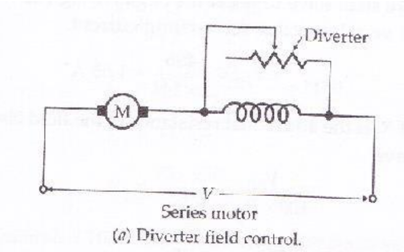


Fig.11 Field diverter control

Tapped Field control:

Tapping are provided on the field winding and current may be passed through different number of turns there by changing the field ampere-turns. This method is commonly used for series motors used in traction work.

Series-Parallel Field control:

The field winding is designed in two sections which may either be connected in series or in parallel .The field ampere-turns are reduced to half the value in parallel connection as compared to those in series connection. The speed, therefore, becomes about twice the initial value. Though the method is simple and inexpensive, only two speeds are possible.

CONTROL OF SPEED BY CHANGE OF SERIES RESISTANCE IN THE ARMATURE CIRCUIT

Since $N \propto \frac{V - I_a R}{\emptyset}$, the speed of a D.C.motor can be changed by varying R, resistance in the armature circuit. The torque of a motor is proportional to the product of the flux,$\emptyset$ and the armature current I_a .In the case of a shunt motor,since $\emptyset$ is constant,N will be proportional to V-$I_a R$ .if constant torque is required I_a should remain unchanged .But since speed is to be varied R has to be varied.Increase of R(for constant torque and therefore constant armature current)will give decreasing values of speed.The minimum value of R is R_a ,the resistance of the armature itself.The figure shows the armature speed torque characteristics.

$$R = r + R_a$$

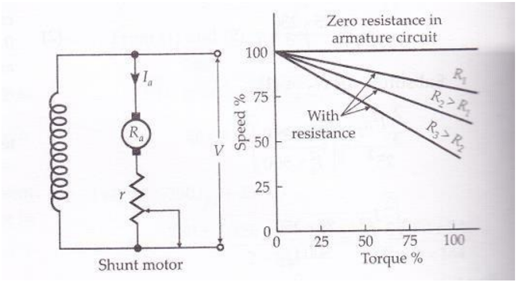


Fig.12 Speed control of shunt motor taking series resistance in armature

For a theoretical value of R = 0, the horizontal straight line passing through 100% speed ordinate is the limiting value. For any other values of R which may be $R_1 = r_1 + R_a$ or $R_2 = r_2 + R_a$, $R_2 > R_1$ or $R_3 = r_3 + R_a$, $R_3 > R_2$ etc. the curves are as shown.

If this method is used for a load requiring constant torque at all speeds, the armature current must remain constant and so the input to the motor (i.e., armature) is also constant. But the output decreases with the decrease in speed and hence the efficiency of the motor is poor at lower speeds. The power loss takes place in the controlling resistance r. In the case of fans and centrifugal pumps where the load torque decreases at lower speeds, this method may be quite convenient and economical for short periods. Creeping speeds may also be obtained by this method.

In a series motor, an increase in the armature circuit resistance will decrease both speed and torque. Since the flux is dependent on the armature current the torque is proportional to I_2. For a constant torque if different speeds are required, current (*I) has* to be constant which will make $\emptyset$ constant. For reducing the speed resistance is to be increased.

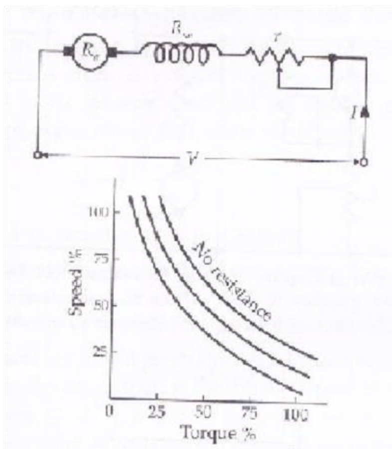


Fig.13 Speed control of series motor with series resistance in armature

Control of Motor Speed by Shunting the Armature by a Resistance

The arrangement of varying the speed of a d.c. motor by changing the series resistance in the armature circuit is at times not applicable as the speed of the motor rises if the load is reduced. We can see from the equation $N \propto (V - I_a R)/\emptyset$ that as I_a diminishes N increases. To eliminate this drawback, the armature is shunted by a variable resistance. A series resistance is also used as shown in fig. 1.14. By adjusting P and Q a number of speed torque curves can he obtained.

If we apply Thevenin‘s Theorem to the circuit in fig. 1.14(a), we get P and Q in parallel i.e., short circuit resistance R_{sh} by short-circuiting the source of supply and removing the branch (i.e., armature) through which we wish to find the value of the current flowing. Therefore the open circuit voltage across the armature is

$V_{oc} = \{P/(P+Q)\} V$. Fig. 1.14(b) shows the equivalent circuit based on The-venin‘s Theorem.

The current is given by

$I = V_{oc} / R_a + R_{sh}$ Where $V_{oc} = P/(P+Q)\ V$ and $R_{sh} = PQ/P+Q$ = short circuit resistance.

The efficiency of this method is poor and heavy currents may be drawn from the supply at certain speeds.

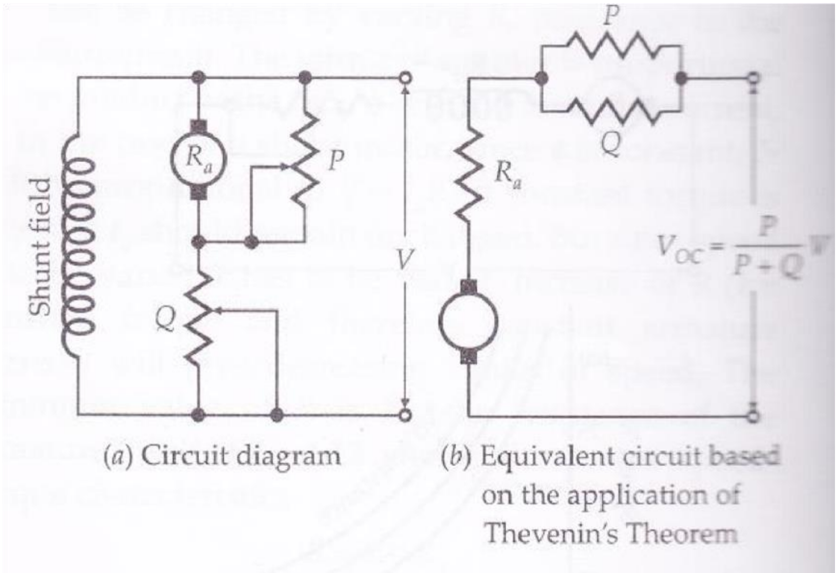


Fig. 14. Controlling resistance in parallel arrangement

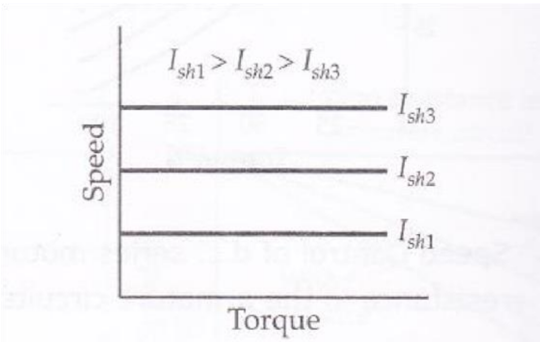


Fig. 15 Speed Torque characteristics

ELECTRIC BREAKING

In many industrial drives, it becomes important to stop motor and its work in a reasonably short time, as in the case of planer where the tool must be stopped quickly at the end of its stroke. To achieve this breaking system has to be used.

Two types of breaking systems are possible:

1. Mechanical or friction braking where the motor is stopped by using a brake shoe or band on brake drum.
2. Electrical braking where the kinetic energy of the motor and tool is converted to electrical energy and is dispatching a heat in a resistance or returned to the supply system.

Electric braking is superior to mechanical braking since it is much quicker and eliminates the cost of maintenance of mechanical brakes. However, in order to finally bring the motor so a standstill and hold it there, friction brakes are essential.

The following types of electric braking are employed:

1. Plugging
2. Rheostatic or dynamic braking
3. Regenerative braking

PLUGGING

The connections of the armature are reversed so that the motor tends to rotate in the reverse direction thus providing the necessary braking effect. However, the supply must be cut off when the motor comes to rest otherwise it will start rotating in the reverse direction. Plugging may be employed with D.C. motor or induction motor and synchronous machines.

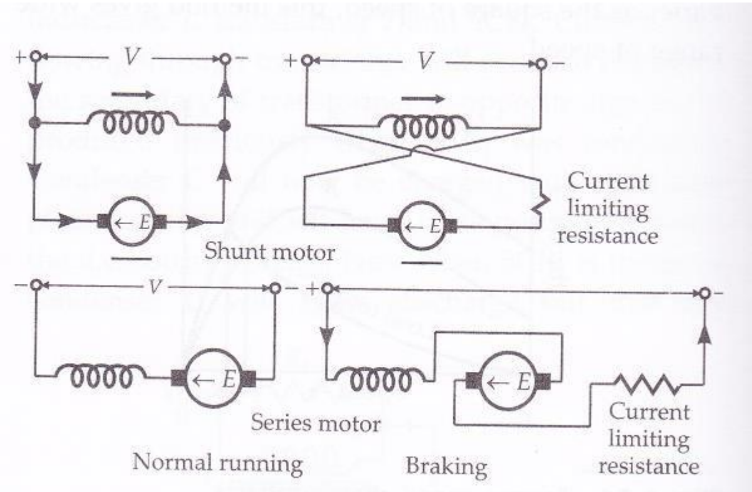


Fig.21 Plugging in DC motors

Plugging with D.C. motors

(a) The armature connections are reversed with respect to the field so that the current in the armature reverse .During normal running the back emf E is opposite to the direction of the armature current but during braking the back emf E and the armature current are in the same direction. At the instant of reversal of armature connections a voltage equal to V+E is impressed across the armature circuit, V being the supply voltage. Since E is very nearly equal to the V, the impressed voltage is approximately 2V.This will cause a great rush of current in the armature circuit. To prevent this, the starting resistance is reinserted in the armature circuit as shown below.

It should, however ,be noted that during braking, in addition to the kinetic energy of the motor being dissipated in the resistance, some energy is being drawn from the supply. There is, therefore, a waste of energy.

(b) If any two supply phases are interchanged with each other the direction of rotation of the magnetic field reverses and, therefore, the torque on the rotor also reverses providing a braking action. Supply, however, has to be cut off when the motor comes to rest, otherwise the rotor would start building up motion in reverse direction. The rotor and stator currents tend to be abnormally high and a resistance may have to be inserted in the rotor or stator circuit for the purpose of protection.

(c) PLUGGING WITH SYNCHRONOUS MOTORS

If the D.C. excitation of the synchronous motor is reversed, the D.C. and A.C. fields will rotate in opposite direction and there can be no braking effect. But in case of motors fitted within damper windings the eddy currents induced in them provide braking.

Rheostatic or Dynamic Braking

The motor is disconnected from the supply and worked as a generator driven by the kinetic energy of the rotor and the load. A resistance is connected across the motor terminals; the kinetic energy of rotation is converted into electrical energy and is dissipated in the resistance.

(a) D.C. Motors-shunt

The armature is disconnected from the supply and connected across a resistance. The motor now works as a separately excited generator and a braking torque is applied by the current delivered to the resistance. If, however, the supply fails, the braking action vanishes as the excitation disappears. This drawback is sometimes removed by fitting a series winding in the armature circuit which is connected during the braking period only. Due to the action of this winding, the motor self excites a series generator and the current delivered by the armature provides braking action.

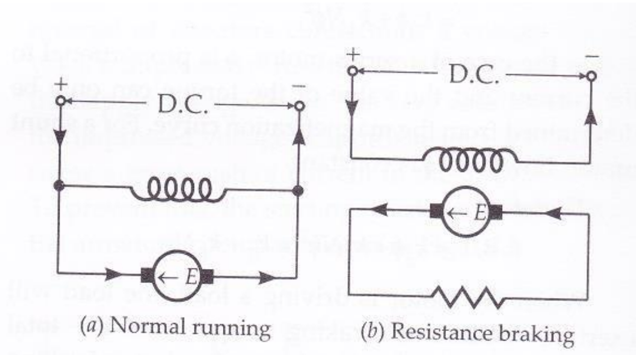


Fig..22 Rheostatic braking of shunt motor

(b) Series D.C. Motor- The motor after being disconnected from the supply is made to excite as a series generator. For this it is necessary that the total resistance in the motor circuit should be less than the critical resistance, so that the generator may self excite. Also in order that the flux may build up, the connections of the armature with respect to the field have to be reversed.

(c) Synchronous Motors

The field excitation is maintained and the motor after being disconnected from the supply is connected to resistances in star or delta. It now works as an alternator and the kinetic energy is dissipated in the form of losses in the resistances.

(d) Induction Motors

The stator is disconnected from the supply and direct steady current is passed through its windings .A flux is produced. When the short-circuited rotor conductors cut this steady flux emf is induced in them which provide the necessary braking effect. If the rotor is wound, the braking torque can be controlled by the insertion of suitable resistances in the rotor circuit.

Regenerative Braking

In regenerative breaking the motor is run as generator by the kinetic energy of the load which is returned to the mains as electrical energy. There is, therefore, an overall saving in energy.

(a) D.C.Motors-shunt: If the emf generated by the motor is greater than the supply voltage, power will be fed back into the supply. The emf in a shunt motor depends upon its excitation and speed. If the field is disconnected from the supply and the field current is increased by exciting it from another source, the induced emf will exceed the supply voltage and the motor will feed energy into the supply. The speed of the motor, however, falls to value corresponding to the field current at any instant. The condition is shown in Figure.

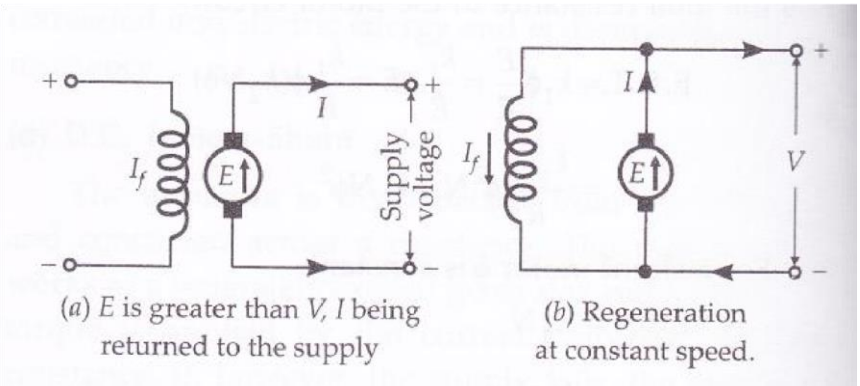


Fig.23. Regenerative Braking with d.c. shunt motor

There is another way in which regeneration takes place resulting in braking effect. If the field excitation does not change but the load causes the speed to increase, the induced emf may become greater than the supply voltage and power will be fed back in to the supply. The regenerative effect, however, will prevent any tendency of speed to increase further. This itself constitutes a form of braking effect since in the absence of regeneration, the speed would increase continuously.

(b)D.C. Motor-Series

Regenerative braking with series motors is employed mainly in traction work.

(c)Induction Motors

When an induction motor runs at a speed above the synchronous, it works as an induction generator feeding power back in to the supply. No extra devices need be employed .It may be noted that regenerative braking of induction motors is hardly useful for stopping the motor but it helps in keeping the load at a speed slightly above the synchronous and returns valuable power to the supply.

CHAPTER-6

ELECTRIC TRACTION

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 exist today. 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 motor due 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 are being attempted.

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 traction services.
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 stable.
5. In case of dc series motor commutation is excellent up to twice full load so 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 and commutating 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 continent and 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 be short-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.

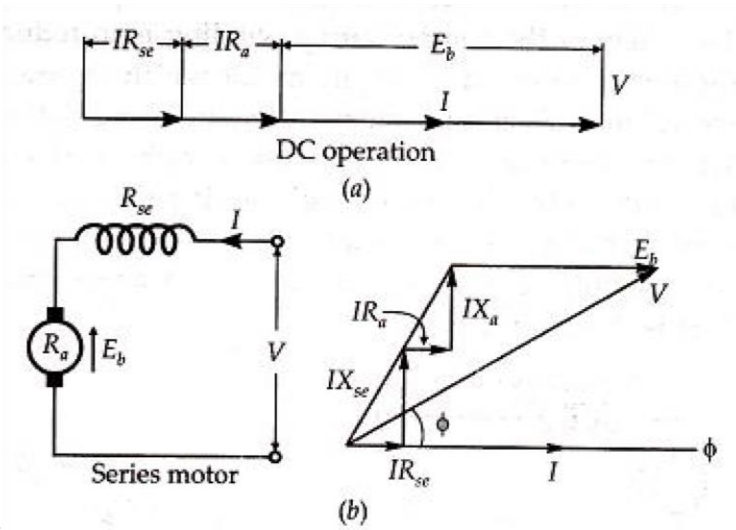


Fig. 1 Operation of series wound motor on dc and ac

Operation on d.c. is simple enough. I is the current drawn by the motor, $IR_{se}$and IR_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 emf E_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.

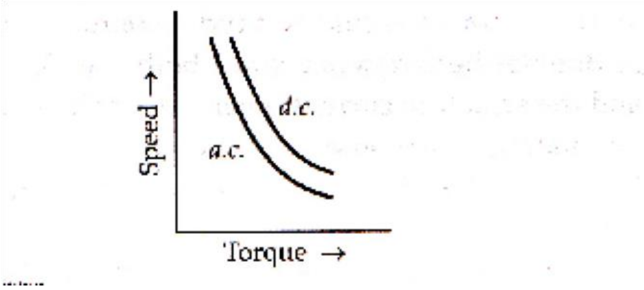


Fig.2 Speed – torque curves for d.c. and a.c. operation

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

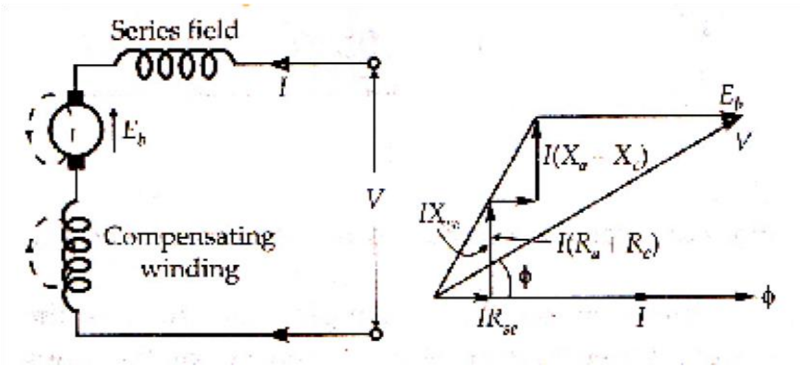


Fig. 3 Circuit diagram & phasor diagram of the series motor with compensating winding

$R_a + R_c$ 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.

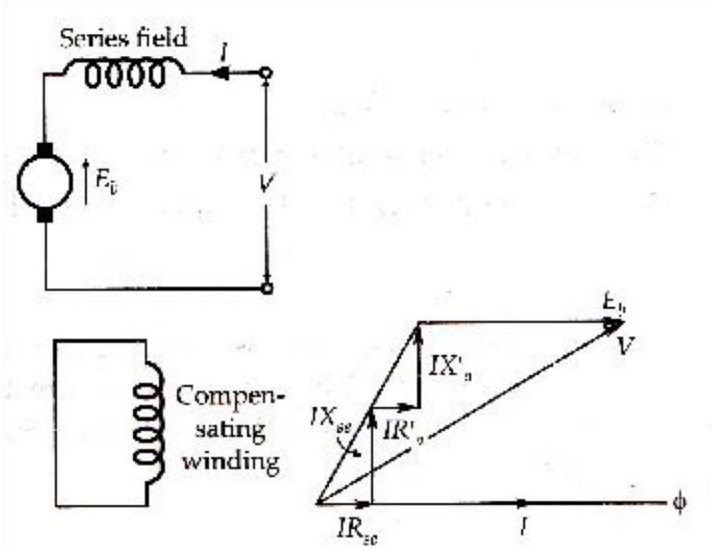


Fig.4. Circuit and phasor diagram for an inductively compensating series motor

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.

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.

The Series-Parallel Control

The series-parallel control is carried out as follows:

(a) Shunt Transition: The various stages involved in this method of seriesparallel

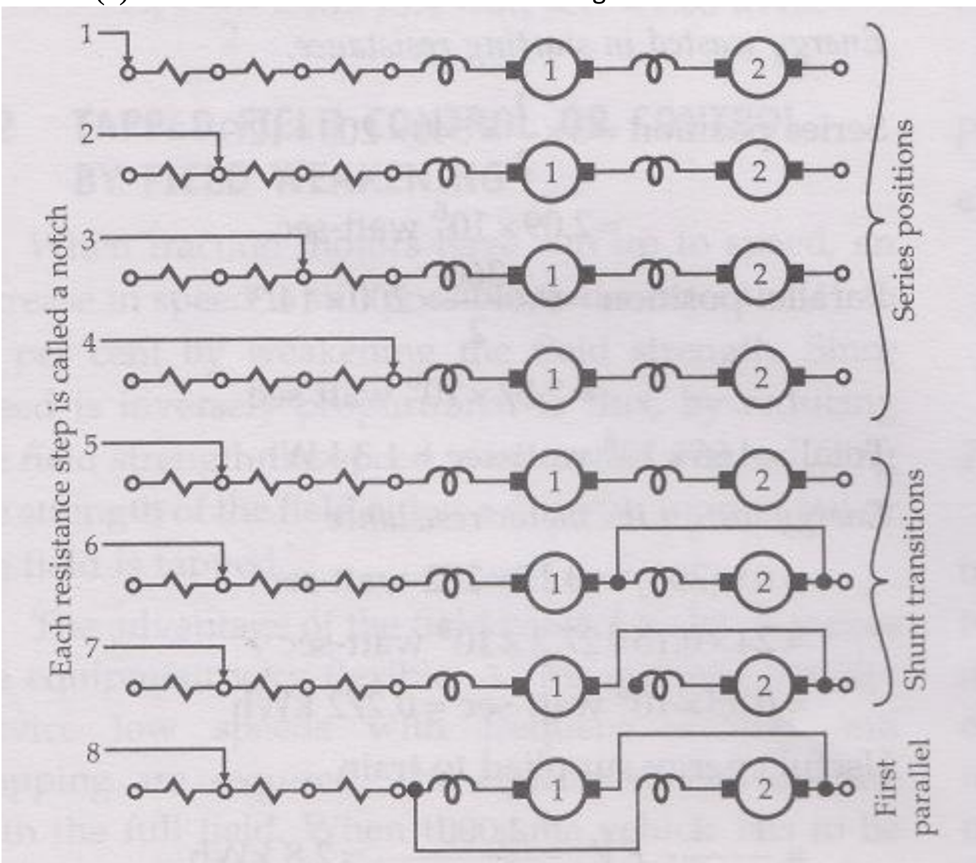


Fig..11 Series position

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.

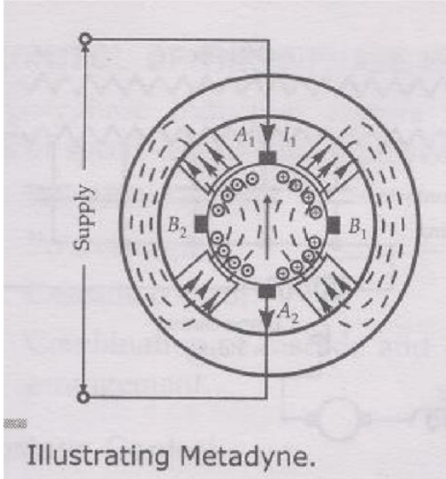


Fig.12 Illustrating Metadyne

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.

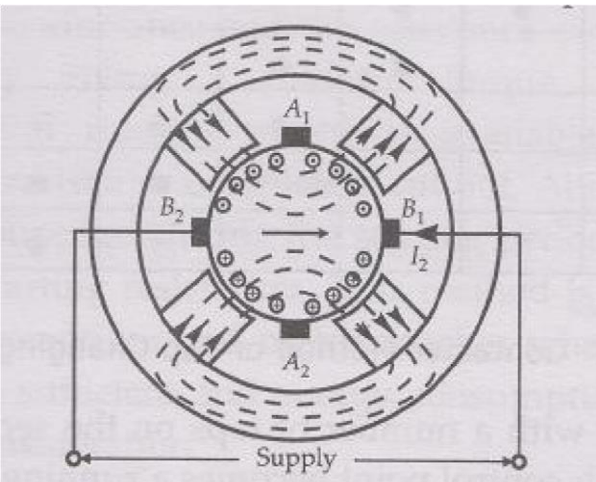


Fig.6.14

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.

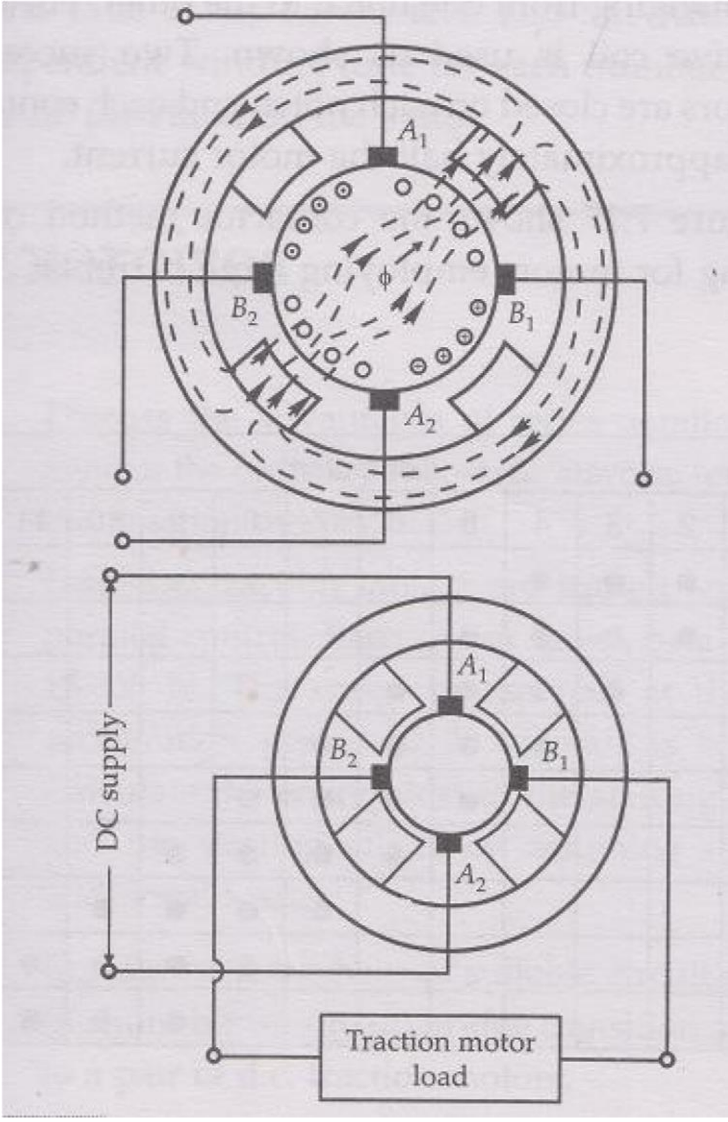


Fig.15

The total flux may be assumed to be made up of two components $\emptyset_1$ and $\emptyset_2$ at right angles and directed along A_2A_1 and B_2B_1 .The rotation of the armature in $\emptyset_2$ 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

$E_1 \propto \emptyset_2$ $=KI_2$

$E_2 \propto \emptyset_1$ $=KI_1$

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 emf developed 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.

BRAKING

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.

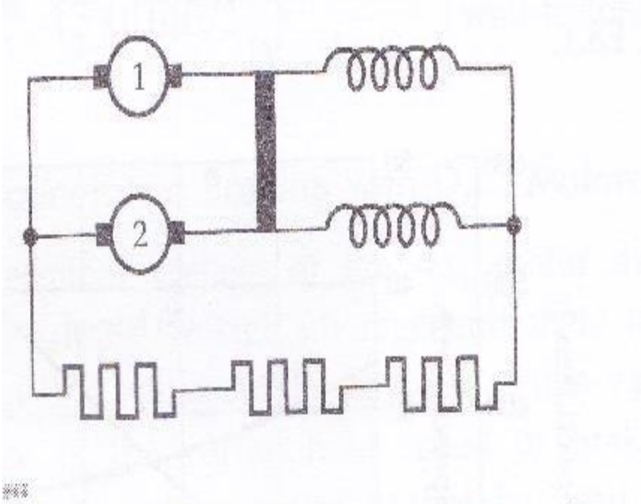
For D.C. motorsThere are three methods emp-loyed for electric braking:

(i) Plugging
(ii) Rheostatic braking
(iii)Regenerative braking

Plugging : Elaborate discussions have already been made on this in previous 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 the motors 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 the equalizer 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.



Rhestatic Braking-Equaliser connection.

Fig.17

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.

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.

REGENERATIVE BRAKING WITH THREE-PHASE INDUCTION MOTORS

Regenerative braking with three-phase induction motor occurs automatically when the motor 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 extra resistance 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.

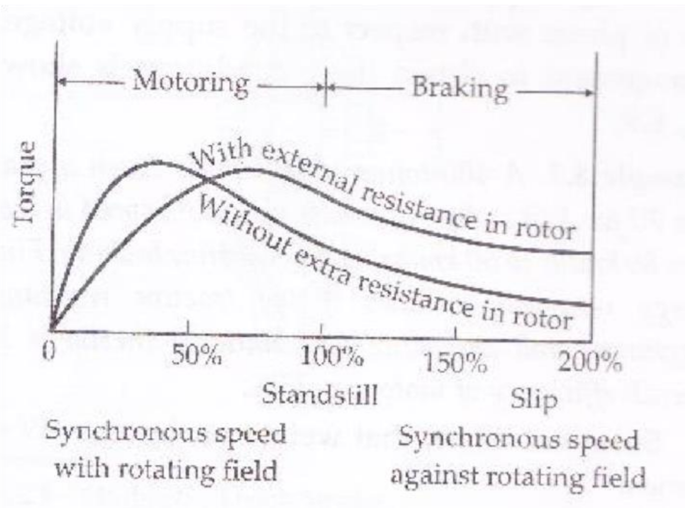


Fig.24 Torque speed curve of an Induction motor

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.

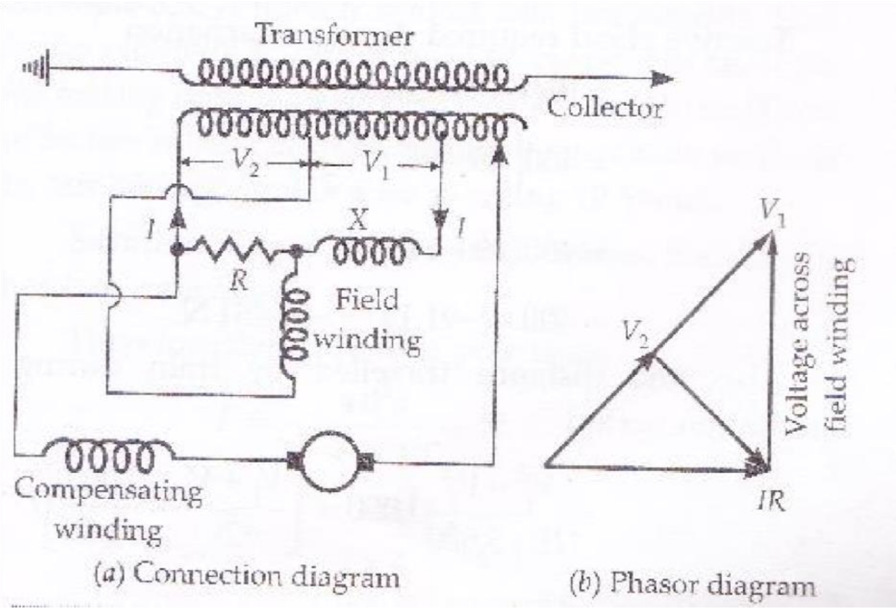


Fig.25 Regenerative braking with single phase series motor

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 airbrakes 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 and released 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.