MODULE-1

HEATING AND WELDING

Structure

Heating and welding

- Electric Heating
- Resistance ovens
- Radiant Heating
- Induction Heating
- High frequency Eddy Current Heating
- Dielectric Heating
- The Arc Furnace
- Heating of Buildings
- Air – Conditioning, Electric Welding
- Modern Welding Techniques.

Electrolytic Electro – Metallurgical Process:

- Ionization
- Faraday's Laws of Electrolysis
- Definitions
- Extraction of Metals
- Refining of Metals, Electro deposition

Module Objectives:

1. To discuss electric heating, air-conditioning and electric welding
2. To explain laws of electrolysis, extraction and refining of metals and electro deposition.

1. Introduction

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 tor 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.

1.1 Advantages of Electric 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. The material to be heated does not get contaminated.

(ii) No Pollution. Since no flue gases, soot 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 or 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 $\pm 5^{\circ}$ celsius which is not possible in any other form of heating. The required temperature variation can be achieved to meet the predetermined heating and cooling cycle.

(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.

(xi) Economic Furnaces: In the absence of chimney, flue pipes and grating, electric furnaces are cheap.

(Xiii) Easy to start and stop: It is easy to start the electric furnace and attain the required temperature with less time.

1.1.1 Different Methods of Heat Transfer

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

1. 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 i.e the heat conduction through a substance depends upon the temperature difference.
- Consider a solid material of cross-section *A* sq.m. and thickness *x* metre as shown in Fig. 1.1

If Tl 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:

$$H = \frac{KA(T_1 - T_2)t}{x}$$

Where K is thermal conductivity of the material

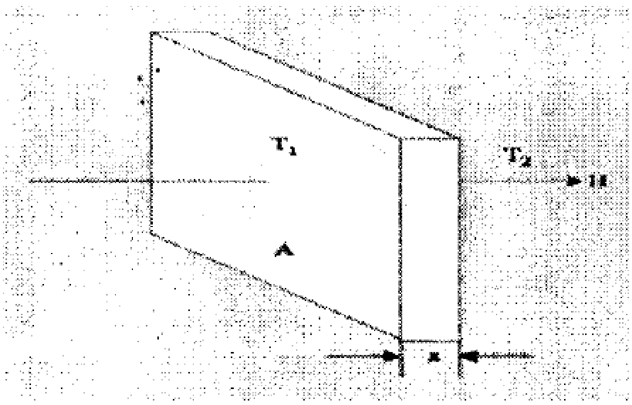


Fig1.1

2. 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 clement 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 = α (T1 - T2), where (a and b are constants and Tl and 72 are the temperatures of the heating surface and the fluid in $^{\circ}K$ respectively.

In electric furnaces, heat transferred by convection is negligible.

Heat dissipation=3.876x 10^{-4} (T1-T2) 1.25 watts/ cm^2

3. Radiation

- The object receives heat from the source without heating the medium in between. Thus heat is transferred by means of heat waves.
- The rate of heat emission is given by Stefan's law according to which Heat dissipated

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

Where T1= temperature of heating or radiating surface
T2= temperature of object absorbing the heat
K is radiating efficiency and depends upon the pattern of placement of heating elements
K=1 for single heating element
K =0.5 to 0.8 for number of heating elements placed side by side.
e is known as emissivity of the heating clement,
=1 for black body
=0.9 for resistive heating element

- The law states that the total energy radiated from blackbody is proportional to the fourth power of its absolute temperature

Note: Black body: The rate of energy emitted by an ideal surface is black body

1.1.2 Methods of Electric Heating:

- Basically heat is produced due to the circulation of current through a resistance. The current may circulate directly due to the application of potential difference or it may be due to induced eddy currents. Similarly, in magnetic materials, hysteresis losses are used to create heat.

- In dielectric heating, molecular friction is employed for heating the substance. An arc established between an electrode and the material to be heated can be made a source of heat. Bombarding the surface of material by high energy particles can be used to heat the body.

1. Power Frequency heating

- **Resistance heating**
    1. Direct resistance heating
    2. Indirect resistance heating

- **Arc heating**
    1. Direct arc heating
    2. Indirect arc heating
- **Electron bombardment heating**

2. High frequency heating

- **Induction heating**
    1. Direct core type induction heating
    2. Coreless type induction heating
- **Dielectric heating**
- **Infrared heating**

Different methods of producing heat for general industrial and domestic purposes may be classified below:

1.1.3 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**.

1. In this method the material (or charge) to be heated is treated as a resistance and current is passed through it.
2. 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.Cor D.C. supply (Fig. 1.2).
3. **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 ease 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.
4. Heat is produced when current passes through it. This method of heating has high efficiency because the heat is produced in the charge itself.

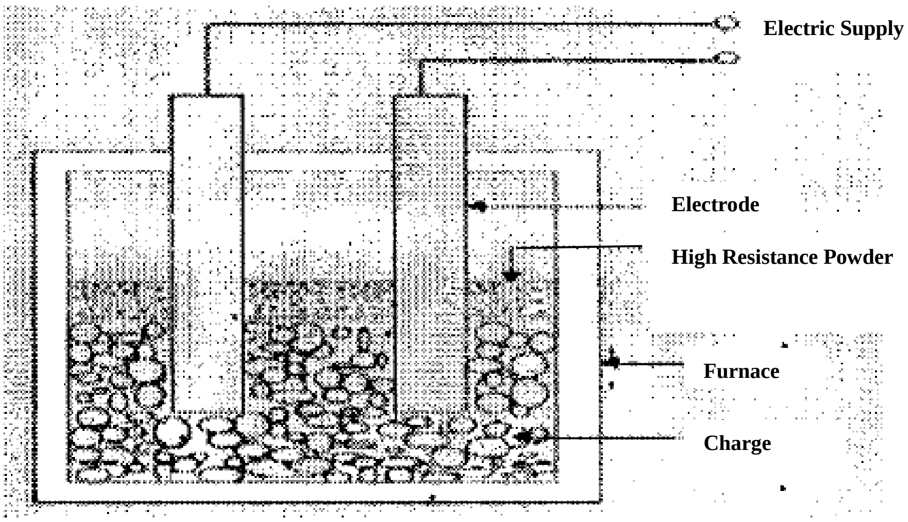


Fig1.2

b) Indirect Resistance Heating.

1. 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 dement.
2. The heat so produced is delivered to the charge either by radiation or convection or by a combination of the two.
3. Sometimes, resistance is placed in a cylinder which is surrounded by the charge placed in the jacket as shown in the **Fig. 1.3**. This arrangement provides uniform temperature. Moreover, automatic temperature control can also be provided.

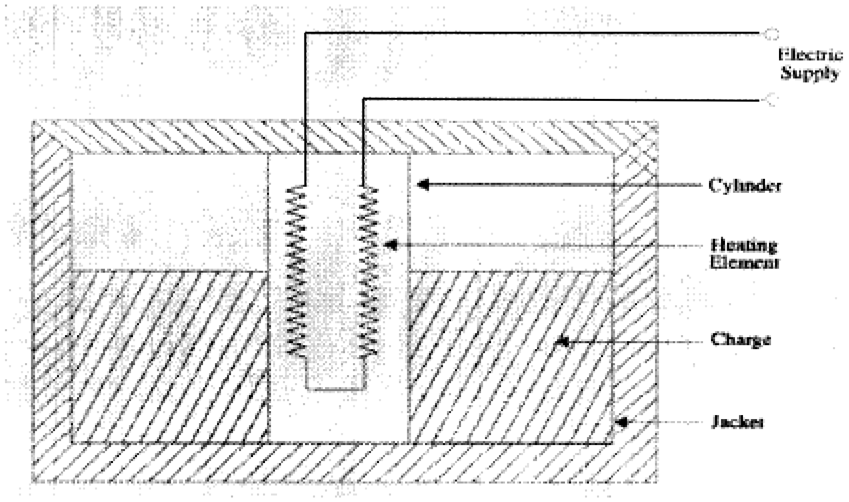


Fig1.3

1.1.4 Requirement of a Good Heating Element

Indirect resistance furnaces use many different types of heating elements for producing heat. A good heating element should have the following properties:

1. **High Specific Resistance**. When specific resistance of the material of the win: is high, only short length of it will be required for a particular resistance (and hence heat) or for the same length of the wire and the current, heat produced will be more.
2. **High Melting Temperature**. If the melting temperature of the heating element is high. it would be possible to obtain higher operating temperatures.
3. **Low Temperature Coefficient of Resistance**. In case the material has low temperature coefficient of resistance, there would be only small variations in its resistance over its normal range of temperature. Hence, the current drawn by the heating element when cold would be practically the same when it is hot.
4. **Oxidising Temperature**. Oxidisation temperature of the heating element should be high in order **to** ensure **longer** life.
5. **Positive Temperature Coefficient of Resistance**. If the temperature coefficient of the resistance of heating element is negative, its resistance will decrease with rise in temperature and it will draw more current which will produce more wattage and hence heat. With more heat, the resistance will decrease further resulting in instability of operation.
6. **Ductile.** Since the material of the heating elements has to have convenient shapes and sizes. It should have high ductility and flexibility.
7. **Mechanical Strength.** The material of the heating clement should possess high mechanical strength of its own. Usually different types of alloys arc used to get different operating temperatures.
   For example maximum working temperature of *constant*an (45% Ni, 55% Cu) is 400°C that of *nichrome* (50% Ni, 20% *Cr)* is 1150°C
   With the passage of time every heating clement breaks open and becomes unserviceable.

Some of the factors responsible for its failure are:

(1) **Formation of hot spots which shine brighter during operation**,
Hot spots are the points in heating element that are at higher temperatures than that of the body of the element. The hot spots are due to

- High rate of local oxidation which may reduce the cross section.
- Poor heat radiation at those points due to shielding by supports.
- Sagging and warping may result in uneven spacing leading to high temperature at the points.

(2) **Oxidation**

- At high temperature oxide scale is formed on the surface. This prevents future oxidation of the inner metal. However, when the element is subjected to frequent cooling and heating, it leads to **thermal stress**. Thus the oxide scale cracks off exposing further fresh metal to oxidation. This local oxidation develops **hot spots**.

(3) **Corrosion**

- Elements may be subjected to dry corrosion leading to uneven temperature.

(4) **Mechanical failure**

(5) **Embrittlement due to grain and growth**

- All heating alloys form large brittle grains at high temperature.

1.2 Resistance Furnaces or Ovens

1. 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.. Stoving of enamelled wares, drying and baking of potteries, vulcanizing and hardening of synthetic materials and for commercial and domestic heating.
2. 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.**
3. Heating elements may consist of circular wires or rectangular ribbons. The ovens arc usually made of a metal framework having an internal lining of fire bricks.
4. The heating clement 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.**

1.2.1 Applications of Resistance ovens:

1. Bright Annealing

1. The process of annealing is eliminating brittleness and removing stains from the metals by heating and followed by slow cooling. This leaves the charge with scale of oxide.
2. To get bright finish it is required to remove the scale of oxide. The formation of scale is due to the oxygen, carbon dioxide and water vapours in atmosphere. This is achieved by expelling out the air during heating through valves.
3. On cooling, the valves are closed thereby preventing access of oxygen and other gases to the charge. This ensures the retention of bright surface.

2. Air circulation ovens

1. In ordinary ovens the heat is directly transferred to the charge entirely by radiation. There is a chance of considerable temperature difference in various parts of the charge.
2. An air circulation oven can be employed to heat the charge uniformly up to 600° C. Air is passed over the heating elements and becomes hot.
3. This hot air is circulated over the charge to import its heat. The direction of air flow can be changed from bottom to top and vice versa to avoid uneven heating.

3. Salt bath heating

1. In order to avoid oxidation during hardening, a salt bath furnace is used.The charge is heated by immersion in molten sodium chloride or some other suitable salt.
2. The fusing point of such salt is approximately 1000° C and can be heated to a temperature of 1500° C. By supplying electric current between electrodes immersed in the salt. Such an arrangement is known as salt bath furnace.

1.2.2 Temperature Control of Resistance Furnaces

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

Following different methods are used for the above purpose:

1. **Supply voltage**
   - Resistance ovens are fed from low voltage 240V or 415V. D.C supply can also be used. The ovens are usually 50kW to 60kW, but in certain cases upto 300kW.
   - The change in the current is obtained by changing the tappings of transformer and by using auto transformer. Sometimes series inductance is connected to divide the voltage.

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

3. **Change in connection**
   - The elements may be connected in series or parallel or series-parallel. In certain cases elements are connected either in star or delta as shown in Fig 1.5.

4. **Automatic control**
    - When automatic control is required, the temperature sensors are used. For example a thermostat employed operated the relay when the temperature exceeds certain preset value. The switching is carried out by contactors.
5. **Protection of equipment**
    - Protection against over current, excess temperature is required when the charge falls below certain level. Sometimes failure of automatic temperature control would result in excessive temperature, which might impair the life of the elements or damage the charge.
    - Protection can be affected by the use of fuse placed inside and connected in the main over circuit or in the hold on coil of the energising contactors.
6. **Intermittent Switching.**
    - In this case, the furnace voltage is switched ON and OFF intermittently.
    - When the voltage supply is switched off, heat production within the surface is stalled and hence its temperature is reduced.
    - When the supply is restored, heat production starts and the furnace temperature begins to increase. Hence, by this simple method, the furnace temperature can be limited between two limits.
7. **Variation in Circuit Configuration.**
    - In the case of 3-phase secondary load, the heating elements give less heat when connected in a star than when connected in delta because in the two cases, voltages across the elements is different.
    - In single-phase circuits, series and parallel grouping of the heating elements causes change in power dissipation resulting in change of furnace temperature.
    - Heat produced is more when all these elements arc connected in parallel than when they are connected in series or series-parallel.
8. **Change of Applied Voltage.**
    - *Lesser* the magnitude of the voltage applied to the load, lesser the power dissipated and hence, lesser the temperature produced.
    - In the case of a furnace transformer having high voltage primary, the tapping control is kept in the primary winding because the magnitude of the primary current is less. Consider the multi-tap step-down transformer shown in **Fig. 1.6.**

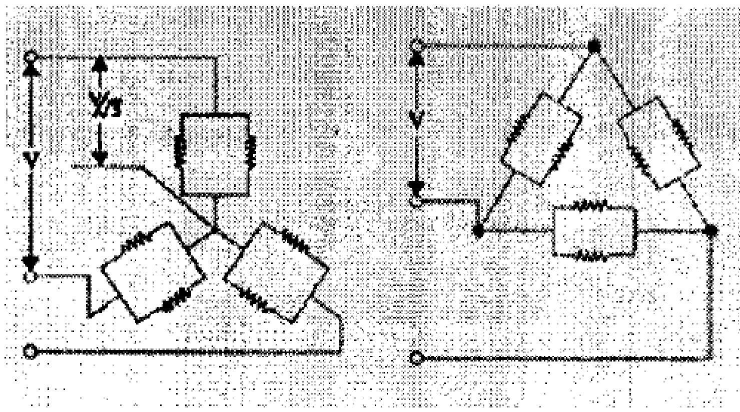


Fig1.5

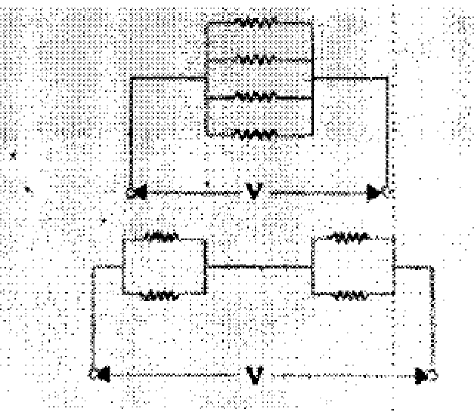


Fig1.6

- **Bucking-Boosting the Secondary Voltage**. In this method, the transformer secondary is wound in two sections having unequal number of turns. If the two sections are connected in series aiding. The secondary voltage is boosted *i.e.,* increased to (E2 + E3)
  When the two sections are connected in series-opposing the secondary voltage is reduced *i.e.,* there is bucking effect. Consequently, furnace voltage becomes (E2 - E3) .and, hence, furnace temperature is reduced.

9. **Autotransformer Control.** Tapped autotransformer can be used for decreasing the furnace voltage and, hence temperature of small electric furnaces. The required voltage can be selected with the help of a voltage selector.

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

1.2.3 Losses and efficiency

The loss of heat in resistance oven occurs due to

- Heat required to raise the temperature of the oven to the operating value. This depends upon the weight and specific heat of the refractory lining etc.

$$h_{1=} \textbf{ weight of oven x specific heat x rise in temperature}.$$

- Heat required to raise the temperature of the containers. This loss appears when oven starts from cold. If the oven is working for weeks together this loss becomes negligible.

$$\mathbf{h_{2=}}\ \textbf{weight of containers x specific heat x rise in temperature}.$$

- The loss of heat through the walls is a continuous loss that takes place as long as the oven works. This loss is given by:

$$\boldsymbol{h_3 = \frac{kA}{t}(\theta_1 - \theta_2)}\ \textbf{CHU}$$

CHU-Centigrade heating unit

Where k= thermal conductivity in CHU per hour per square meter per cm per˚C

t= thickness of walls in cm

A= wall area in sq-cm

θ_1 =inside temp in ˚C

θ_2 = outside temp in ˚C

- Loss of heat on opening of the door for charging and inspection purpose. This can be estimated by experience and cannot be calculated.

Then the efficiency of the oven is

$$= \frac{h}{h+h_1+h_2+h_3+h_4}$$

h = the temperature to which the charge is to be heated and is given by

h =**weight of charge x specific heat x rise in temperature**.

Efficiency of such furnace will be 60% - 80%

1.2.4 Design of Heating Element

Normally, **wires of circular cross-section or rectangular conducting ribbons** are used as heating elements. Under steady-state conditions, a heating element dissipates as much heat from its surface as it receives the power from the electric supply.

Circular heating element

If *P* is the power input and *H is* the heat dissipated

by radiation, then *P* = *H* under steady-state conditions.

Let V= System voltage
R= resistance of the heating element
ρ =specific resistance
l = length of the heating element
d=diameter of the heating element

As per Stefan's law of radiation, heat radiated by a hot body is given by:

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

where $T1$ is the temperature of hot body in °K and $T2$ that of the cold body (or cold surroundings) in °K

$$\text{Now,}\quad P = \frac{V^2}{R}, \quad \text{and} \quad R = \rho\frac{l}{A} = \rho\frac{l}{\pi d^2/4} = \frac{4\rho l}{\pi d^2}$$

$$\therefore \quad P = \frac{V^2}{4\rho l/\pi d^2} = \frac{\pi d^2 V^2}{4\rho l} \quad or \quad \frac{l}{d^2} = \frac{\pi V^2}{4 l \rho}$$

Total surface area of the wire of the element = ($\prod d$) × l……………………………………i

If H is the heat dissipated by radiation per second per unit surface area of the wire, then heat radiated per second = ($\prod d$) × l × H……………ii

Equating (i) and (ii), we have

$$P = (\pi d) \times l \times H \quad \text{or} \quad \frac{\pi d^2 V^2}{4\rho l} = (\pi d) \times H \quad \text{or} \quad \frac{d}{l^2} = \frac{4\rho H}{V^2} \qquad \ldots\ldots\ldots\ldots iii$$

We can find the values of l and d from Eq. (i) and (iii) given above.

Ribbon Type Element

If w is the width of the ribbon and t its thickness, then

$$P = \frac{V^2}{R} = \frac{V^2}{\rho l/A} = \frac{V^2}{\rho l/Twt} = \frac{wtV/^2}{\rho l} \quad or \quad \frac{t}{wt} = \frac{V^2}{\rho P} \qquad \ldots\ldots\ldots\ldots iv$$

Heat lost from ribbon surface = 2wl H (neglecting the side area 2tl)

$$\therefore \quad \frac{wtV^2}{\rho l} = 2wlH \quad \text{or} \quad \frac{t}{l^2} = \frac{2\rho H}{V^2} \qquad \ldots\ldots\ldots\ldots v$$

Values of l and w for a given ribbon of thickness t can be found from Eqn. (iv) and (v) given above.

1.3 Arc Furnaces

1. 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.
2. When electrodes are made of carbon/graphite, the temperature obtained is in the range of **3000°C-3500 ° C**. 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. 1.10

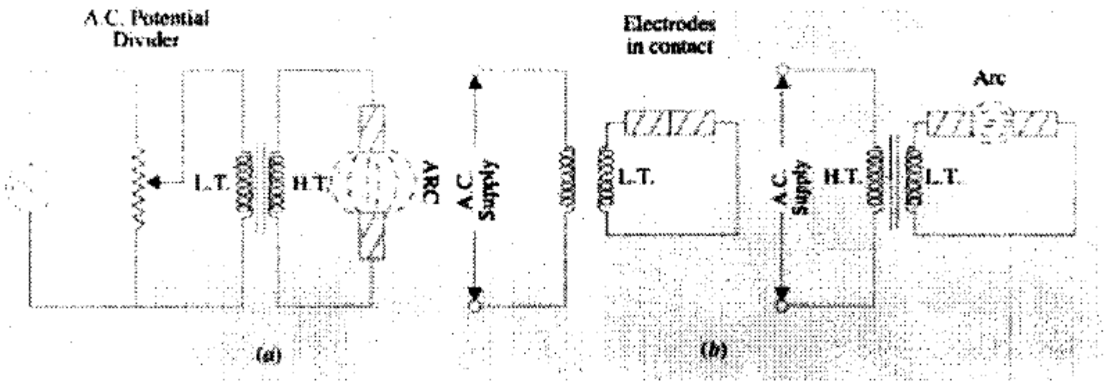


Fig1.10

3. All arc can also be obtained by using low voltage across two electrodes initially in contact with each other as shown in Fig. 1.10 *(b).* The low voltage required for this purpose can be obtained by using a step-down transformer. Initially, the low voltage is applied, when the two electrodes are in contact with each other. Next, when the two electrodes are gradually separated from each other. an arc is established between the two.

Arc furnaces can be of the following two types:

1. **Direct 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. Such furnaces produce very high temperatures. The construction is shown in **Fig 1.11(a).**
   - It could be either of conducting-bottom type [**Fig. 1.12 *(a)*]** or non-conducting bottom type [**Fig. 1.12 *(b)*].**
   - *As* seen from **Fig. 1.12 *(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. 1.12 *(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 arc of non-conducting bottom type due to insulation problem faced in case of conducting bottom.

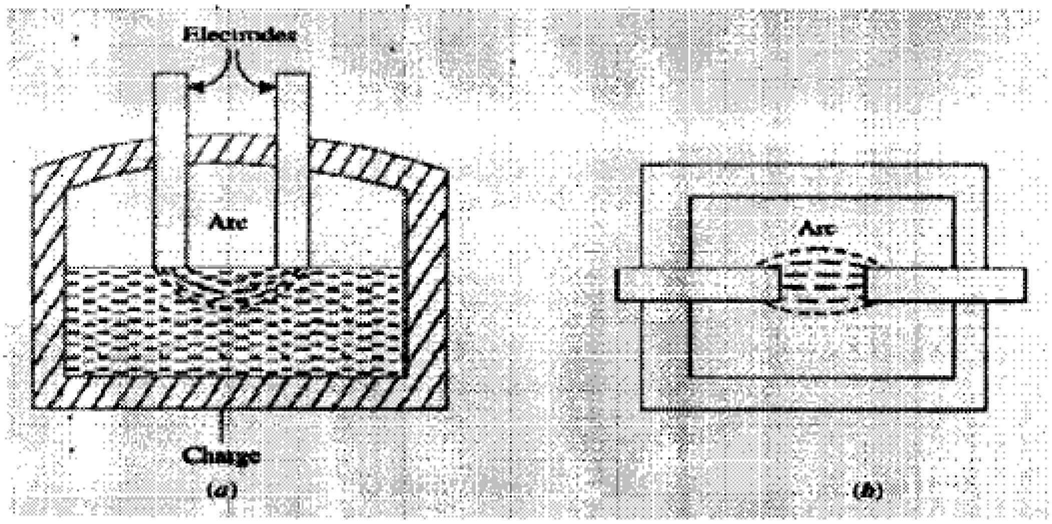


Fig1.11

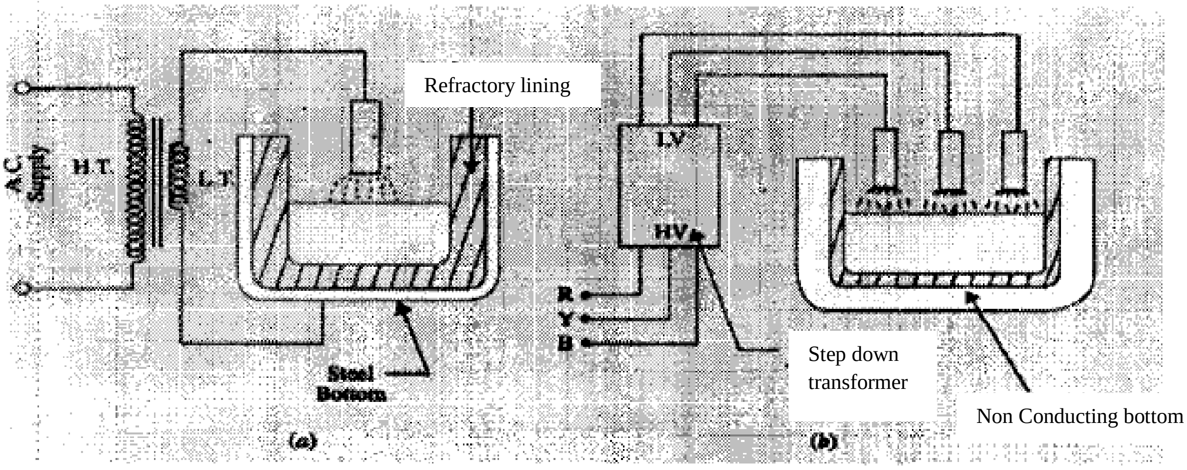
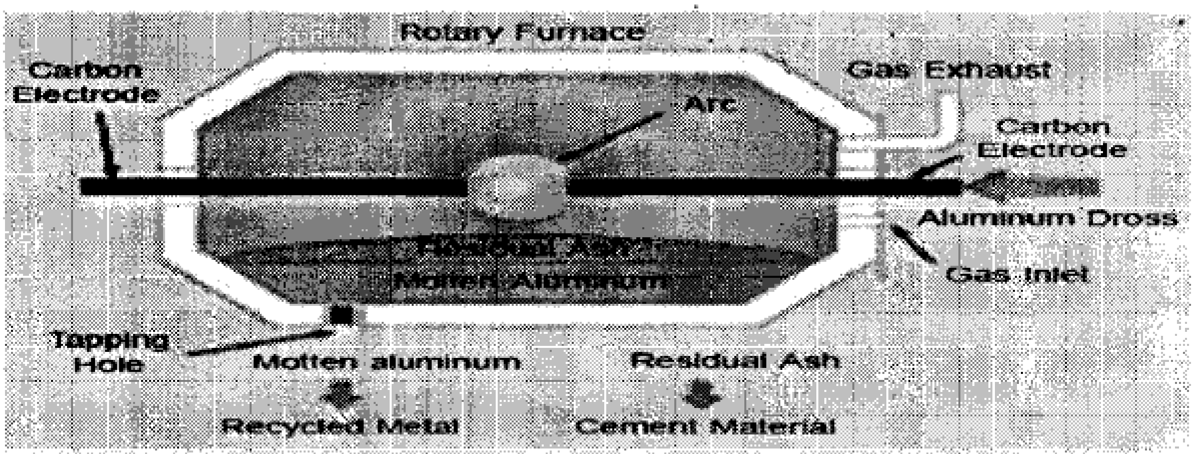


Fig 1.12

2. Indirect Arc Furnace

- 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. *1.11.(b).***
- **Fig. 1.13** 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 arc mainly used for melting nonferrous metals although they can be used in iron foundries where small quantities of iron are required frequently.



Schematic view of an indirect electric arc furnace

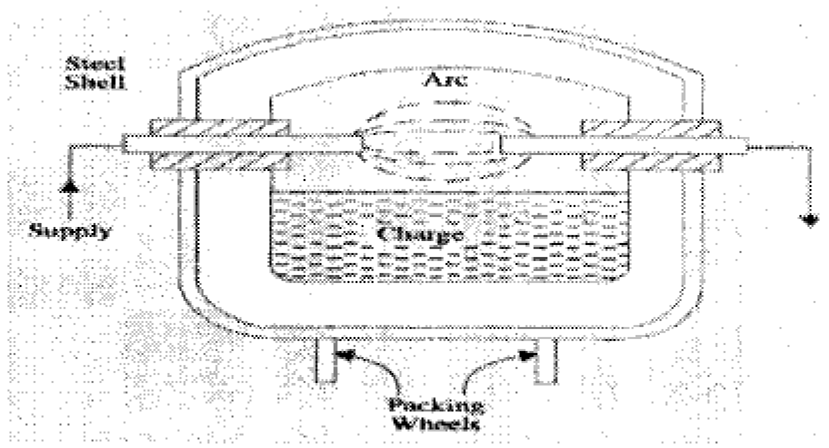


Fig1.13

1.4 Induction Heating

1. This heating process makes use of the currents induced by the electro-magnetic action in the charge to be heated induction heating is based on the principle of transformer working.
2. 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.
3. 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.
4. **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.

1. **Core-type Furnaces** - which operate just like a two winding transformer. These can be further sub-divided into
   a. **Direct core-type furnaces**
   b. **Vertical core-type furnaces** and
   c. **Indirect core-type fumaces.**
2. **Coreless-type Furnaces -** in which an inductively-heated element is made to transfer heat to the charge by radiation.

\

a. Core Type Induction Furnace: Direct core type

1. It is shown in Fig. 1.14 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.

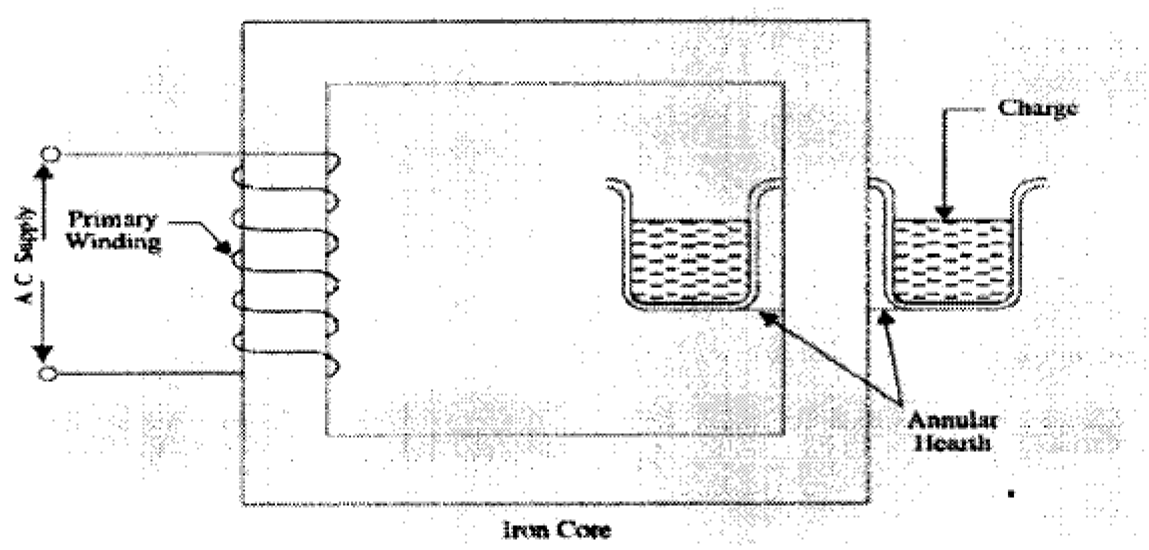


Fig1.14

2. 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 molted metal has to be poured in the annular hearth.
3. 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.**

This furnace suffers from the following drawbacks:

I. It has to be run on low-frequency supply which entails extra expenditure on motor-generator set or frequency convertor.

2. It suffers from pinching effect.

3. The crucible for charge is of odd shape and is very inconvenient for tapping the molten charge.

4. It does not function if there is no molten metal in the hearth *i.e.* when the secondary is open. Every time molten metal has to be poured to start the furnace.

5. It is not suitable for intermittent service. However, in this furnace, melting is rapid and clean and temperature can be controlled easily. Moreover, inherent stirring action of the charge by electro-magnetic forces ensures greater uniformity of the end product.

b.Vertical Core-Type Induction Furnace

1. It is also known as **Ajax-Wyatt furnace** and represents an improvement over the core-type furnace discussed above.

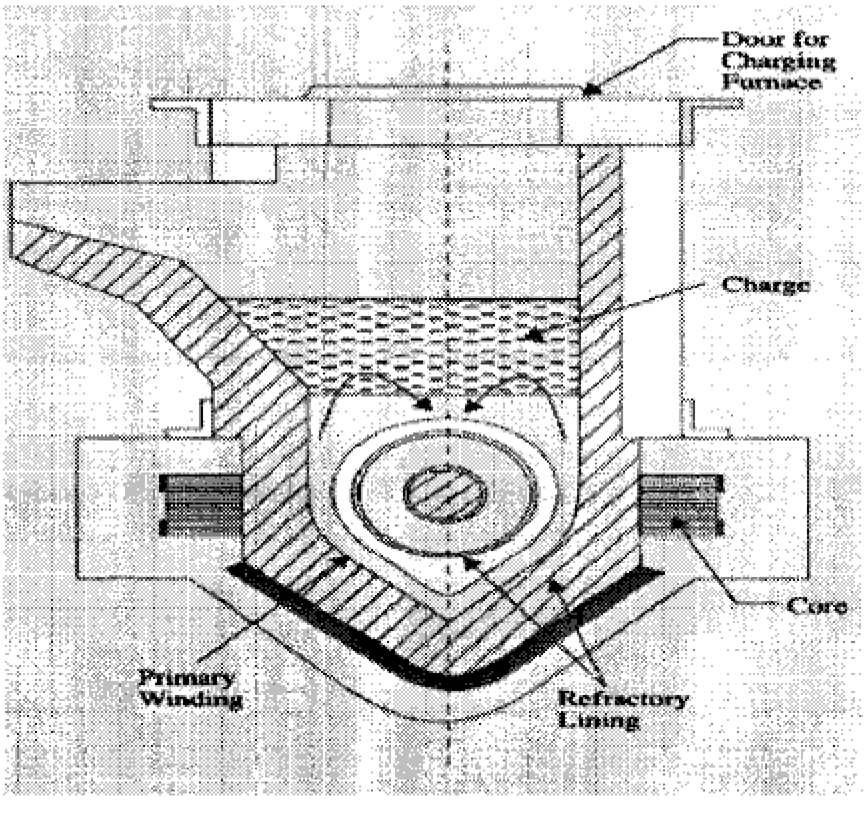


Fig1.15

2. As shown in **Fig1.15.,** 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 fumace magnetic coupling is comparatively better and power factor is high. Hence, it can be operated from normal frequency supply.
3. The circulation of the molten metal is kept up round the Vee portion by convection currents as shown in Fig. 1.15. 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.

4. 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.
5. The choice of material for inner lining of the fumace 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.
6. This furnace is widely used for melting and refining of brass and other non-ferrous metals. 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.

c. Indirect Core-Type Induction Furnace

In this furnace, a suitable clement 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.

1. As shown in Fig. 1.16, 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.
2. When primary winding is connected to A.Csupply, 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.
3. A special advantage of this furnace is that its temperature can be automatically controlled without the use of 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.
4. 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.

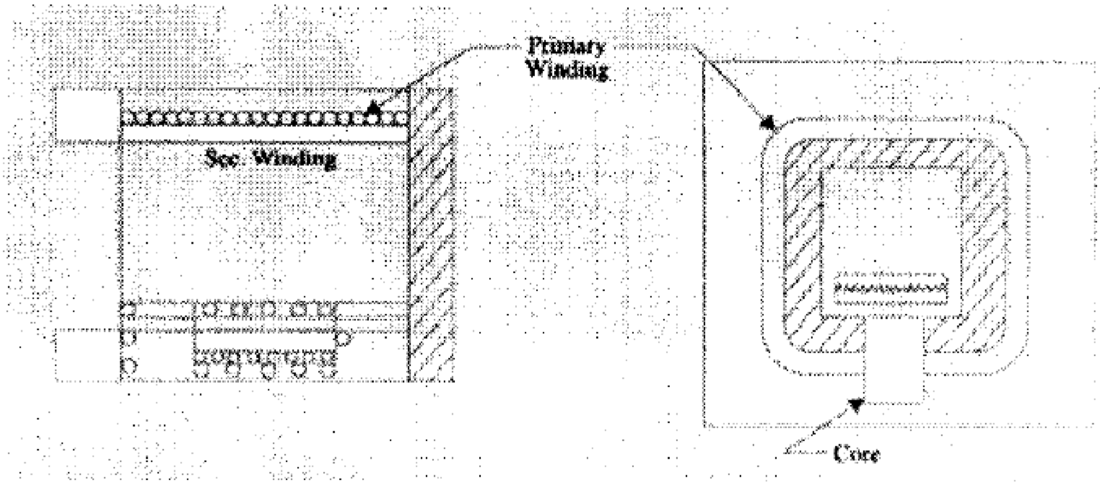
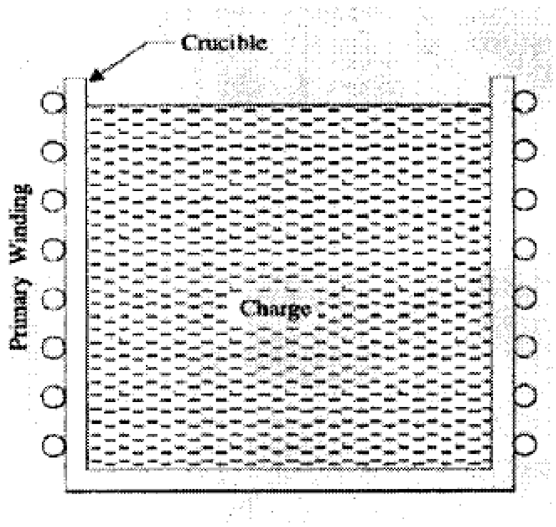


Fig1.16

2. Coreless Induction Furnace

1. As shown in Fig. 1.17, 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.
2. The distinctive feature of this fumace 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.
3. The charge is put into the crucible and primary winding is connected to a high-frequency A.C supply. The flux produce by the primary sets 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.
4. Since flux density is low (due to the absence of the magnetic core) high frequency supply has to be used because eddy-current loss.
5. 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.
6. 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.
7. Such furnaces arc 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.



8. Fig1.17

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 **core less induction furnaces** arc 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 he used for all industrial applications requiring heating and melting.

(6) They have low erection and operating costs.

(7) Their charging and pouring is simple.

1.5 High Frequency Eddy-current Heating

1. For heating an article by eddy-currents, it is placed inside a high frequency A.C current-carrying coil (Fig. 1.18).
2. The alternating magnetic field produced by the coil sets up eddy-currents in the article which consequently, gets heated up. Such a coil is known as heater coil or work coil and the material to be heated is known as ***charge or load.***
3. Primarily it is the eddy-current loss which is responsible for the production of heat although hysteresis loss also contributes to some extent in the case of non-eddy-current loss.

4. We α B^2 f^2 .Hence, this loss can be controlled by controlling flux density B and the supply frequency .f. This loss is greatest on the surface of the material but decreases as we go deep inside. The depth of the material upto which the eddy-current loss penetrates is given by

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu_r . f}}$$

where ρ = resistivity of the molten metal

f = supply frequency

μ_r = relative permeability of the charge

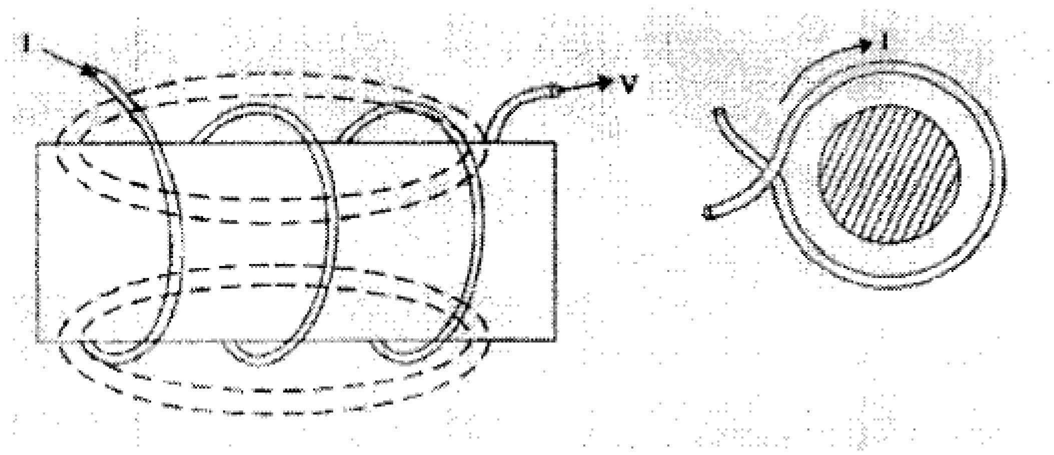


Fig1.18

Choice of Frequency: Induction Heating.

The selection of frequency for heating is important because it has a great bearing on the work to be heated and the method of its heating whether by induction heating or dielectric heating. Furnaces running on power frequency of 50 Hz can be of I MW capacity whereas those running on medium frequencies (500 Hz to 1000 Hz) have a capacity of 50 kW and those running on high frequency **(1MHz to 2 MHz)** have capacities ranging from 200 kW to 500 kW.

While choosing frequency for induction heating, the following factors arc

(a) Thickness of the surface to be heated. Higher the frequency, thinner the surface that will get heated.

(b) The time of continuous heating. Longer the duration of heating, deeper the penetration of heat in the work due to conduction.

(c) The temperature to be obtained. Higher the temperature, higher the capacity of the generator required.

Advantages of Eddy-current Heating

1. There is negligible wastage of heat because the heat is produced in the body to be heated.
2. It can take place in vacuum or other special environs where other types of heating are not possible.
3. Heat can be made to penetrate any depth of the body by selecting proper supply frequently.

Applications of Eddy-current Heating

(1) **Surface Hardening.** The bar whose surface is to be hardened by heat treatment is placed within the working coil which is connected to an A.Csupply of high frequency. The depth upto which the surface is to be hardened can be obtained by the proper selection of frequency of the coil current, After a few seconds, when surface has reached the proper temperature, A.C supply is cut off and the bar is at once dipped in water.

(2) **Annealing**. Normally, annealing process takes long time resulting in scaling of the metal which is undesirable. However, in eddy-current heating, time taken is much less so that no scale formation takes place.

(3) **Soldering.** Eddy-current healing is economical for precise high-temperature soldering where silver, copper and their alloys are used as solders.

1.6 Dielectric Heating

1. 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.
2. 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, 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. 1.19 *(a)*.
- Fig. 1.19 (b) shows the equivalent circuit of the capacitor and Fig. 1.19 (e) gives its vector diagram 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^2f .That is why high-frequency voltage is used in dielectric heating. Generally, A.Cvoltage of about **20 Kv** at a frequency of **10-30 MHz** is used.

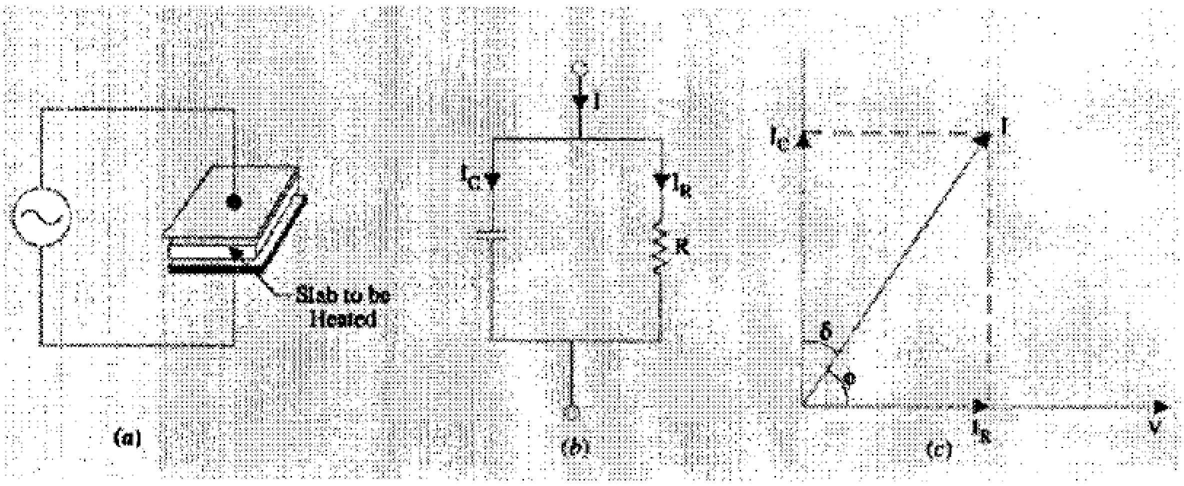


Fig1.19

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

Applications of Dielectric Heating

Since cost of dielectric heating is very high, it is employed where other methods are not possible or are too slow. Some of the applications of dielectric heating are as under:

1. For gluing of multilayer plywood boards.
2. For baking of sand cores which an; used in the moulding process.
3. For preheating of plastic compounds before sending them to the moulding section.
4. For drying of tobacco after glycerine has been mixed with it for making cigurattcs.
5. For baking of biscuits and cakes etc. in bakeries with the help of automatic machines.
6. For electronic sewing of plastic garments like raincoats etc. with the help of cold rollers fed with high-frequency supply.
7. For dehydration of food which is then sealed in air-tight containers.
8. For removal of moistures from oil emulsions.
9. In diathermy for relieving pain in different parts of the human body.
10. For quick drying of glue used for book binding purposes.

1.7 Infrared Heating

- When tungsten filament lamps arc operated at about 2300°C (instead of 3000°C), they produce plenty of heat radiations called ***infrared radiations***. With the help of suitable reflectors, these infrared radiations arc focused on the surface to be heated. The lamps so employed have ratings varying from 250 W to 1000 W operating at 115 W.
- Lower voltage results in robust filaments. With this arrangement, the charge temperature obtain is between 200°C and 300°C. The heat emission intensity obtained is about 7000 *W/m2* as compared to 1500*W/m2* obtained with ordinary resistance furnaces.
- In this type of heating, heat absorption remains practically constant whatever the charge temperature whereas it falls rapidly as the temperature of charge rises in the ordinary resistance furnace. Infrared heating is used for paint drying and for drying foundary moulds, for low temperature heating of plastics and for various dehydration and other processes.

1.8 ELECTRIC WELDING

Definition of Welding

"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.

(ii) Gas welding and thermit 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.

Electrical Welding Classification

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 $I^2 Rt/J$ kilocalories"

- **Butt welding** which could be further subdivided into **flash welding, upset welding and stud welding** etc.
- **Spot Welding**
- **Seam Welding**
- **Projection welding**

2. Arc welding

"Here electricity is **conducted in the form of an arc** which is established between the two metallic surfaces"

- **Carbon arc welding, Metal arc welding**
- **Automic Hydrogen and helium, argon arc**

1. Resistance Welding

1. 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.
2. 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.
3. According to Joule's law, heat produced electrically is given by $H = I^2Rt/J$.
4. The amount of heat produced depends on.
   (i) Square of the current
   (ii) The time of current and
   (iii) The resistance offered.
5. 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.

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.

Disadvantages

1. High initial as well as maintenance cost.

a. Butt Welding

1. 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.
2. As in other forms of resistance welding, the weld heat is produced mainly by the electrical resistance of the joint faces.

3. 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. 1.53].
4. 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.**

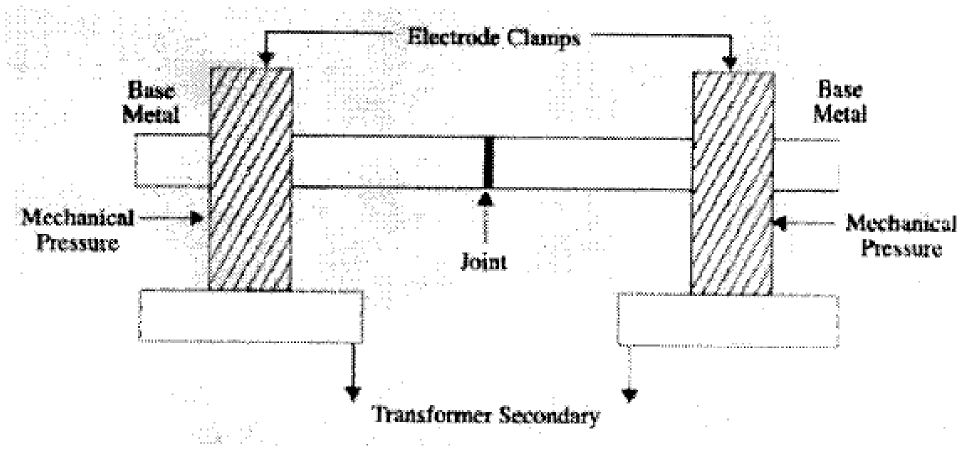


Fig 1.53

b. Spot Welding

- 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.
- The process depends on two factors:
    1. Resistance heating of small portions of the two work pieces to **plastic state** &
    2. Application of **forging pressure** for welding the two work pieces.
- Heat produced is $H = I^2 Rt/J$. The resistance R is made up of
    1. Resistance of the electrodes and metals themselves
    2. Contact resistance between electrodes and work pieces and
    3. Contact resistance between the two work pieces. Generally, contact resistance between the two work pieces is the greatest.
- As shown in **1.48 *(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. *1.48(a)*** shows diagrammatically the basic parts of a modem spot welding. It consists of a step-down transformer which can supply huge currents (up to 5,000 A) for short duration of time.
- The **lower arm is fixed** whereas the **upper one is movable**. The electrodes are made of low resistance, hard-copper alloy and are either air cooled or butt-cooled by water circulating through the rifled drillings in the electrode.

- Pointed electrodes 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.
- The welding machine is cycled in order to produce the required heat timed to coincide with the pressure exerted by the electrodes is shown in Fig. 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 upto 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 300 strokes minute are common.

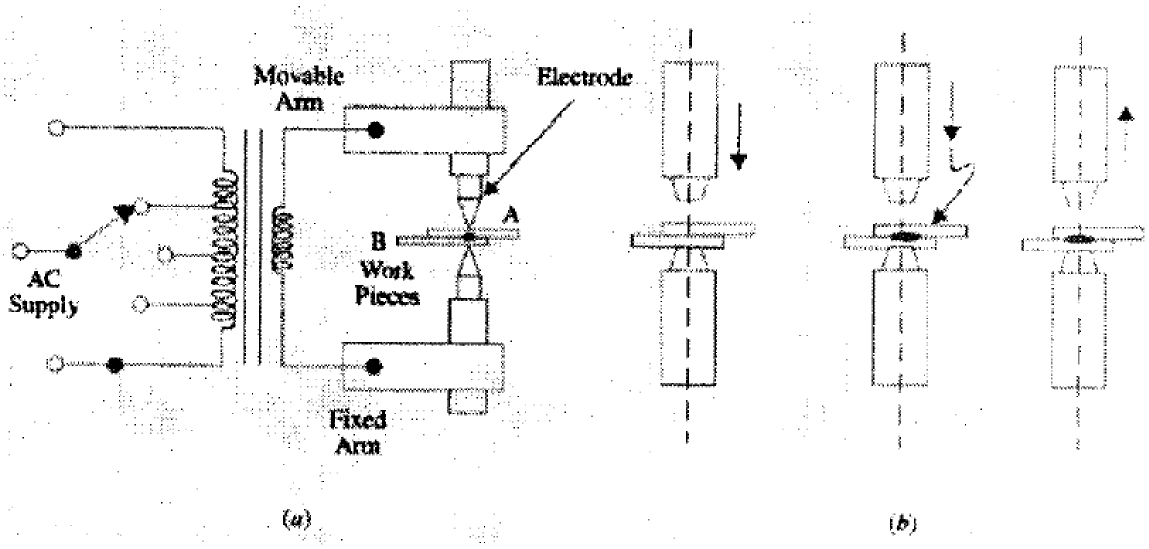


Fig: 1.48

Advantages

- 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.

Applications

- 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

c. Projection Welding

- It can be regarded as a **<u>mass-production form of spot welding</u>**. 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.
- As seen in Fig 1.51 , the upper and lower platens are connected across the secondary of a stepdown 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.

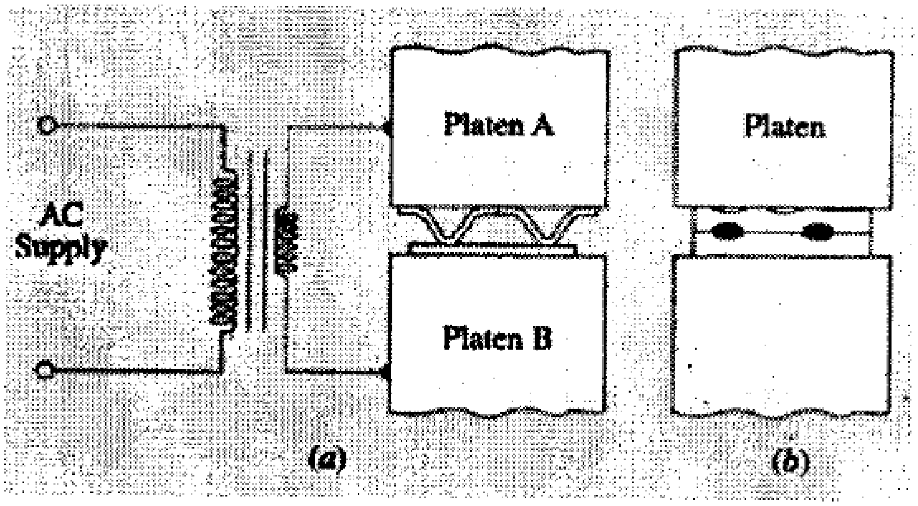


Fig1.51

Advantages:

I. They increase the welding resistance of the material locally.

2. They accurately locate the positions of the welds.

3. They speed up the welding process by making it possible to perform several small welds simultaneously.

4. They reduce the amount of current and pressure needed to form a good bond between two surfaces.

5. They prolong the life of the electrode considerably because the metal itself controls the heat produced.

Applications

- 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.

Note: Additional Info

A variation of projection welding is the metal fibre welding which uses a metal fibre rather than a projection point (Fig. 1.52). This metal fibre is generally a felt material. Instead of projections, tiny elements of this felt material arc placed between the two metals which arc then projection-welded in the usual way

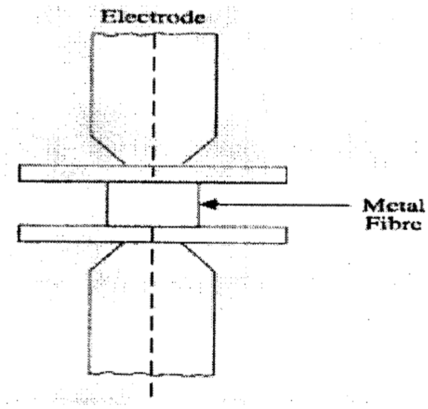
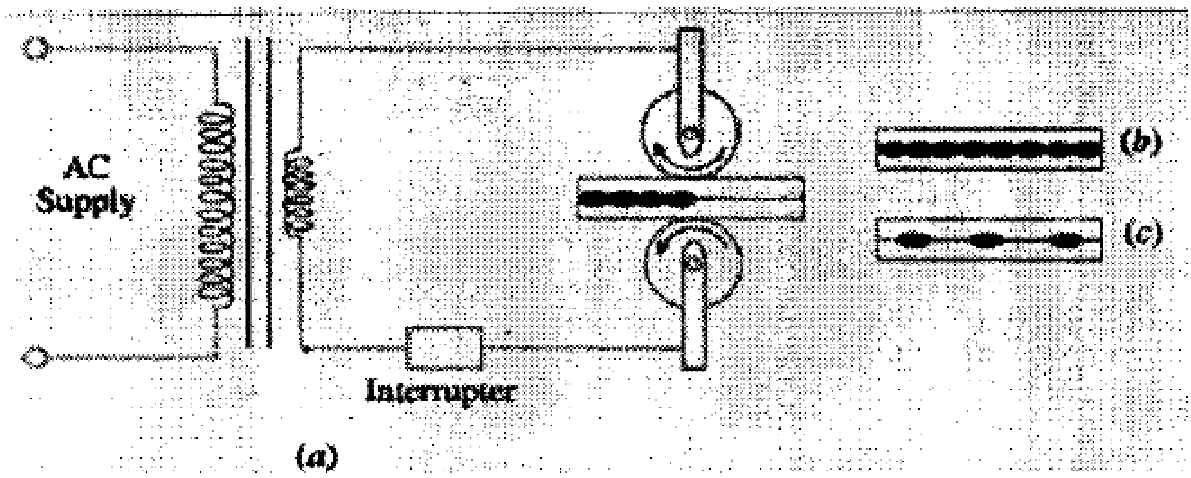


Fig 1.52

d. Seam Welding

1. 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. 1.50 *(a).*
2. These copper wheels are power driven and rotate whilst gripping the work.
3. The current is so applied through the wheels that the weld spots either overlap as in Fig. 1.50 *(b)* or are made at regular intervals as in Fig. 1.50 *(c).* The continuous or overlapped seam weld is also called ***stitch weld*** whereas the other is called **roll weld.**
4. **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 hardenability rating such as hot-rolled grades of low alloy steels.
5. 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.



NOTE: Additional information

Butt welding classification

a. Flash Butt Welding

1. It is also called by the simple name of *flash welding,* It is similar to butt welding but with the difference that here current is applied when ends of the two metal pieces are quite close to each other *but do not touch intimately.*
2. Hence, an arc or flash is set up between them which supplies the necessary welding heal. As seen, in the process heat is applied *before* the two parts arc pressed together.
3. As shown in Fig. 1.54 *(a),* the work pieces to be welded are clamped into specially designed electrodes one of which is fixed whereas the other is movable. After the flash has melted their faces, current is cut off and the movable platen applies the forging pressure to form a fusion weld.
4. As shown in Fig. 1.54 (b), there is increase in the size of the weld zone because of the pressure which forces the soft ends together

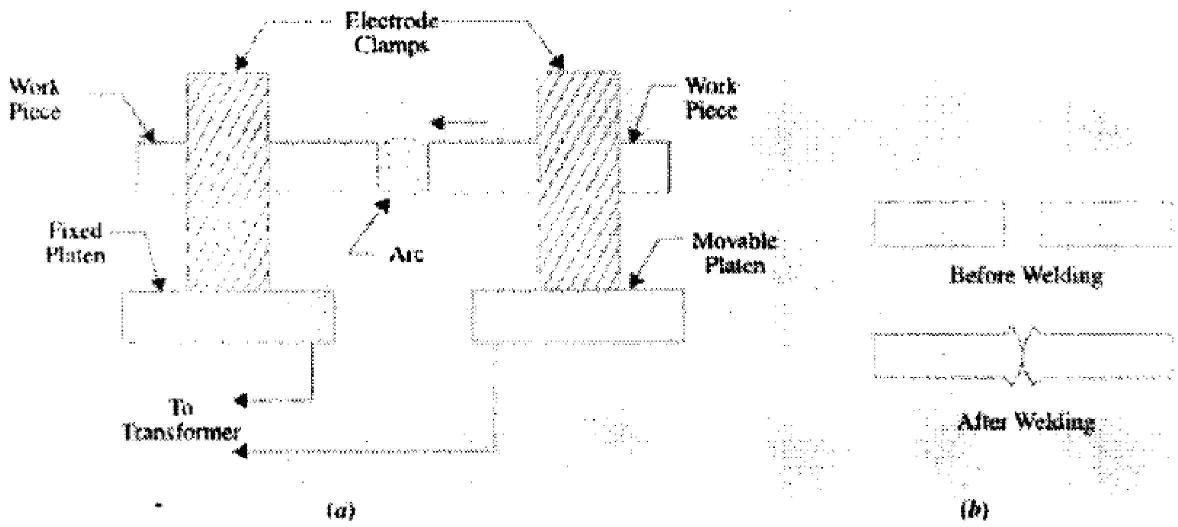


Fig 1.54

b.Upset Welding

1. In this process, *no flash is allowed to occur* between the two pieces of the metals to be welded. When the two base metals are brought together to a single interface, heavy current is passed between them which heats them up.
2. After their temperature reaches a value of about 950°C, the two pieces of base metal are pressed together more firmly. This pressing together is called ***upsetting***.
3. This upsetting takes place *while current is flowing and continues even after current is switched off.* This upsetting action mixes the two metals homogeneously while pushing out many atmospheric impurities.

c. Stud Welding

(a) Basic Principle

It is similar to flash welding because it incorporates a method of drawing an arc between the stud (a rod) and the surface of the: base metal. .Then, the two molten surfaces are brought together under pressure to form a weld. Stud welding eliminates the need for drilling holes in the main structure.

(b) Welding Equipment

The stud welding equipment consists of a stud welding gun, a D.C. power supply capable of giving currents up to 400 A, a device to control current and studs and ferrules which are used not only as arc shields but also as containing walls for the molten metal.

(c) Applications

It is a low-cost method of fastening extensions (studs) to a metal surface. Most of the ferrous and non-ferrous metals can be stud-welded successfully. Ferrous metals include stainless steel, carbon steel and low-alloy steel. Non-ferrous metals include aluminium, lead-free brass, bronze and chrome plated metals. Stud welding finds application in the installations of conduit pipe hangers, planking and corrugated roofing's. This process is also used extensively in shipbuilding, railroad and automotive industries.

a. Carbon Arc Welding

(a) General

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

(b) Welding Circuit: Working

1. The basic circuit is shown in Fig. 1.34 and can be used with D.C. as well as A.C supply. When direct current is used, the electrode is **mostly negative**.
2. The process is started by adjusting the amperage on the D.C. welder, turning welder ON and bringing the electrode into contact with the workpiece.
3. After the arc column starts, electrode is withdrawn 25 - 40 mm away and the arc is maintained at this distance. The arc can be extinguished by simply removing the electrode from the workpiece completely.
4. The only function of the carbon arc is to supply heat to the base metal. This heat is used to melt the base metal or filler rod for obtaining fusion weld Depending on the type and size of electrodes maximum current values range from 15 A to 600 A for single-electrode carbon arc welding.

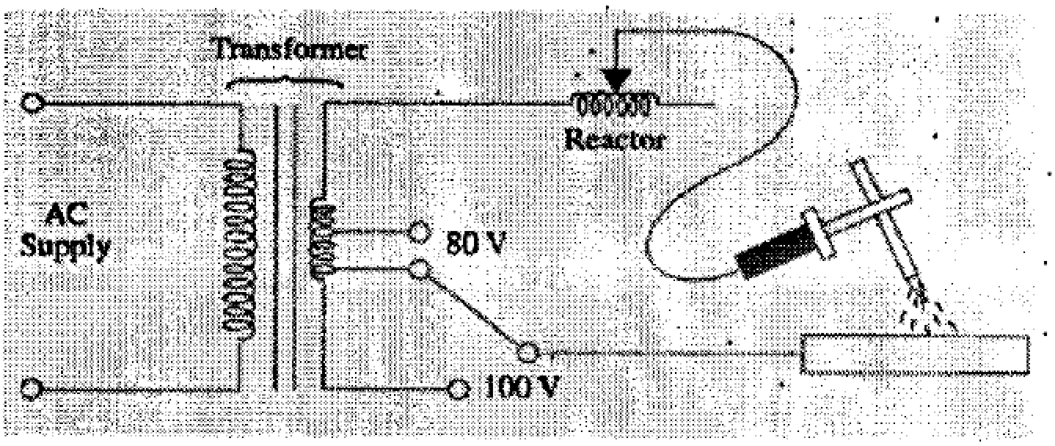


Fig1.34

(c) Electrodes

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

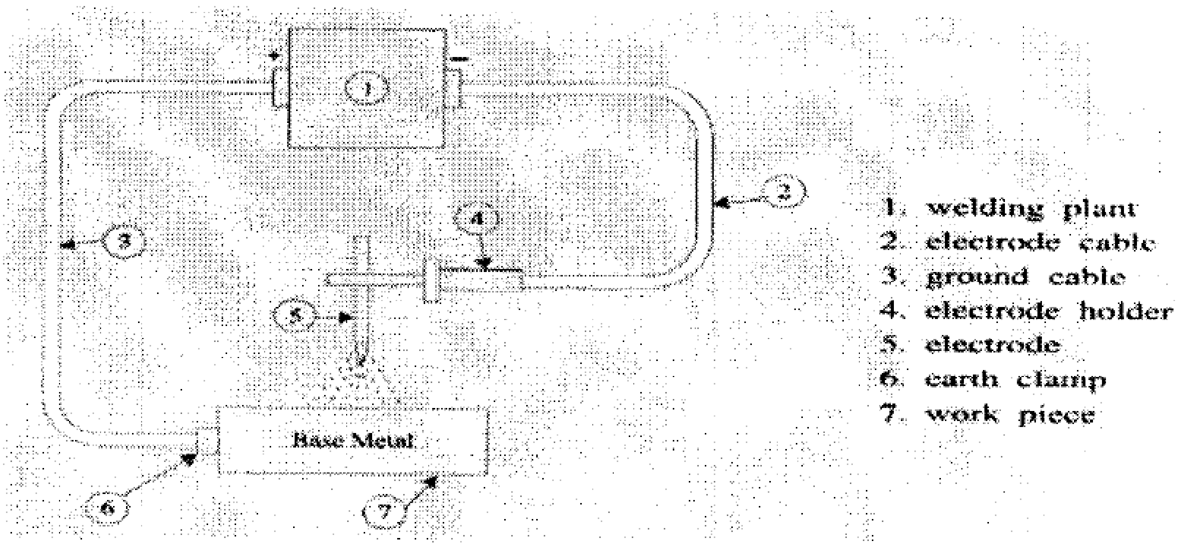


Fig1.35

(d) Applications

a. The joint designs that can be used with carbon arc welding are butt joints, bevel joints, flange joints, lap joints and fillet joints.
b. This process is easily adaptable for automation particularly where amount of weld deposit is large and materials to be fabricated arc of simple geometrical shapes such as water tanks.
c. It is suitable for welding galvanised sheets using copper-silicon-manganese alloy filler metal.
d. It is useful for welding thin high-nickel alloys.
e. Stainless steel of thinner gauges is often welded by the carbon-arc process with excellent results.

(e) Advantages and Disadvantages

The main **advantage** of this process is that

a. The temperature of the molten pool can be easily controlled by simply varying the arc length.
b. It is easily adaptable to automation.

c. It call be easily adapted to inert gas shielding of the weld
d. It call be used as all excellent heat source for brazing, braze welding and soldering etc.

Disadvantages:

a. A separate filler rod has to be used if any filler material is required.
b. Since arc serves only as a heat source, it does not transfer any metal to help reinforce the weld joint.
c. 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.

Metal Arc welding

Formation and Characteristics of Electric Arc

a. An electric arc is formed whenever electric current is passed between two metallic electrodes which are separated by a short distance from each other.
b. 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.
c. When electrode first touches the plate, a large short-circuit 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.
d. Due to this spark (or discharge), the air in the gap becomes ionized *i.e.* is split into **negative electrons and positive ions.**
e. Consequently, air becomes conducting and current is able to flow across the gap in the form of an arc.

1. As shown in Fig. 1.23, the arc consists of ***lighter* electrons** which flow from cathode to anode and ***heavier positive ions*** which flow from anode to cathode.
2. 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.
3. 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.
4. 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.
5. If positive supply end is connected to the base metal (which is normally grounded), penetration will be greater **due to more heat** and, at the same time, the electrode will burn away slowly [Fig. 1.23((a))].since it is connected to the negative end of the supply. If supply connections are reversed, the penetration of heat zone in the base metal will be comparatively shallow and, at the same time electrode will burn fast

6. [Fig. 1.23 *(b)]*. AC supply produces a penetration depth that is early halfway between that achieved by the D.C. positive ground and negative ground as shown in Fig.1.23(c) It may be noted that with A.C supply, heat is developed equally at the anode and cathode due to rapid reversal of their polarity.
7. The arc utilized for arc welding is a low-voltage high-current discharge. The voltage required for striking the arc is higher than needed for maintaining it. Moreover, amperage increases as voltage decreases after the arc has been established.

Fig 1.24 shows **V/I characteristics of an electric arc** for increasing air-gap lengths. The voltage required 10 strike a D.C arc is about 50-55 V and that for A.C arc is 80-90 V. The voltage drop across the arc is nearly 15-20V. It is difficult to maintain the arc with a voltage less than 14 V or more than 40 V.

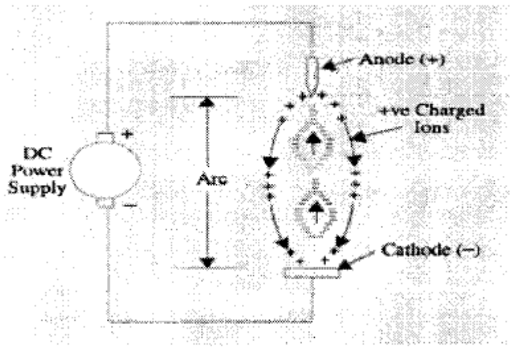


Fig1.22

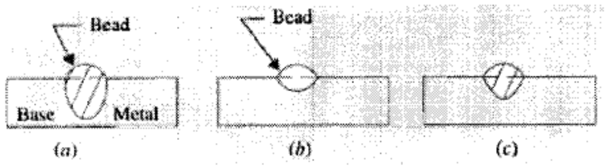


Fig 1.23

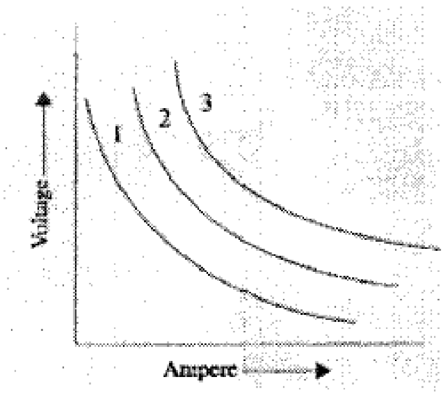


Fig1.24

Plasma Arc Welding

(a) Basic Principle

1. It consists of a high-current electronic arc which is forced through a small hole in a water-cooled metallic nozzle [Fig. 1.55 *(a)*].
2. The plasma gas itself is used to protect the nozzle from the extreme heat of the arc. The plasma arc is shielded by inert gases like **argon and helium** which are pumped through an extra passageway within the nozzle of the plasma torch.
3. As seen, plasma arc consists of electronic are, plasma gas and gases used to shield the jet column. The idea of using the nozzle is to constrict the arc thereby increasing its pressure
4. Collision of high-energy electrons with gas molecules produces the plasma which is swept through the nozzle and forms the current path between the electrode and the work piece. Plasma jet torches have temperature capability of about **35,000° C.**

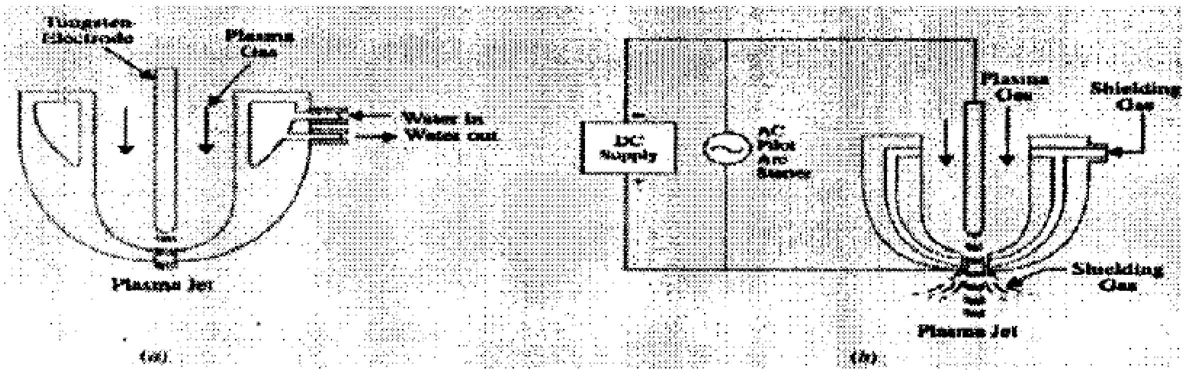


Fig 1.55

(b) Electrodes

For stainless steel welding and most other metals, straight polarity **tungsten electrodes** arc used. But for aluminium welding, reverse polarity water-cooled **copper electrodes** are used

(c) Power Supply

1. Plasma arc welding requires D.C. power supply which could be provided either by a motor-generator set or transformer-rectifier combination. The latter is preferred because it produces better arc stability.
2. The D.C. supply should have an open-circuit voltage of about 70V and drooping voltage ampere characteristics. A high-frequency pilot arc circuit is employed to start the arc [Fig. 1.55 (b)]·

(d) Method of Welding

1. Welding with plasma arc jet is done by a process called **keyhole method.**
2. As the plasma jet strikes the surface of the workpiece, it burns a hole through it. As the torch progresses along the workpiece, this hole also progresses along with but is filled up by the molten metal as it moves along.
3. 100 percent penetration is achieved in this method of welding. Since plasma jet melts a large surface area of the base metal, it produces a weld bead of wineglass design as shown in Fig. 1.56. The shape of the bead can be changed by changing the tip of the nozzle of the torch. Practically, all welding is done mechanically.

(e) Applications

1. Plasma arc welding process has many aerospace applications.
2. It is used for welding of reactive metals and thin materials.
3. It is capable of welding high-carbon steel, stainless steel, copper and copper alloys, brass alloys, aluminium and titanium.
4. It is also used for metal spraying.

Fig 1.56

(f) Disadvantages

1. Since it uses more electrical equipment, it has higher electrical hazards.
2. It produces ***ultra-violet and infra-red*** radiations necessitating the use of tinted lenses.
3. It produces high-pitched noise (100 dB) which makes it necessary for the operator to use car plugs.
4. It can be modified for metal cutting purposes. It has been used for cutting aluminium. Carbon steel, stainless steel and other hard-to-cut steels. It can produce high-quality aluminium cuts 15 crn deep.

Laser Welding

1. It uses an extremely concentrated beam of coherent ***monochromatic light*** *i.e.* light of only one colour (or wavelength).
2. It concentrates tremendous amount of energy on a very small area of the workpiece to produce fusion.
3. It uses solid laser (ruby, saphire), gas laser (CO2) and semiconductor laser.
4. Both the gas laser and solid laser need capacitor storage to store energy for later injection into the flash tube which produces the required laser beam
5. When triggered, the capacitor bank supplies electrical energy to the flash tube through the wire. This energy is then converted into short-duration beam of laser light which is pin-pointed on the workpiece as shown in **Fig, 1.58**. Fusion takes place immediately and weld is completed last.

The gas laser welding equipment consists of

1. Capacitor bank for energy storage
2. A triggering device
3. A flash tube that is wrapped with wire
4. lasing material
5. Focussing lens and
6. A worktable that can rotate in the three *X*, *Y* and Z directions.

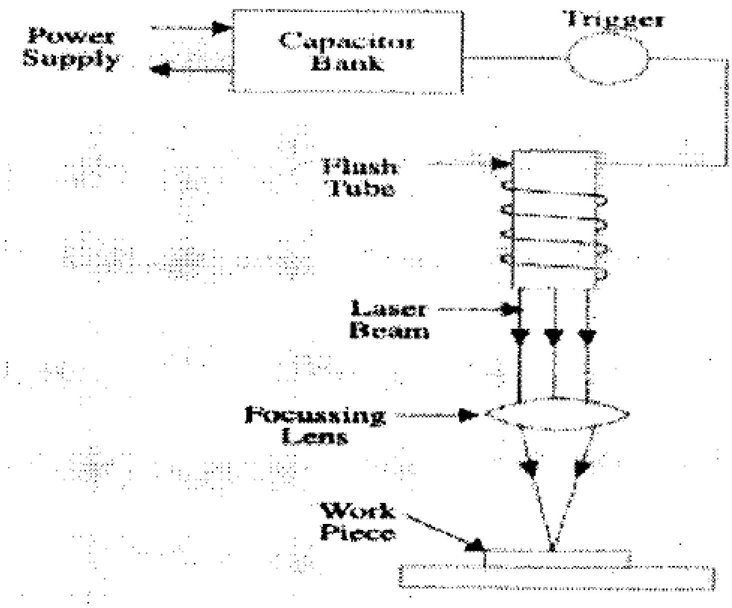


Fig 1.58

6. Since duration of laser weld beam is very short (2 ms or so), two basic welding methods have been adopted.

7. In the first method, the work piece is moved so fast that the entire joint is welded in a single burst of the light. The other method uses a number of pulses one after the other to form the weld joint similar to that formed in electric resistance scam welding.

Applications

Laser welding is used in the aircraft and electronic industries for lighter gauge metals.

Advantages:

1. It does not require any electrode.
2. It can make welds with high degree of precision and on materials as thin as 0.025 mm.
3. It does not heat the work piece except at one point. In fact, heat-affected zone is virtually nonexistent.
4. It can produce glass-to-metal seals as in the construction of klystron tubes.
5. Since laser beam is small in size and quick in action, it keeps the weld zone uncontaminated.
6. It can weld dissimilar metals with widely varying physical properties.

Disadvantage

1. Slow welding speed.
2. Limited to welding with thin metals only.

1.9 Introduction to Electrolysis

1.9.1 Definition of Electrolysis

An electrolyte is such a chemical that's atoms are normally closely bonded together but when it is dissolved in water, its molecules split up into positive and negative ions. The positively charged ions are referred as cations whereas negatively charged ions are referred as anions. Both cations and anions move freely in the solution.

1.9.2 Fundamental Principle of Electrolysis

Whenever any electrolyte gets dissolved in water, its molecules split into cations and anions moving freely in the electrolytic solution. Now two metal rods are immersed in the solution and anelectrical potential difference applied between the rods externally preferably by a battery. These partly immersed rods are technically referred as electrodes. The electrode connected with negative terminal of the battery is known as cathode and the electrode connected with positive terminal of the battery is known as anode. The freely moving positively charged cations are attracted by cathode and negatively charged anions are attracted by anode. In cathode, the positive cations take electrons from negative cathode and in anode, negative anions give electrons to the positive anode. For continually taking and giving electrons in cathode and anode respectively, there must be flow of electrons in the external circuit of the electrolytic. That means, electric current continues to circulate around the closed loop created by battery, electrolytic and electrodes. This is the most basic principle of electrolysis

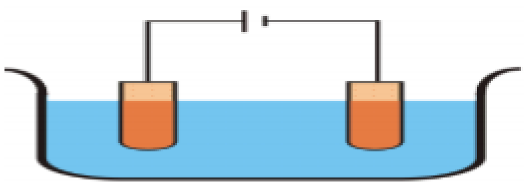


Fig 1.59: Electrolysis Process

1.9.3 Electrolysis of Copper Sulfate

Whenever copper sulfate or CuSO4is added to water, it gets dissolved in the water. As the C

electrolyte, it splits into Cu++(cation) and SO4−−(anion) ions and move freely in the solution. copper electrodes are immersed in that solution, the Cu++ions (cation) will be attracted towards i.e. the electrode connected to the negative terminal of the battery. On reaching on the cathode +ion will take electrons from it and becomes neutral copper atoms. Similarly the SO4--(anion be attracted by anode i.e. the electrode connected to the positive terminal of the battery. So S will move towards anode where they give up two electrons and become SO4radical but since S can not exist in the electrical neutral state, it will attack copper anode and will form copper during electrolysis of copper sulfate, we use carbon electrode instead of copper or other metal then electrolysis reactions will be little bit different. Actually SO4can not react with carbon case the SO4will react with water of the solution and will form sulfuric acid and liberate oxygen

$$2SO_4 + 2H_2O \rightarrow 2H_2SO_4 + O_2$$

The process described above is known as electrolysis. In the above process, after taking neutral copper atoms get deposited on the cathode. At the same time, SO4reacts with copper becomes CuSO4but in water it can not exist as single molecules instead of that CuSO4 will split into SO4−−and dissolve in water. So it can be concluded that, during electrolysis of copper sulphate electrodes, copper is deposited on cathode and same amount of copper is removed from anode.

1.9.4 Faraday's Laws of Electrolysis

Before understanding Faraday's laws of electrolysis, we have to recall the process of electrolysis of a metal sulfate.

Whenever an electrolyte like metal sulfate is diluted in water, its molecules split into positive and negative ions. The positive ions or metal ions move to the electrodes connected with negative terminal of the battery where these positive ions take electrons from it, become pure metal atom and get deposited on the electrode. Whereas negative ions or sulphions move to the electrode connected with positive terminal of the battery where these negative ions give up their extra electrons and become SO4radical. Since SO4cannot exist in electrically neutral state, it will attack metallic positive electrode and form metallic sulfate which will again dissolve in the water. Faraday’s laws of electrolysis combine two laws

1.9.5 Faraday's First Law of Electrolysis

From the brief explanation above, it is clear that the flow of current through the external battery circuit fully depends upon how many electrons get transferred from negative electrode or cathode to positivemetallic ion or cations. If the cations have valency of two like Cu^{++} then for every cation, there would be two electrons transferred from cathode to cation. We know that every electron has negative electrical charge -1.602×10^{-19} Coulombs and say it is - e. So for disposition of every Cu atom on the cathode, there would be - 2.e charge transfers from cathode to cation. Now say for t time there would be total n number of copper atoms deposited on the cathode, so total charge transferred, would be - 2.n.e Coulombs. Mass m of the deposited copper is obviously function of number of atoms deposited. So, it can be concluded that the mass of the deposited copper is directly proportional to the quantity of electrical charge that passes through the electrolyte. Hence mass of deposited copper m ∝ Q quantity of electrical charge passes through the electrolyte.

a)Faraday's First Law of Electrolysis

According to this law, the chemical deposition due to flow of electric current through an electrolyte is directly proportional to the quantity of electricity (coulombs) passed through it**.**

i.e.mass of chemical deposition,

$$m \propto Quantity\, of\ electricity,\ Q \Rightarrow m = Z \cdot Q$$

Where Z is a constant of proportionality and is known as electrochemical equivalent of the substance.

If we put Q = 1 coulombs in the above equation, we will get Z = m which implies that electrochemical equivalent of any substance is the amount of the substance deposited on passing of 1 coulomb through its solution. This constant of passing of electrochemical equivalent is generally expressed in terms of milligram per coulomb or kilogram per coulomb.

b)Faraday's Second Law of Electrolysis

So far we have learned that the mass of the chemical, deposited due to electrolysis is proportional to the quantity of electricity that passes through the electrolyte. The mass of the chemical, deposited due to electrolysis is not only proportional to the quantity of electricity passes through the electrolyte, but it also depends upon some other factor. Every substance will have its own atomic weight. So for same number of atoms, different substances will have different masses. Again, how many atoms deposited on the electrodes also depends upon their number of valency. If valency is more, then for same amount of electricity, number of deposited atoms will be less whereas if valency is less,then for same quantity of electricity, more number of atoms to be deposited. So, for same quantity of electricity or charge passes through different electrolytes, the mass of deposited chemical is directly proportional to its atomic weight and inversely proportional to its valency.

c)Faraday'ssecond law of electrolysis states that, when the same quantity of electricity is passed through several electrolytes, the mass of the substances deposited are proportional to their respective chemical equivalent or equivalent weight.

1.9.6 Applications of Electrolysis

Electrolytic Refining of Metals: The process of electrolytic refining of metals is used to extract impurities from crude metals. Here in this process, a block of crude metal is used as anode, a diluted salt of that metal is used as electrolyte and plates of that pure metal is used as cathode.

a)Electrolytic Refining of Copper

For understanding the process of electrolytic refining of metals, we will discuss about an example of electrolytic refining of copper. Copper extracted from its ore, known as blister copper, is 98 to 99 % pure but it can easily be made up to 99.95% pure for electrical application by the process of electrorefining. In this process of electrolysis, we use a block of impure copper as anode or positive electrode, copper sulfate acidified with sulfuric acid, electrolyte and pure copper plates coated with graphite, as cathode or negative electrode.

The copper sulfate splits into positive copper ion (Cu^{++}) and negative sulfate ion (SO_4^{--}). The positive copper ion (Cu^{++}) or cations will move towards negative electrode made of pure copper where it takes electrons from cathode, becomes Cu atom and is deposited on the graphite surface of the cathode.

On the other hand, the SO_4^{--} will move towards positive electrode or anode where it will receive electrons from anode and become radical SO_4 but as radical SO_4 can not exist alone, it will attack copper of anode and form $CuSO_4$. This $CuSO_4$ will then dissolve and split in the solution as positive copper ion (Cu^{++}) and negative sulfate ion (SO_4^{--}). These positive copper ions (Cu^{++}) will then move towards negative electrode where it takes electrons from cathode, become Cu atoms and are deposited on the graphite surface of the cathode. In this way, the copper of impure crude will be transferred and deposited on the graphite surface

of the cathode. The metallic impurities of anode are also merged with SO_4, form metallic sulfate and dissolve in the electrolyte solution. The impurities like silver and gold, which are not effected by sulfuric acid-copper sulfate solution, will settle down as the anode sludge or mud. At a regular interval of electrolytic refining of copper, the deposited copper is stripped out from the cathode and anode is replaced by a new block of crude copper.

1.10 . Electroplating

The process of electro platingis theoretically same as electrorefining -only difference is that, in place of graphite coated cathode we have to place an object on which the electroplating has to be done. Let's take an example of brass key which is to be copper-platted by using copper electroplating.

1.10.1 Copper Electroplating

We have already stated that copper sulfate splits into positive copper ion (Cu^{++}) and negative sulfate ion (SO_4^{--}) in its solution. For **copper electroplating**, we use copper sulfate solution as electrolyte, pure copper as anode and an object (a brass key) as cathode. The pure copper rod is connected with positive terminal and the brass key is connected with negative terminal of a battery. While these copper rod and key are immersed into copper-sulfate solution, the copper rod will behave as anode and the key will behave as cathode. As the cathode or the brass key is connected with negative terminal of battery, it will attract the positive cations or Cu^{++} ions and on reaching of Cu^{++} ions on the surface of the brass key, they will receive electrons from it, become neutral copper atom and are about to be deposited on the surface of the brass key as uniform layer. The sulfate or SO_4^{--} ions move to the anode and extract copper from it into the solution as mentioned in the process of electro-refining. For proper and uniform copper plating, the object (here it is brass key) is being rotated slowly into the solution.

1.11 Factors affecting Electro deposition Process

Electrophoretic deposition(EPD),is a term for a broad range of industrial processes which includes electrocoating, e-coating, cathodic electrode position, anodic electrode position, and electrophoretic coating, or electrophoretic painting. A characteristic feature of this process is that colloidal particles suspended in a liquid medium migrate under the influence of an electric field (electrophoresis) and are deposited onto an electrode. All colloidal particles that can be used to form stable suspensions and that can carry a charge can be used in electrophoretic deposition. This includes materials such as polymers, pigments, dyes, ceramics and metals.

The process is useful for applying materials to any electrically conductive surface. The materials which are being deposited are the major determining factor in the actual processing conditions and equipment which may be used. Due to the wide utilization of electrophoretic painting processes in many industries, aqueous EPD is the most common commercially used EPD process. However, non-aqueous electrophoretic deposition applications are known. Applications of non-aqueous EPD are currently being explored for use in the fabrication of electronic components and the production of ceramic coatings. Non-aqueous processes have the advantage of avoiding the electrolysis of water and the oxygen evolution which accompanies electrolysis.

This process is industrially used for applying coatings to metal fabricated products. It has been widely used to coat automobile bodies and parts, tractors and heavy equipment, electrical switch gear, appliances, metal furniture, beverage containers, fasteners, and many other industrial products.

EPD processes are often applied for the fabrication of supportedtitanium dioxide (TiO_2) photocatalysts for water purification applications, using precursor powders which can be immobilised using EPD methods onto various support materials. Thick films produced this way allow cheaper and more rapid synthesis relative to sol-gelthin-films, along with higher levels of photocatalyst surface area.

EPD processed have a number of advantages which have made such methods widely used

1. The process applies coatings which generally have a very uniform coating thickness without porosity.
2. Complex fabricated objects can easily be coated, both inside cavities as well as on the outside surfaces.
3. Relatively high speed of coating.
4. Relatively high purity.
5. Applicability to wide range of materials (metals, ceramics, polymers, etc.)
6. Easy control of the coating composition.
7. The process is normally automated and requires less human labor than other coating processes.
8. Highly efficient utilization of the coating materials result in lower costs relative to other processes.
9. The aqueous process which is commonly used has less risk of fire relative to the solvent-borne coatings that they have replaced.
10. Modern electrophoretic paint products are significantly more environmentally friendly than many other painting technologies.

1.12 Process of electrophoretic painting

The overall industrial process of electrophoretic deposition consists of several sub-processes**:**

1. The object to be coated needs to be prepared for coating. This normally consists of some kind of cleaning process and may include the application of a conversion coating, typically an inorganic phosphate coating.
2. The coating process itself. This normally involves submerging the part into a container or vessel which holds the coating bath or solution and applying direct current electricity through the EPD bath using electrodes. Typically voltages of 25 - 400 volts DC are used in electrocoating or electrophoretic painting applications. The object to be coated is one of the electrodes, and a set of "counter-electrodes" are used to complete the circuit.
3. After deposition, the object is normally rinsed to remove the undeposited bath. The rinsing process may utilize an ultrafilter to dewater a portion of the bath from the coating vessel to be used as rinse material. If an ultrafilter is used, all of the rinsed off

materials can be returned to the coating vessel, allowing for high utilization efficiency of the coating materials, as well as reducing the amount of waste discharged into the environment.

4. A baking or curing process is normally used following the rinse. This will the polymer and allows the coating, which will be porous due to the evolution of gas during the deposition process, to flow out and become smooth and continuous.

1.13 Power Supply for electrolytic process

Electrolysis is a method of using a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction. Electrolysis is commercially highly important as a stage in the separation of elements from naturally occurring sources such as ores using an electrolytic cell. The voltage that is needed for electrolysis to occur is called decomposition potential.

Electrolysis is the passage of a direct electric current through an ionic substance that is either molten or dissolved in a suitable solvent, resulting in chemical reactions at the electrodes and separation of materials.

1.13.1 The main components required to achieve electrolysis are:

An electrolyte : a substance containing free ions which are the carriers of electric current in the electrolyte. If the ions are not mobile, as in a solid salt then electrolysis cannot occur.

A direct current (DC) supply : provides the energy necessary to create or discharge the ions in the electrolyte. Electric current is carried by electrons in the external circuit.

Two electrodes : an electrical conductor which provides the physical interface between the electrical circuit providing the energy and the electrolyte

Electrodes of metal, graphite and semiconductor material are widely used. Choice of suitable electrode depends on chemical reactivity between the electrode and electrolyte and the cost of manufacture.

1.14Energy changes during electrolysis

The amount of electrical energy that must be added equals the change in Gibbs free energy of the reaction plus the losses in the system. The losses can (in theory) be arbitrarily close to zero, so the maximum thermodynamic efficiency equals the enthalpy change divided by the free energy change of the reaction. In most cases, the electric input is larger than the enthalpy change of the reaction, so some energy is released in the form of heat. In some cases, for instance, in the electrolysis of steam into hydrogen and oxygen at high temperature, the opposite is true. Heat is absorbed from the surroundings, and the heating value of the produced hydrogen is higher than the electric input.

Module Outcomes:

1. Students will be able to discuss electric heating, air-conditioning and electric welding.
2. Explain laws of electrolysis, extraction and refining of metals and electro deposition.

MODULE -2 -ILLUMINATION

Structure

- Introduction
- Radiant Energy
- Definitions
- Laws of Illumination
- Polar Curves, Photometry
- Measurement of Mean Spherical Candle Power by Integrating Sphere
- Illumination Photometer
- Energy Radiation and luminous Efficiency
- Electric Lamps
- Cold Cathode Lamp
- Lighting Fittings
- Illumination for Different Purposes
- Requirements of Good Lighting

Module objective:

- To explain the terminology of illumination, laws of illumination, construction and working of electric lamps.

- To explain design of interior and exterior lighting systems- illumination levels for various purposes light fittings- factory lighting- flood lighting-street lighting

2. Introduction:

1. Light is the prime factor in the human life as well as activities of human beings ultimately depend upon the light. Where there is no natural light, use of artificial light is made.

2. Artificial lighting produced electrically, on account of its cleanness, ease of control, reliability, steady output, as well as its low it is playing an increasingly important part in modern everyday life. The science of illumination engineering is, therefore, becoming of major importance.

Nature of light:

1. Light is a form of radiant energy. Various forms of incandescent bodies are the sources of light and the 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.

2. The heat of the body, as seen, can be classified as red hot or white-hot. While the body is red-hot , the wave length of radiated energy will be sufficiently large and the energy available is in the form of heat.

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

Colour:

The sensation of colour is due to the difference in the wave lengths of the light radiations. Visible light can have wave lengths of the light between **4,000A and 7,500A (Angstrom)**

Relative sensitivity:

1. The sensitivity of the eye to the lights of different wave lengths varies from person to person and according to the age.
2. The high have greatest sensitivity for wave lengths of about 5,500A: that is yellow green can be seen under such poor conditions of illumination when blue or red cannot

be see under dim illumination, the sensitive curve shifts as shown by the shaded region in the fallowing figure.

3. Therefore, violate disappears first and red remains visible. Yellow disappears last as the illumination becomes very dim.
4. As each colour disappears, it becomes a grey shade and finally black. The sensitivity of eye to yellow-green radiation is taken as unity or 100% and the sensitivity to other wave lengths is expressed as a fraction or percentage of it.

Illumination:

1. Illumination differs from light every much, though generally these terms are used more or less synonymously. Strictly speaking light is the cause and illumination is the result of that light on surfaces on which it falls. Thus the illumination makes the surface look more or less bright with certain colour and it is this brightness and colour which the eye sees and interrupts as something useful or pleasant or otherwise.

2. Light may be produced by passing electric current through filaments as in the incandescent lamps, through arcs between carbon or metal rods, or through suitable gases as in neon and other gas tubes. In some forms of lamps the light is due to fluorescence excited by radiation arising from the passage electric current through mercury vapour.

3. Some bodies reflect light in some measure, and when illuminated from an original source they become secondary source of light. The good example is the moon, which illuminates earth by means of the reflected light originating in the sun.

2.1 Terms used in illumination:

The modern lighting schemes and the selection of fittings and type of lamps require knowledge of the terms and quantities in general use for such purposes. Therefore, the following definitions are given in simple form to facilitate easy identification and reference.

1. **Light:** It is defined as the radiation energy from a hot body which produces the visual sensation upon the human eye. It is usually denoted by Q, expressed in lumen-hours and is analogous to watt-hour.

2. **Luminous flux:** it is defined as the total quantity of light energy emitted per second form a luminous body. It is represented by symbol **F** and is measured in lumens. The

concept of luminous flux helps us to specify the output and efficiency of a given light source.

3. **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/steradian.

If **F** is the luminous flux radiated out by source within a solid angle of ω steradian in any particular direction then $I = \frac{F}{\omega}$ lumens/steradian or candela (cd).

4. **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.

Lumens = candle power × solid angle = cp × ω

Total lumens given out by source of one candela are 4π lumens.

5. Candle power: Candle power is the light radiating capacity of a source in a given direction and is defined as the number of lumens given out by the source in a unit solid angle in a given direction. It is denoted by a symbol **C.P.**

$$\text{C.P.} = \frac{lumens}{\omega}$$

6. Illumination: When the light falls upon any surface, the phenomenon is called the illumination. It is defined as the 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 meter-candle or lux.

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

$E = \frac{F}{A}$ lumens/m^2 or lux

7. Lux or meter candle: It is the unit of illumination and is defined as the luminous flux falling per square meter on the surface which is every where perpendicular to the rays of light from a source of one candle power and one meter away from it.

8. Foot candle: It is also the unit of illumination and is defined as the luminous flux falling per square foot on the surface which is everywhere perpendicular to the rays of light from a source of one candle power and one foot away from it.

1 foot-candle = 1 lumen/ft^2 =10.76 meter candle or lux

Candle: It is the unit of luminous intensity. It is defined as $\frac{1}{60}$ th of the luminous intensity per cm^2 of a black body radiator at the temperature of solidification of platinum (2,043^{0}K).

10. Mean horizontal candle power: (M.H.C.P): It is defined as the mean of candle powers in all directions in the horizontal plane containing the source of light.

11. Mean spherical candle power: (M.S.C.P): It is defined as the mean of the candle powers in all directions and in all planes from the source of light.

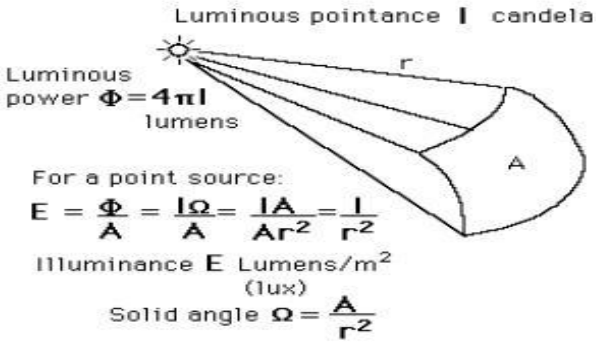
12. Mean hemi-spherical candle power: (M.H.S.C.P) It is defined as the mean of candle powers in all directions above or below the horizontal plane passing through the source of light

13. Brightness or luminance: When the eye receives a great deal of light from an object we say it is bright, and brightness is an important quantity in illumination. It is all the same whether the light is produced by the object or reflected from it.

Brightness is defined as the luminous intensity per unit projected area of either a surface source of light or a reflecting surface and is denoted by L. If a surface area A has an effective luminous intensity of I candelas in a direction θ to the normal, than the brightness (luminance) of that surface is

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

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



$$\theta = \frac{arc}{radious} \ radians$$

The largest angle subtended at a point is 2Π radians.

15. Solid angle: Solid angle is the angle generated by the surface passing through the point in space and the periphery of the area. Solid angle is denoted by **ω**, expressed in **steradians** and is given by the ratio of the area of the surface to the square of the distance between the area and the point.

$$\text{i.e } \omega = \frac{\text{Area}}{(\text{Radious})^2} = \frac{A}{r^2}$$

The largest solid angle subtended at a point is that due to a sphere at its centre. If **r** is the radius of any sphere, its surface area is $4\pi r^2$ and the distance of its surface area from the centre is r, therefore, solid angle subtended at its centre by its surface, $\omega = \frac{4\pi r2}{r^2} = 4\pi$ steradians

2.2 Laws of illumination:-

There are two laws of illumination

1. Law of inverse squares

2. Lamberts cosine law

1. Law of inverse squares:-

1. If a source of light which emits light equally in all directions be placed at the center of the hallow 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.

2. 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 diminishes as the radius increases, and will be **inversely proportional to the square of the distance**.

3. A similar relation holds if we have to deal with a beam of light in the form of a cone or pyramid as shown in the **fig**. if we consider parallel surfaces which cut the pyramid at different distances from the source, the areas of these surfaces are proportional to the square of these distances, and therefore the amount of light which falls on the one unit of the area of these surfaces is inversely proportional to the square of the distances from the source. **This relation is referred to as the law of inverse squares.**

The illumination of a surface is inversely proportional to the square of the distance of the surface from the source. In other words, $E \propto 1/r2$

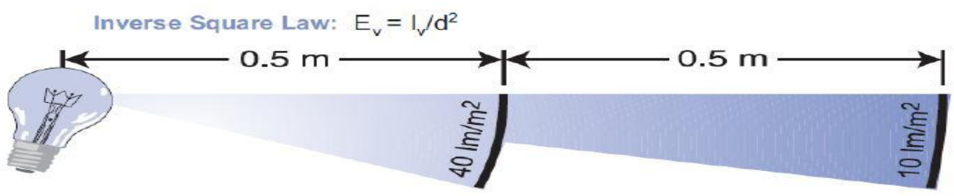


Fig 2.1 : Inverse square law

2. Lamberts cosine law

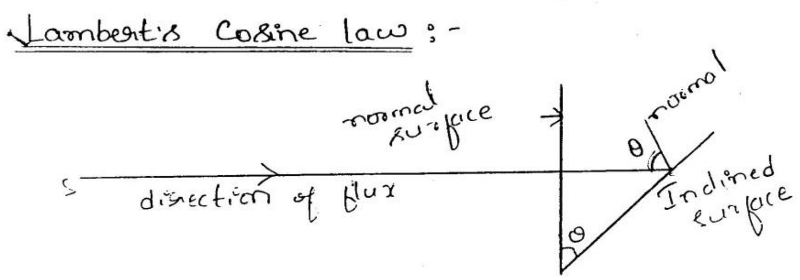


Fig 1.2 : Lamberts cosine law

The illumination at any point on an inclined surface is directly proportional to cosine of the angle between the normal to the surface and the direction of the luminous flux.
The angle between the normal to the inclined surface at any point on the surface and the lines of flux is the same as the angle between the surface normal to the lines of flux and the inclined surface as shown in fig.

$$E = \frac{I\cos\theta}{r^2}$$

3. Polar curves:-

1. All over discussions so far were based on the assumption that luminous intensity or the candle power from a source is uniformly distributed over the surrounding surface.
2. **But none of the practical type of lamp** gives light uniformly distributed in all directions because of its unsymmetrical shapes.
3. It is often necessary to know the distribution of light in various directions to as certain how the candle power of light source varies in different directions.
4. The luminous intensity in all directions can be represented by **polar curves**.
5. If the luminous intensity is a horizontal plane passing through the lamp is plotted against angular position, a curve known as horizontal polar curve is obtained.
6. If the luminous intensity in a vertical plane is plotted against the angular position, a curve known as vertical polar curve is obtained.
7. The typical polar curves for an ordinary filament lamp are shown in the following fig:
8. The polar curves are used to determine the mean horizontal candle power (m.h.c.p.) and mean spherical candle power (m.s.c.p.). these are also used to determine the actual illumination of a surface by employing the candle power in that particular direction as read from the vertical polar curve in the illumination calculations.

9. The mean horizontal candle power of a lamp can be determined from the horizontal polar curve taking the mean value of the candle power in a horizontal direction. Mean spherical candle power can be determined from the vertical polar curve by **Rousseau's construction.**

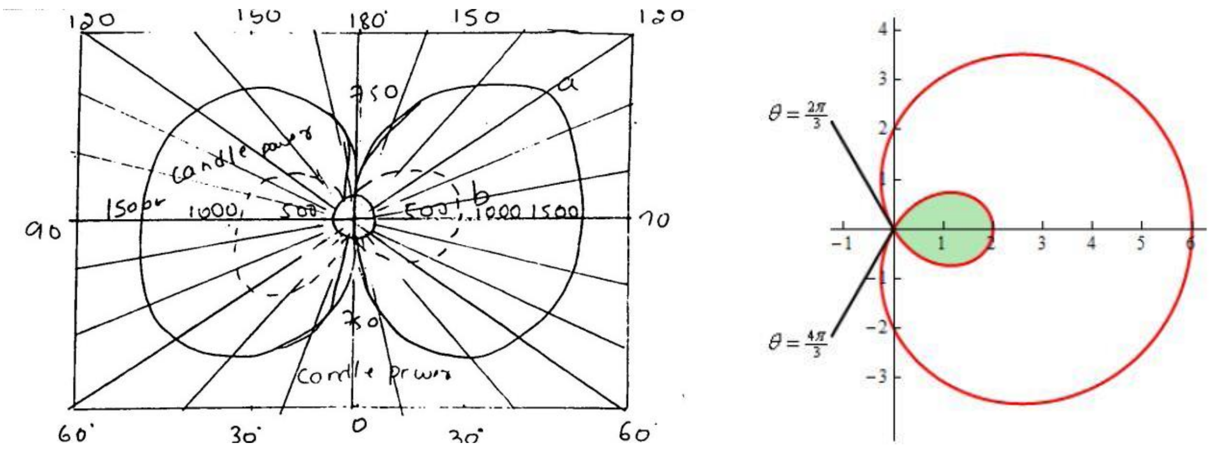


Fig 2.3: Polar curves

4. Rousseau’s construction:

1. The construction is illustrated in the fallowing figure. A semi circle of any convenient radius is drawn with the pole of the polar diagram as centre. The line CD is drawn equal and parallel to the vertical diameter YY¹.

2. Now from this line CD co-ordinate equal to corresponding radius on the polar curve are set up such as BD = OK, GH= Of and so on.

3. The curve obtained by joining the ends of these ordinates is known as Rousseau’s curve. The mean ordinate of this curve gives the m.s.c.p. of the lamp having polar curve given as in the fallowing figure

$$\text{The mean ordinate of the curve} = \frac{\textbf{Area CSTGDBHLC}}{\textbf{Length of CD}}$$

The area under the curve can either be determined on the graph paper or found by Simpson’s rule.

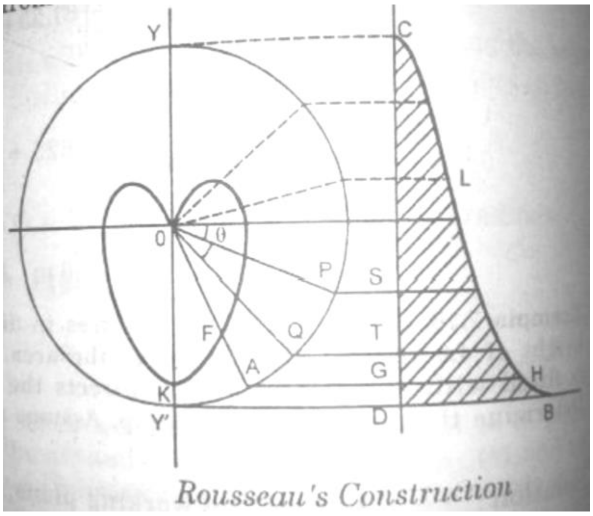


Fig 2.4: Rousseau’s construction

2.3 Photometry

1. The candle power of a source in any given direction is measured by comparison with a standard or substandard source employing photometer bench and some form of photometer.
2. The experiment is performed in dark room with dead black walls and ceiling in order to eliminate the errors due to reflected light.
3. The photometer bench consists essentially of two steel rods which carry the stands or saddles for holding the two sources, the carriage for the photometer head and for any other operators employed in making measurements.
4. One of the bar carries a bar strip, graduated in centimeters and milli-meters the carriages which slides upon the bench have expect that carrying the photometer head, a circular table which can be rotated in a horizontal plane and clamped in any position.
5. The circular table is provided with a scale graduated in degrees round its edge so that the angle of rotation of lamp from the direction of the axis of bench can be measured
6. The bench should be rigid so that the source is being compared may be free from vibrations and carriage holding the photometer head should be capable of moving smoothly and with every little effort.
7. The photometer head acts as a screen for comparison of illumination of the standard source and the source under test. There are different types of photometers, which can be used for the purpose. Some of them are described here. The principle of the most methods of measurement is based upon the **inverse square law.**

The standard source, whose candle power is known (say S) and the source under test whose candle power is to be determined, are set on the bench at a distance apart with some type of screen in line with, and between, them as shown in the above figure. The photometer head or screen id moved in between the two fixed sources until the illumination on the both sides of the screen is same. If the distance of the standard source S and source under test T from photometer head are l_1 and l_2 respectively then according to inverse square law.

$$\frac{\textit{Candle power of source under test}}{\textit{Candle power of standard source}} = \frac{l_2^2}{l_1^2}$$

$$\text{Candle power of source under test} = \text{S} \times \frac{l_2^2}{l_1^2}$$

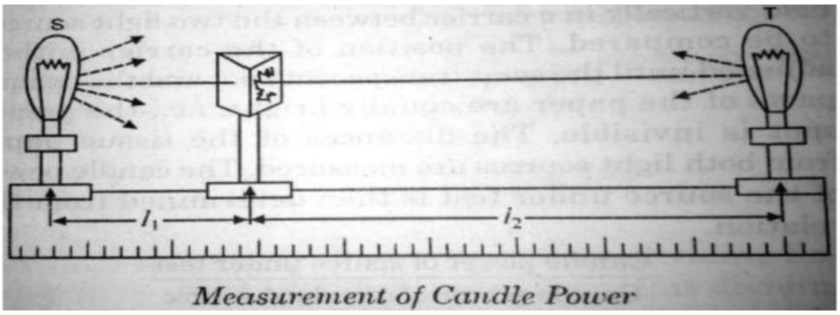


Fig 2.5 Photometer

2.3.1 Photometer bench

It consists of 2 steels rods placed at a distance of 3 to 4 meters from each other which consists of stands to hold the lamps .One steel rod carries a brass strip with a graduated scale in mm.The bench must be rigid enough to be free from vibrations. It should be ensured that there should not be any light except the 2 lamps used.Photometer room is made dark by painting its wall and ceiling as black.

Common types: Bunsen and Lummer Brodhun type. It consists of a piece of thin opaque paper at the centre of which is a translucent spot which is made by treating the paper with oil or wax, also called as 'Grease spot photometer'. Light falls on paper from both the lamp sides. Transparent spot will be illuminated from both the lamps. Photometer head is adjusted such that the transparent spot is not perceptible(there should not be any movements). The paper is viewed from one side first and then from the other side

We get 2 distances d_1,d_1' of photometer head from the test lamp and d_2,d_2' from standard lamp

$$\frac{\text{Candle power of test lamp}}{\text{Candle power of standard lamp}} = \frac{d_1 d_1'}{d_2 d_2'}$$

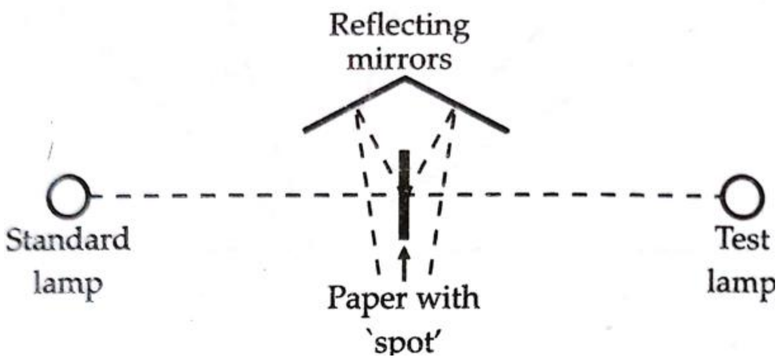


Fig:2.6 Grease spot Photometer head

a) **Lummer –Brodhun photometer head**

2 types of Lummer –Brodhun photometer head:

1. Equality of brightness type
2. 2.Contrast type

1. **Equality of brightness type**:

- Light falling on the plaster-of-paris screen from the test lamp side is reflected by the screen on to mirror M2 from where it is reflected to the compound prism.
- The light from the standard lamp in a similar manner is reflected by the screen surface and mirror M1 and then it reaches the compound prism
- The compound prism is made up of two right-angled glass prisms. The surface of one of the prisms is spherical but a small portion of it is flat and is in contact with the flat surface of the other prism
- Light from M2, passes through the compound prism direct and into the telescope. That portion of light from M1 which falls on the surface of contact of the two prisms

passes through the compound prism, the remaining light is reflected and passes through the telescope

- When we see through the telescope, we see a central circular area illuminated by the test lamp and surrounding circular area illuminated by the standard lamp. The effect is the same as in Grease spot photometer
- The photometer head is adjusted till the distinction between the two areas disappears
- The distinction will disappear completely provided the lights from the two lamps are of same colour

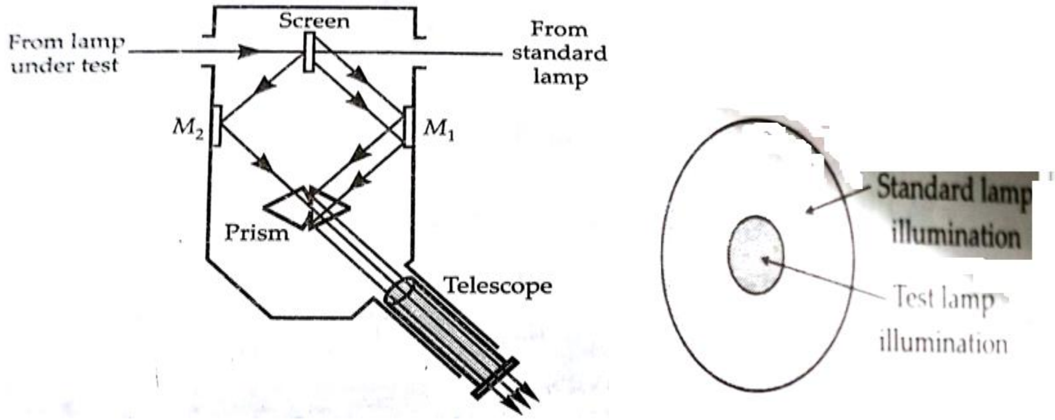


Fig 2.7: Equality of brightness type of Lummer –Brodhun photometer head

b) Contrast type Lummer –Brodhun photometer:

- Two right-angled prisms are joined together. One has its hypotenuse surface etched away at a,b and c which forms a pattern as shown
- The light falling on the prism from the two sources as reflected from the two sides of the screen passes through the unetched portion and is reflected at the etched surfaces.
- The etched portion will be less illuminated than the unetched portion as shown by the shaded and unshaded portion in Fig.
- G1 and G2, are glass sheets which give a little reflected light for maintaining some "difference" between the illumination of the etched and unetched areas in all positions of the photometer head.

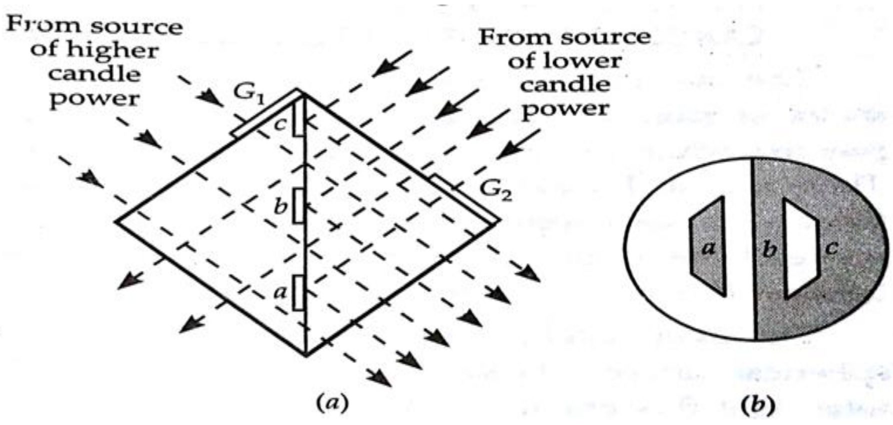


Fig 2.8: Contrast type Lummer –Brodhun photometer

- In the balance position the "difference" in illumination between the etched and unetched portion should be the same on each half of the circular area
- If we move away from the balance position, the ,contrast in illumination between area c and its surrounding area, let us say becomes less and the contrast between the illumination of ab and the inner trapezium will become greater.
- The balance position is at which equal contrast and not equal brightness is obtained.

Flicker photometer

- The principle of such a photometer is that if the human eye sees two illuminated surfaces alternately and the alternations are quite rapid, the flicker produced disappears when the surfaces are of equal brightness. Colour differences between the two illuminated surfaces do not affect such photometers. The speed of alternation should be the lowest speed with which disappearance of flicker can be obtained .Fig. shows the rotating disc used in Simance-Abady flicker photometer. The disc made from plaster-of-paris is in the form of a double- truncated cone. Two cones are truncated by a cut in a plane at an angle with the base of the cone and passing through a point on the circumference of the base. Two such truncated portions are joined together to form the disc shown in Fig. The disc is placed with its axis along the line joining the two lamps which are being compared

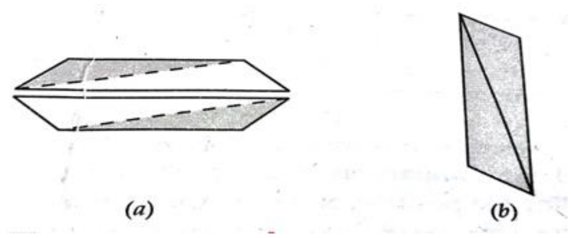


Fig 2.9 Rotating disc of Flicker photometer

2.4 Measurement of mean spherical candle power by integrating sphere

Integrating sphere- Hollow sphere, with dia 1m or more, inner surface is painted white to make it diffusing. There is a small window on surface of the sphere fitted with translucent glass. Small screen is placed between the lamp and window.The illumination at every point on internal spherical surface is the same and is proportional to total light emitted by lamp.Hence it is proportional to mean spherical candle power of the lamp . The brightness of the window is measured 1^{st} by placing the test lamp inside the integrating sphere and then by placing a sub-standard lamp of known MSCP.MSCP of each lamp is proportional to the brightness of the window illuminated by it. Lummer Brodhum photometer head is used in which mirror is placed.The light from the glass window is reflected by the mirror. Other lamp is used for comparison and for obtaining balance by shifting the position of the comparison lamp from the photometer head

Two distances are obtained:

- 1st distance: when glass window is illuminated by the test lamp
- 2nd distance: when the glass window is illuminated by sub-standard lamp
- The squares of these distances are inversely proportional to the mean spherical candle powers of these lamps

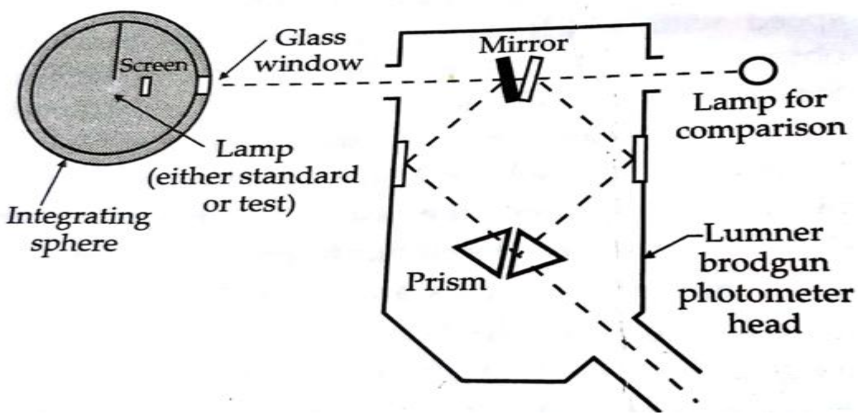


Fig 2.10: Measurement of mean spherical candle power by integrating sphere

2.5 Illumination Photometer

Used for measuring the illumination of the surfaces.They have to be Portable type as it is used to find the illumination level on street or room or in any other type of surface. Eg., Trottar illumination photometer, Macbeth illuminometer, Holophane Lumeter, etc

Fig 2.11 Illumination Photometer

2.6 Energy Radiation & Luminous Efficiency

Normal human eye can perceive Radiant energy of wavelength 4000 to 7500 A.U.Human eye is most sensitive to radiation of 5500 A.U. i.e, to light of greenish yellow colour. Let the energy radiate on a wavelength λ.Visual effect produced on a normal eye is proportional to $K_\lambda E_\lambda$ .If the variation of E_λ with respect to λ(known),

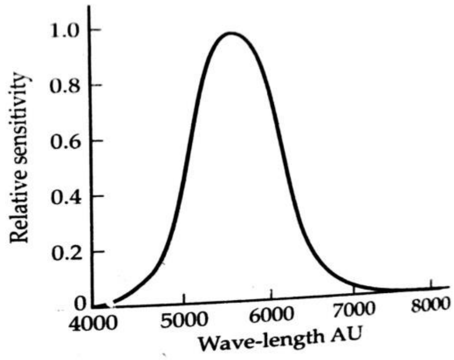


Fig 2.12: Energy Radiation

the total visual effect is proportional to

$$\int_{\lambda_1}^{\lambda_2} K_\lambda E_\lambda d_\lambda \quad \text{or} \quad k\int_{\lambda_1}^{\lambda_2} K_\lambda E_\lambda d\lambda$$

The total energy on all wavelengths

$$= \int_0^\infty E_\lambda d\lambda = \frac{k\int_{\lambda_1}^{\lambda_2} K_\lambda E_\lambda d\lambda}{k\int_0^\infty E_\lambda d\lambda} = \frac{\int_{\lambda_1}^{\lambda_2} K_\lambda E_\lambda d\lambda}{\int_0^\infty E_\lambda d\lambda}$$

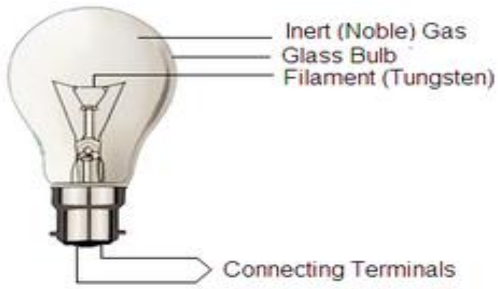
2.7 Electric Lamps

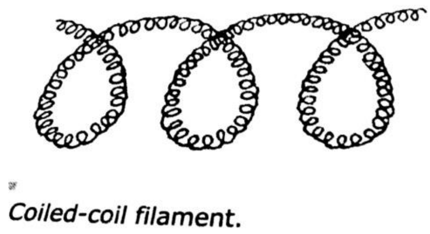
1. **Incandescent lamps** in which a filament heated by electric current produces light
2. **Arc lamps** in which an electric arc is struck between two electrodes.
3. **Electric discharge lamps** in which light is produced by ionisation and excitation process.

2.7.1 Filament Lamps

The radiation of energy from a heated body is proportional to T_1^4-T_2^4.T1 is the temp. (deg c) of heated body & T2 is the temp. of the medium in which energy radiation takes. As T1 increased, more and more of radiated energy falls in the visible range and body emits light. When black body is heated to 6250 deg c, it emits maximum energy in visible range. Element used as filament is tungsten(MP is 3500 deg c) in incandescent lamp.Tungsten has positive resistance characteristic and constitutes stable electric circuit. Heat lost by convection is negligible when compared with heat lost by radiation. Filament lamps radiate only 10 to 12% of input energy as light Current inrush attains max value of 0.003 and falls to normal operating value in 0.2 sec. Inert gas .i.e, nitrogen and argon is filled in the bulb. Advantage of gas is filament can be worked at higher temp. and evaporation is reduced. Vaccum type of lamps- below 40W; Gas filled lamps- 40W and above.

Filament shape is coiled-coil due to its increased efficiency and work at high temperatures Change in rated voltage produces max. change in lamp life





2.13(a) : Filament Lamp

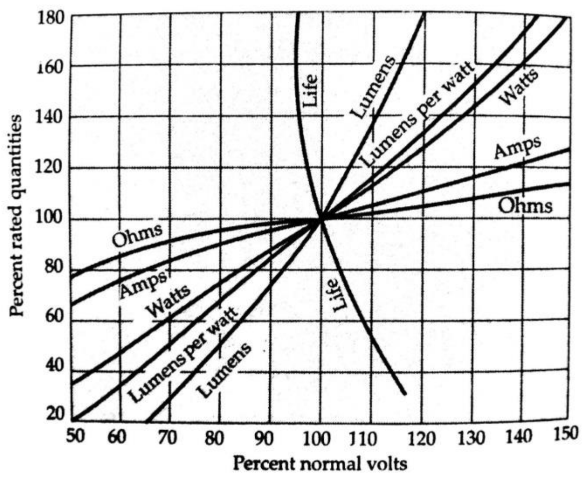
1.13(b) Coiled coil filament

Operation at high voltage than normal value results in:

- High efficiency
- High wattage
- More light output(white light)
- Shorter lamp life (life of filament reduces)

Operation at a voltage less than rated value results in:

- Savings in voltage
- Loss of light(loss of lumens)
- Very much sensitive to voltage changes



Advantages:

- Operates at unity power factor
- Operates directly on standard distribution voltage
- Available in various shapes and shades
- Good radiation characteristic in the luminous range

- Not affected by ambient temp.

2.7.2 Arc Lamps: Current will flow through two electrodes in contact with each other, when these are drawn apart an ARC will strike between them.

Types of Arc lamps: Carbon arc, flame arc type or metal electrode arc type

i. Carbon-Arc Lamps

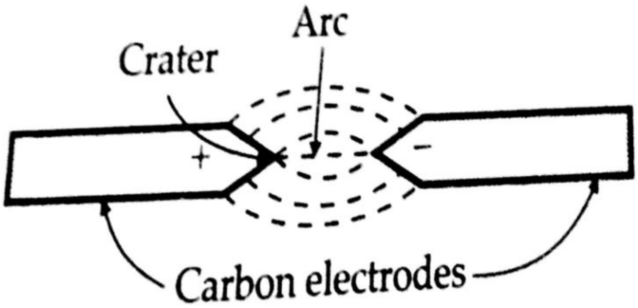


Fig 2.14(i): Carbon Arc Electrodes

Electrodes of hard carbon maintains the arc between them.Cavity called ‘CRATOR’ is formed at positive electrode, where crator produces white light and emits 85% of light. Temp. in crator is 3700k, 4200k in arc and 2700k in negative electrode. Voltage necessary to maintain the arc is V=(39+28l)volts where l is length of arc in cm. Arc length is maintained constant by adjusting electrodes as the electrodes are consumed due to burning.Since arc has negative resistance characteristic, a stabilising resistor has to be placed in series with the arc

ii. Flame arc

Uses carbon electrodes having 5 to 15 % fluoride content.The arc is drawn out one side by a magnet.As though the arc is very efficient, the colour of light obtained is not desirable.It is superseded by electric discharge lamp

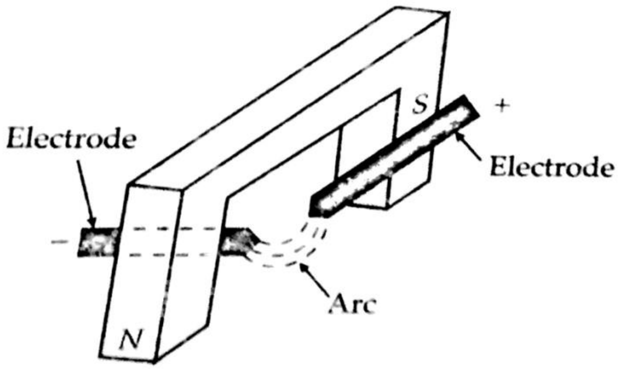


Fig 2.14(ii): Flame arc electrode

iii) Magnetic Arc Lamps

Struck between a positive electrode of copper and negative electrode of magnetic oxide of iron.Such arc lamps are mainly used in USA

2.7.3 Electric Discharge Lamps

Light production is by phenomenon of excitation and ionisation in a gas or vapour .Potential difference is applied to two electrodes placed in a gas having large no. of electrons.These electrons will be attracted to positive electrode and velocity acquired by an electron will depend upon potential gradient.During its motion towards the positive electrode, an electron will strike other atoms results in the following

a) Elastic Collision
b) Excitation
c) Ionisation by collision

a) Elastic Collision:

Electron may be bounced off the atom it strikes.No change in its velocity.This happens when the Striking electron has a small amount of kinetic energy

b) Excitation:

Electron has acquired KE above critical value is termed as excitation potential, i.e, the collision may cause one of the electrons to jump from its normal orbit to another. This happens when colliding electron has KE of 2.1volts.In this way atom can be placed in different orbits depending upon KE of colliding electron. In returning from higher excited state to lower excited state , energy is given out as radiation of definite wavelength

c) Ionisation by Collision:

If the KE of colliding atom is large, it will knock out an electron from the orbit which behaves as free electron.Produce more free electrons by collision .Large number of free electrons constitute heavy current and may result in electric arc. This phenomenon is Ionisation .Ionisation potential is the potential difference though which an electron must travel to acquire energy for ionisation by collision

Electric Discharge Lamps Characteristics:

Radiation is produced by excitation and ionisation .Electrodes with barium and strontium oxide which emits large no. of electrons when heated are necessary for starting and maintaining the flow. Since plasma column has negative resistance characteristic , ballast are necessary for stabilizing the flow of current. Special transformers are needed as starting and operating voltages are quite different. In AC since the current passes through zero after every half cycle the flow of electrons stops momentarily and a rapid flicker which give rise to stroboscopic effect

i) **Neon Lamp:**

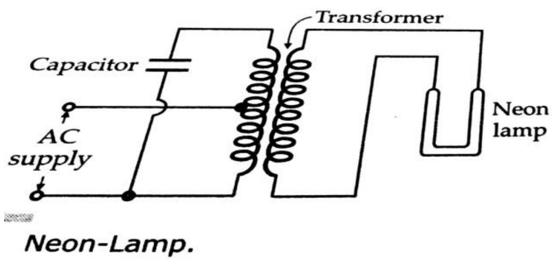


Fig 2.15: Neon Lamp

- Cold-Cathode type
- Electrodes are in the form of iron shells and are coated on inside
- Colour of light emitted is red
- Used for electrical advertising
- High voltage is used for starting
- If helium gas is used in place of neon, pinkish white light is obtained
- In the ckt, Transformer has a high leakage reactance which stabilise the arc
- Capacitor is used for power factor improvement

ii) **Sodium Vapour Lamp**

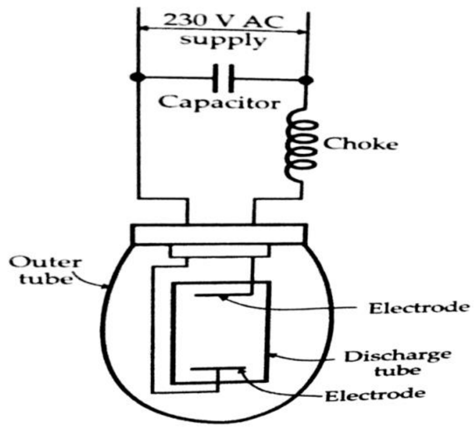


Fig 2.16: Sodium Vapour Lamp

- SVL has highest theoretical luminous efficiency and gives monochromatic orange-yellow light
- Monochromatic light makes object appear as grey
- Used for street and highway lighting
- Lamp consist of a discharge tube having special composition of glass to withstand the high temperature of the electric discharge
- In the fig, the discharge tube is surrounded by outer tube
- For heating the cathode a transformer is included
- Sodium below 60 deg c is in solid state
- For starting the lamp the electric discharge is allowed to take place in neon gas
- The temp. inside the discharge tube rises and vaporizes sodium
- Operating temp. 230 deg c
- Sodium vapour displace the red colour of neon by its brown yellow colour
- Choke is used for stabilising electric discharge and a capacitor is used for power factor improvement

iii) **Mercury Vapour Lamp**

- Construction is similar to sodium vapour lamp
- Electrodes are tungsten coils containing an electron emitting material .i.e, thorium or oxide mixture
- Argon is introduced to start the lamp

- Electric discharge first takes place through argon and vaporizes the mercury drops inside the discharge tubes
- Electron emitting material supplies electron to maintain arc
- Space between the two bulbs is filled with an inert gas
- Efficiency is 30 to 40 lumens per watt
- The pressure inside the discharge tube may range from 1 to 10 atmospheres, the radiations are in visible range at these pressures
- If the pressure inside the discharge tube is low, most of the light is in UV region

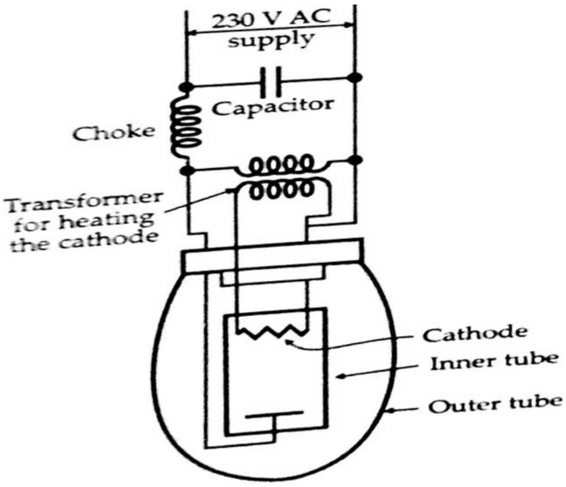


Fig 2.17: Mercury Vapour Lamp

iv) **Fluorescent Lamp**

Table 2.1: Fluorescent lamp colours

phosphor	colour
Zinc silicate	Green
Calcium tungstate	Blue
Cadmium borate	pink
Calcium halo phosphate	Whites of various shades
Magnesium tungstate	Bluish white

- It is advanced form of MVL
- In MVL, considerable amount of radiation is in ultra violet range
- By coating the inside of the tube by phosphor this UV radiation is converted to visible light
- Phosphors are stable compounds and give a high output throughout the life of the lamp
- Phosphors when mixed produce large variety of colours

3 types of Fluorescent lamp:

1. Iron cathode or cold cathode

2. Tungsten cathode , preheated type
3. Tungsten cathode, cold

v) **Cold Cathode Lamps**

- For normal operating conditions :The discharge tube depend on the type and pressure of the gas and the type of electrodes
- At cathode-there is a large fall in voltage (voltage drop) which depends on cathode material and gas pressure.Voltage drop- between100 to 200V
- A cold cathode tube is not operated from the mains, as the voltage available from mains may be utilised utilised in overcoming the cathode voltage drop of the voltage would be utilised in overcoming the cathode voltage drop
- Hence operated at high voltage for economic operations
- Positive column -which provides useful illumination.
- Cold cathode tubes are of smaller diameter and can be given any shape which makes them suitable for display and advertisement purposes
- Life is 10000 hours of operation
- Various types of fluorescent powders used in these lamps give different colours.

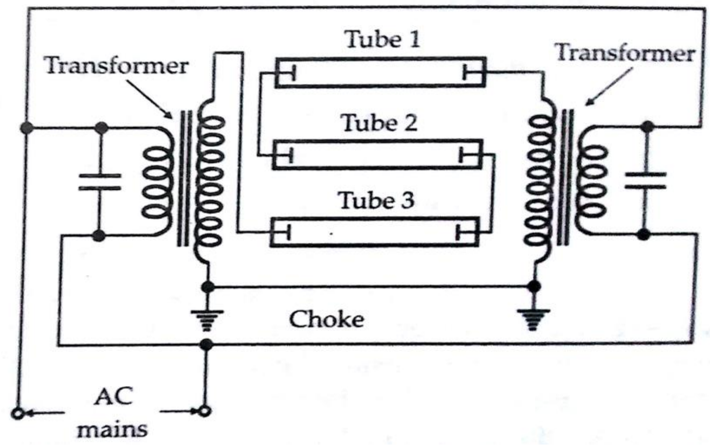


Fig 2.18: Operation of 3 cold Cathode lamps in series

Disadvantages:

- Fluorescent lamps produce flicker or stroboscopic effect
- It produces radio interference

Advantages:

- Under normal conditions -Efficiency and life of lamp is 3 times greater than filament lamp
- Less number of switchings, and applications of rated voltage and current further increases life of lamp

Starters for Fluorescent lamps

1. Thermal Starter

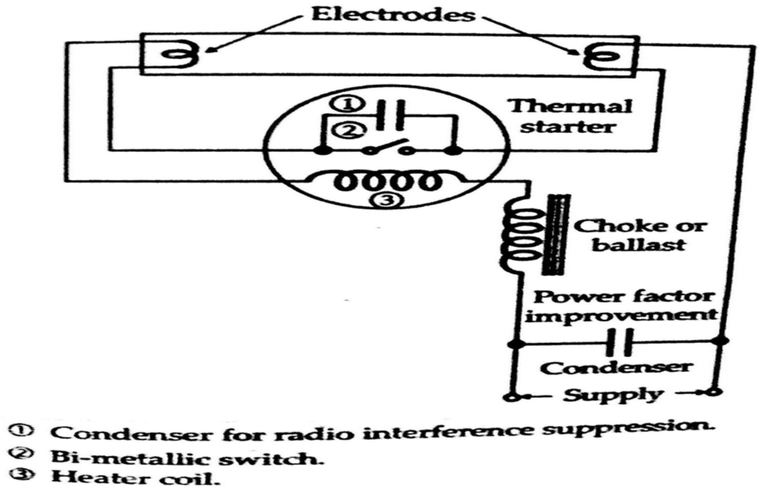


Fig 2.19: Fluorescent lamp using thermal starter

Thermal starter has a heater coil which heats the bimetallic switch.Heater coil remains energised to keep the switch open throughout the operation of lamp.When the supply is switched on the contacts of the bimetallic switches are closed and current passes through the electrodes and heats them.After 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 the presence of choke or ballast in the circuit, therefore the arc is struck between the electrodes. The high frequency radio interference is bypassed through the filter circuit provided by a radio interference suppression condenser

2. Glow starter

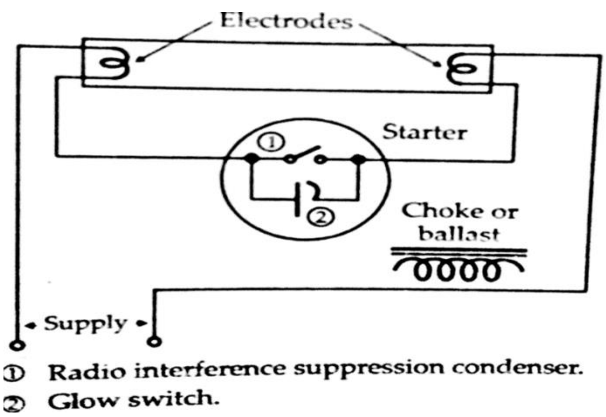


Fig 2.20: Fluorescent lamp using glow starter

Circuit for instant starting

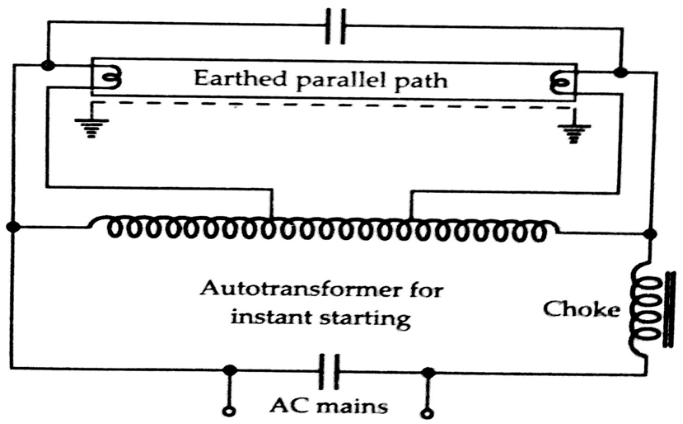


Fig 2.21: Circuit for instant starting of fluorescent lamp

This is the ckt does not use starter.When the supply is switched on the voltage across the lamp is very nearly the full supply voltage.The tappings of autotransformer heats up the electrodes such that the arc strikes after immediate switching. Since a lower voltage is required to maintain the discharge through the tube, the voltage across the transformer falls to a normal value.Voltage across tappings is reduced which in turn reduces current through the electrodes.Choke is necessary to limit the current though the tube

Operation on Direct current:

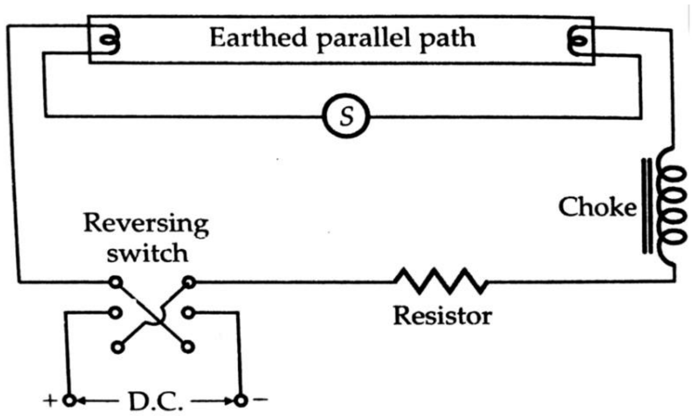


Fig 2.22: Operation of fluorescent lamp on Dc

The choke coil will have a low impedence on d.c. and hence a series resistor limiting the current will have to be used**.** Positive end will become dark as there is tendency of mercury vapour migrate towards negative end of tube**.** On systems below 220v starting becomes less certain on d.c than a.c. Only thermal type of starters should be used at any voltage

2.8 Lighting Fittings

A lighting fitting may be one out of large no. of shades, reflectors, diffusers, etc. Helpful in controlling & directing the luminous flux from a lamp.Reducing the observed brightness of the lamp.Light can be controlled by specular reflection, diffuse reflection, spread reflection, refraction & transmission

1. **Symmetrical fittings**:

The light fittings in which the flux distribution is symmetrical about vertical axis

a) Direct fittings or A type fittings:

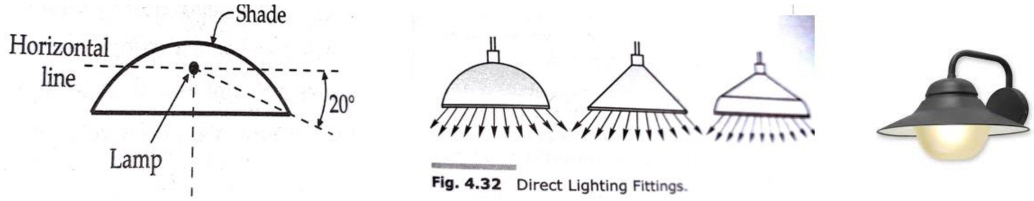


Fig 2.23 a) Direct fittings or A type fittings

- 90 per cent of the total luminous flux is directed in the lower hemisphere and only about 10 per cent of the total flux goes in the upper hemisphere.
- Consists of a reflector mounted above the lamp
- Generally used in industrial applications.
- The reflector may be of plastic or vitreous enamel.
- The spacing to height ratio generally used is 1.5.
- The angle of cut off is about 20 deg when they are be used at a height of 45 metres or so.

b) Semi-direct fittings or B type fittings:

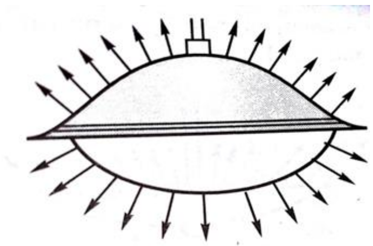


Fig 2.23 b) Semi-direct fittings or B type fittings

- More than 60 per cent but less than 90 per cent of the total flux is in the lower hemisphere.
- Remaining flux goes up, the ceiling and the upper portions of the side walls are also bright to some extent and this helps in reducing the overall brightness contrast.
- For use with incandescent lamps, they are translucent fittings

c) General diffusing fittings or C type fittings:

- In which not less than 40 per cent and not more than 60 per cent of the total flux is directed
- These are also translucent fittings and the brightness contrast is further reduced.
- The shadows are soft.

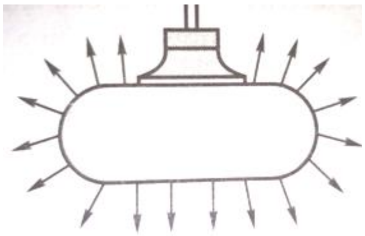


Fig 2.23 c) General diffusing fittings or C type fittings

d) Semi-indirect fittings or D type fittings:

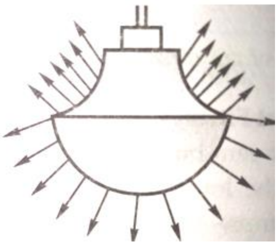


Fig 2.23 d) Semi-indirect fittings or D type fittings

- more than 60 per cent but less than 90 per cent of the total flux is directed in the upper hemisphere
- They require frequent cleaning since their bowl-shape construction collects dust and insects.
- Shadows are faint and such fittings are used for decorative purposes with high voltage lamps.

e) Indirect fittings or E type fittings:

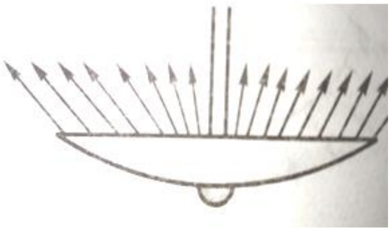


Fig 2.23 e) Indirect fittings or E type fittings

- Not less than 90 per cent of the total flux is directed in the upper hemisphere.
- Since practically all the flux is directed towards the ceiling and upper portions of the walls, light is received by reflection from these.
- There is no glare and no shadow.

2. **Asymmetrical fittings:**

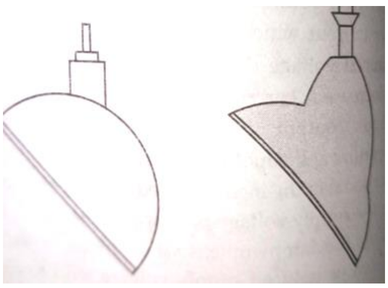


Fig 2.24: Asymmetrical fittings

- There are requirements in industry where the flux may have to be directed at a particular angle and the lighting will have to be provided with a directional feature by having parabolic and elliptical reflectors and some such devices.
- They may have to be watertight and vapour proof also.
- Fittings may also have to take care of the atmospheric conditions and the conditions a obtaining inside shops like foundries, saw mills, textile mills, etc.

2.9 Factory Lighting

Need for factory lighting:

1. increases the productivity of labour
2. improves the quality of the work and product
3. Reduces the number of work stoppages
4. Helps reduce accidents

Light fittings must be simple, easily cleanable, no glare due to reflection

2.9.1 Requirements of good factory lighting

1. There should be enough illumination for the eye to see details clearly without strain or fatigue
2. The shape of objects should be clearly visible to the eye on account of proper brightness contrast.
3. There should be no glare or dazzling effect from light sources
4. Safety lighting fittings must be provided so that these can be used in event of failure of main supply or during accident
5. Requisite illumination level should be obtained at minimum cost

Machine shops are provided with 2 types of lighting

1. General Lighting
2. Local lighting

1.General Lighting:

- Usual lighting scheme in factory: to mount no. of lamps at a reasonable height – uniform light distribution on working plane
- Walls must be white washed or pained – illumination on working plane will be more effective
- Provided by enamelled or mirror type fittings with a suitable cut off angle

2.Local lighting:

- In factories at some work places, more illumination is required and this extra illumination is supplied by local lighting
- Local lighting is provided by adjustable fittings mounted on machine or portable floor stands
- Such lamps must be mounted in deep reflectors to avoid glare
- Low voltage lamps(less than 50v)
- It is provided according to individual requirement of machine

2.10 Flood Lighting

- It is employed to serve one or more of the following purpose :

- **Aesthetic flood** : For enhancing beauty of building at night such as public place , ancient building and monument , religious building on important festival occasion, etc.
- **Industrial and commercial flood:** For illuminating railway yards, sport stadium, car parking, construction sites , quarries, etc.
- **Advertising :** for illuminating advertisement boards and showcases.

2 types of equipment are used in flood lighting:

Enclosed type & *Open type*

Enclosed type:

- Consists of lamp with reflector
- Beam is accurately controlled
- Dust-proof and watertight
- Expensive

Open type:

- Suitable for direct lighting at broad angles
- Reflector protects light source from rain
- Reflector directs light horizontally and downwards
- Less costly

2.11 Street Lighting

Objective:

- To make the traffic and obstructions on the road clearly visible.
- The level of illumination has to be low for economic reasons and the colour of the objects is not important.
- There should be no glare as far as possible

The design principles

(a) The Diffusion Principle.

(b) The Specular Reflection Principle

(a) Diffusion Principle: The lamps are fitted with suitable reflectors which spread the light as uniformly as possible over the road surface. The road surface appears bright to the observer. The reflectors are so shaped with cut off angle of 30 to 45 deg that the lamp filament is not visible except from underneath it. This avoids glare. Illumination at any point road surface is calculated using Inverse square law

(b) Specular Reflection Principle: In this method, light falls on an object at a very large angle of incidence and is therefore reflected at a correspondingly large angle.From Fig.,the object A appear bright against the bright road surface on account of the light from lamps L2 and L3 rather than L1,L2,L3 .The reflector should be so designed throws light on the road surface at a very large angle of incidence. Disadvantage of the method is that it produces glare and is only suitable for straight sections of the road.

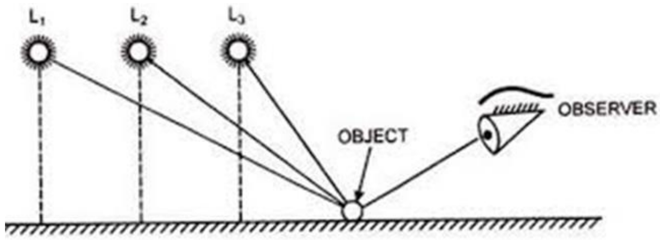


Fig 2.25: Specular Reflection Principle

2.12 Requirements of good lighting

Factors affect good lighting:

1. Illumination level: Degree of illumination is important as it gives the necessary brightness to the object to be viewed.
2. Contrast: Background brightness against which the eye locates the object is the contrast. If the contrast is too much, eye gets irritated.
3. Shadow: Long and sharp shadows cause rapid fatigue of eye. This should be avoided. Avoidance of long and sharp shadows is possible by:

i. Using high mounting heights of lamps
ii. Employing large number of lamps
iii. Employing wide surface source of light fluorescent lamps)

4. Glare:

i. If the light enters directly to the eye in large quantities, it produces glare.

ii. The glare may be due to the source itself or due to the polished surface causing reflection of light and incident directly on the eye.

iii. Glare can be avoided by increasing the height of the lamp and by using proper reflections

5. Colour rendering:

a. Light produced by sun or incandescent source consists of all wavelength in visible spectrum.
b. Radiations of different wavelengts produce sensation of different colours.
c. Thus, when a white light hits an object, the object absorbs all the radiations except one which will, after reflection, enter the eye producing the sensation of the colour of the object.

d. As for example, if a white light falls on a body of blue colour, it will absorb all components wavelengths of the white light except the wavelength corresponding to blue colour.
e. Colour rendering of incandescent light and fluorescent light is better than that of sodium or mercury vapour lamps

Module Outcomes:

1. Explain the terminology of illumination, laws of illumination
2. construction and working of electric lamps.
3. Design interior and exterior lighting systems- illumination levels for factory lighting-flood lighting-street lighting.

MODULE-3

ELECTRIC TRACTION

Structure

Electric Traction Speed - Time Curves and Mechanics of Train Movement

- Introduction, Systems of Traction, Systems of electric Traction
- Speed - Time Curves for Train Movement, Mechanics of Train Movement
- Train Resistance, Adhesive Weight, Coefficient of Adhesion.

Motors for Electric traction: Introduction, Series and Shunt Motors for Traction Services

- Two Similar Motors (Series Type) are used to drive a Motor Car
- Tractive Effort and Horse Power
- AC Series Motor
- Three Phase Induction Motor.

Control of motors: Control of DC Motors, Tapped Field Control or Control by Field Weakening

- Multiple Unit Control
- Control of Single Phase Motors
- Control of Three Phase Motors.

Module Objectives:

1. To discuss systems of electric traction, speed time curves and mechanics of train movement.
2. To discuss motors used for electric traction and their control.

3.1Introduction

Electric traction is meant locomotion in which the driving (or tractive) force is obtained from electric motors. It is used in electric trains, tramcars, trolley buses and diesel-electric vehicles etc.
Electric traction has many advantages as compared to other non-electrical systems of traction including steam traction.

3.2 Traction Systems:

Broadly speaking, all traction systems may be classified into two categories :
(a) Non-electric traction systems

They do not involve the use of electrical energy at ***any stage***. Examples are : steam engine drive used in railways and internal-combustion-engine drive used for road transport.

(b) Electric traction systems

They involve the use of electric energy at some stage or the other. They may be further subdivided into two groups :

1. First group consists of self-contained vehicles or locomotives. Examples are : battery-electric drive and diesel-electric drive etc.

2. Second group consists of vehicles which receive electric power from a distribution network fed at suitable points from either central power stations or suitably-spaced sub-stations.

Examples are : railway electric locomotive fed from overhead ac supply and tramways and trolly buses supplied with dc supply.

3.2.1 Direct Steam Engine Drive:

Though losing ground gradually due to various reasons, steam locomotive is still the most widelyadopted means of propulsion for railway work. Invariably, the reciprocating engine is employed because

1. it is inherently simple.

2. connection between its cylinders and the driving wheels is simple.

3. its speed can be controlled very easily.

However, the steam locomotive suffers from the following disadvantages :

1. since it is difficult to install a condenser on a locomotive, the steam engine runs non-condensing and, therefore, has a very low thermal efficiency of about 6-8 percent.

2. it has strictly limited overload capacity.

4. it is available for hauling work for about 60% of its working days, the remaining 40% being spent in preparing for service, in maintenance and overhaul.

3.2.2 Diesel-electric Drive:

It is a self-contained motive power unit which employs a diesel engine for direct drive of a dc generator. This generator supplies current to traction motors which are geared to the driving axles. In India, diesel locomotives were introduced in 1945 for shunting service on broad guage (BG) sections and in 1956 for high-speed main-line operations on metre-guage (MG) sections. It was only in 1958 that Indian Railways went in for extensive main-line dieselisation.

Diesel-electric traction has the following advantages :

i. no modification of existing tracks is required while converting from steam to diesel-electric traction.

ii. it provides greater tractive effort as compared to steam engine which results in higher starting acceleration.

iii. it is available for hauling for about 90% of its working days.

iv. diesel-electric locomotive is more efficient than a steam locomotive (though less efficient than an electric locomotive)

Disadvantages:

i. for same power, diesel-electric locomotive is costlier than either the steam or electric locomotive.

ii. overload capacity is limited because diesel engine is a constant-kW output prime mover.

iii. life of a diesel engine is comparatively shorter.

iv. diesel-electric locomotive is heavier than plain electric locomotive because it carries the main engine, generator and traction motors etc.

v. regenerative braking cannot be employed though rheostatic braking can be.

3.2.3 Battery-electric Drive:

In this case, the vehicle carries secondary batteries which supply current to dc motors used for driving the vehicle. Such a drive is well-suited for shunting in railway yards, for traction in mines, for local delivery of goods in large towns and large industrial plants.

They have low maintenance cost and are free from smoke. However, the scope of such vehicles is limited because of the small capacity of the batteries and the necessity of charging them frequently.

3.3.1 Advantages of Electric Traction:

As compared to steam traction, electric traction has the following advantages :

1. Cleanliness. Since it does not produce any smoke or corrosive fumes, electric traction is most suited for underground and tube railways. Also, it causes no damage to the buildings and other apparatus due to the absence of smoke and flue gases.

2. Maintenance Cost. The maintenance cost of an electric locomotive is nearly 50% of that for a steam locomotive. Moreover, the maintenance time is also much less.

3. Starting Time. An electric locomotive can be started at a moment's notice whereas a steam locomotive requires about two hours to heat up.

4. High Starting Torque. The motors used in electric traction have a very high starting torque. Hence, it is possible to achieve higher accelerations of 1.5 to 2.5 km/h/s as against 0.6 to 0.8 km/h/s in steam traction. As a result, we are able to get the following additional advantages:

(i) high schedule speed

(ii) increased traffic handling capacity

(iii)because of (*i*) and (*ii*) above, less terminal space is required—a factor of great importance in urban areas.

5. Braking. It is possible to use regenerative braking in electric traction system. It leads to the following advantages :

(i) about 80% of the energy taken from the supply during ascent is returned to it during descent.

(ii) goods traffic on gradients becomes safer and speedier.

(iii)since mechanical brakes are used to a very small extent, maintenance of brake shoes, wheels, tyres and track rails is considerably reduced because of less wear and tear.

6. Saving in High Grade Coal. Steam locomotives use costly high-grade coal which is not so abundant. But electric locomotives can be fed either from hydroelectric stations or pit-head thermal power stations which use cheap low-grade coal. In this way, high-grade coal can be saved for metallurgical purposes.

7. Lower Centre of Gravity. Since height of an electric locomotive is much less than that of a steam locomotive, its centre of gravity is comparatively low. This fact enables an electric locomotive to negotiate curves at higher speeds quite safely.

8. Absence of Unbalanced Forces. Electric traction has higher coefficient of adhesion since there are no unbalanced forces produced by reciprocating masses as is the case in steam traction. It not only reduces the weight/kW ratio of an electric locomotive but also improves its riding quality in addition to reducing the wear and tear of the track rails.

3.3.2 Disadvantages of Electric Traction

1. The most vital factor against electric traction is the initial high cost of laying out overhead electric supply system. Unless the traffic to be handled is heavy, electric traction becomes uneconomical.

2. Power failure for few minutes can cause traffic dislocation for hours.

3. Communication lines which usually run parallel to the power supply lines suffer from electrical interference. Hence, these communication lines have either to be removed away from the rail track or else underground cables have to be used for the purpose which makes the entire system still more expensive.

4. Electric traction can be used only on those routes which have been electrified. Obviously, this restriction does not apply to steam traction.

3.4 Systems of Railway Electrification

Presently, following four types of track electrification systems are available:

1. Direct current system—600 V, 750 V, 1500 V, 3000 V

2. Single-phase ac system—15-25 kV, 16 23, 25 and 50 Hz

3. Three-phase ac system—3000-3500 V at 16 2 3 Hz

4. Composite system—involving conversion of single-phase ac into 3-phase ac or dc.

1. Direct Current System

Direct current at 600-750 V is universally employed for tramways in urban areas and for many suburban railways while 1500-3000 V dc is used for main line railways. The current collection is from third rail (or conductor rail) up to 750 V, where large currents are involved and from overhead wire for 1500 V and 3000 V, where small currents are involved. Since in majority of cases, track (or running) rails are used as the return conductor, only one conductor rail is required. Both of these contact systems are fed from substations which are spaced 3 to 5 km for heavy suburban traffic and40-50 km for main lines operating at higher voltages of 1500 V to 3000 V.

These sub-stations themselves receive power from 110/132 kV, 3-phase network (or grid). At these substations, this high-voltage 3-phase supply is converted into low-voltage 1-phase supply with the help of Scott connected or V-connected 3-phase transformers (Art. 31.9). Next, this low ac voltage is converted into the required dc voltage by using suitable rectifiers or converters (like rotary converter, mercury arc,
metal or semiconductor rectifiers). These substations are usually automatic and are remote controlled.
The dc supply so obtained is fed via suitable contact system to the traction motors which are either dc series motors for electric locomotive or compound motors for tramway and trolley buses where regenerative braking is desired.

2. Single-Phase Low-frequency AC System

In this system, ac voltages from 11 to 15 kV at 23 16 or 25 Hz are used. If supply is from a generating station exclusively meant for the traction system, there is no difficulty in getting the electric supply of 23 16 or 25 Hz. If, however, electric supply is taken from the high voltage transmission lines at 50 Hz, then in addition to step-down transformer, the substation is provided with a frequency converter. The frequency converter equipment consists of a 3-phase synchronous motor which drives a I-phase alternator having or 25 Hz frequency.
The 15 kV 23 16 or 25 Hz supply is fed to the electric locomotors via a single over-head wire (running rail providing the return path).
A step-down transformer carried by the locomotive reduces the 15-kV voltage to 300-400 V for feeding the ac series motors. Speed regulation of ac series motors is achieved by applying variable voltage from the tapped secondary of the above transformer. Low-frequency ac supply is used because apart from improving the commutation properties of ac motors, it increases their efficiency and power factor. Moreover, at low frequency, line reactance is less so that line impedance drop and hence line voltage drop is reduced. Because of this reduced line drop, it is feasible to space the substations 50 to 80 k

3. Three-phase Low-frequency AC System

It uses 3-phase induction motors which work on a 3.3 kV, 23
16 Hz supply. Sub-stations receive power at a very high voltage from 3-phase transmission lines at the usual industrial frequency of 50 Hz. This high voltage is stepped down to 3.3 kV by transformers whereas frequency is reduced from 50 Hz to 23 16 Hz by frequency converters installed at the substations. Obviously, this system employs *two* overhead contact wires, the track rail forming the third phase (of course, this leads to insulation difficulties at the junctions). Induction motors used in the system are quite simple and robust and give trouble-free operation.
They possess the merits of high efficiency and of operating as a generator when driven at speeds above the synchronous speed. Hence, they have the property of automatic regenerative braking during the descent on gradients. However, it may be noted that despite all its advantages, this system has not found much favor and has; in fact, become obsolete because of it‘s certain inherent limitations given below:

1. The overhead contact wire system becomes complicated at crossings and junctions.

2. constant-speed characteristics of induction motors are not suitable for traction work.

3. Induction motors have speed/torque characteristics similar to dc shunt motors. Hence, they are not suitable for parallel operation because, even with little difference in rotational speeds caused by unequal diameters of the wheels, motors will becomes loaded very unevenly.

3.5 Typical Speed/Time Curve

Typical speed/time curve for electric trains operating on passenger services is shown in Fig. 43.8. It may be divided into the following **five** parts :

1. Constant Acceleration Period (0 to t1)

It is also called notching-up or starting period because during this period, starting resistance of the motors is gradually cut out so that the motor current (and hence, tractive effort) is maintained nearly constant which produces constant acceleration alternatively called _rheostatic acceleration‘ or
_acceleration while notching‘.

2. Acceleration on Speed Curve

(t1 to t2)

This acceleration commences after the starting resistance has been all cutout at point *t*1 and full supply voltage has been applied to the motors. During this period, the motor current and torque decrease as train speed increases. Hence, acceleration gradually ***decreases*** till torque developed by motors exactly balances that due to resistance to the train motion. The shape of the portion *AB* of the speed/time curve depends primarily on the torque/speed characteristics of the traction motors.

3. Free-running Period (t2 to t3)

The train continues to run at the speed reached at point *t*2. It is represented by portion *BC* in Fig.
43.8 and is a constant-speed period which occurs on level tracks.

4. Coasting (t3 to t4)

Power to the motors is cut off at point *t*3 so that the train runs under its momentum, the speed gradually falling due to friction, windage etc. (portion *CD*). During this period, retardation remains practically constant. Coasting is desirable because it utilizes some of the kinetic energy of the train which would, otherwise, be wasted during braking. Hence, it helps to reduce the energy consumption of the train.

5. Braking (t4 to t5)

At point t4, brakes are applied and the train is brought to rest at point *t*5.

It may be noted that coasting and braking are governed by train resistance and allowable retardation respectively.

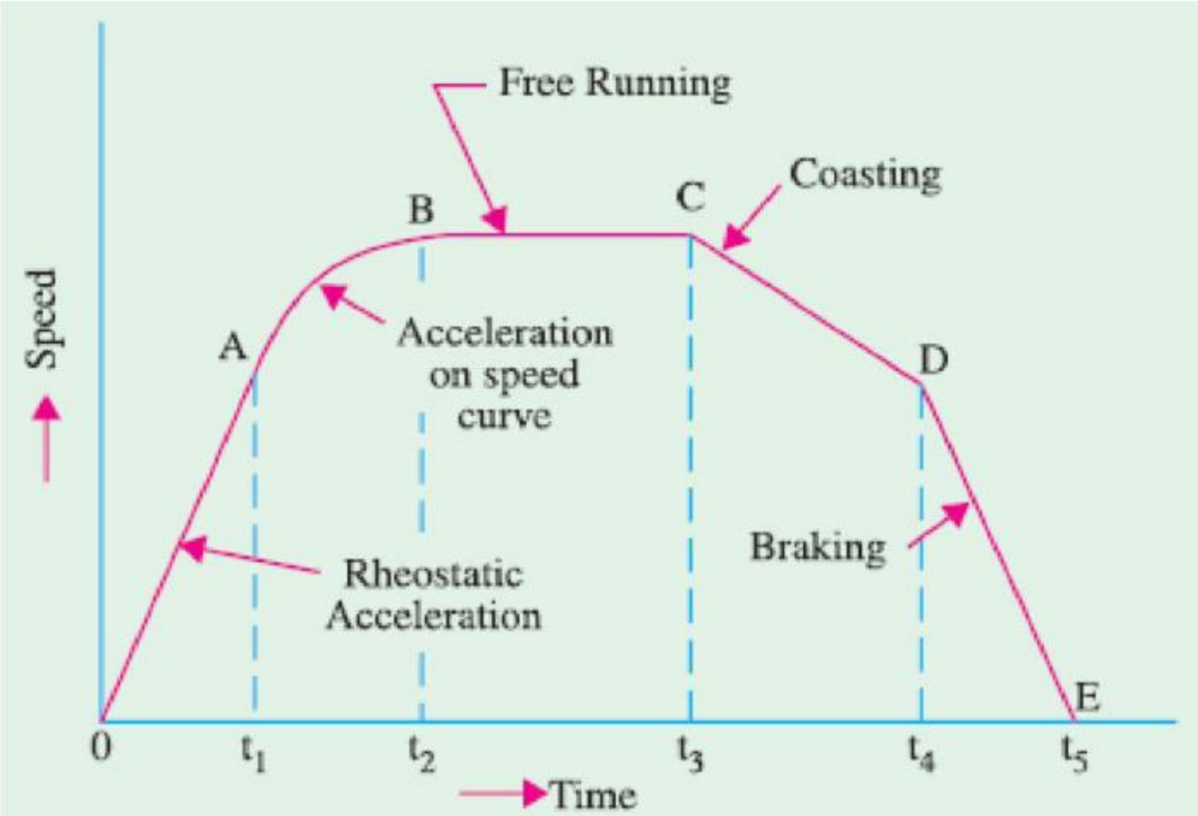


Fig: 3.1 Typical Speed-time curve

3.5.1 Speed/Time Curves for Different Services

Fig. 3.2 is representative of city service where relative values of acceleration and retardation are high in order to achieve moderately high average speed between stops. Due to short Distances between stops, there is no possibility of free-running period though a short coasting period is included to save on energy consumption.

In suburban services, again there is no free-running period but there is comparatively ***longer*** coasting period because of longer distances between stops. In this case also, relatively high values of acceleration and retardation are required in order to make the service as attractive as Possible.

For main-line service, there are long periods of free-running at high speeds. The accelerating and retardation periods are relatively unimportant.

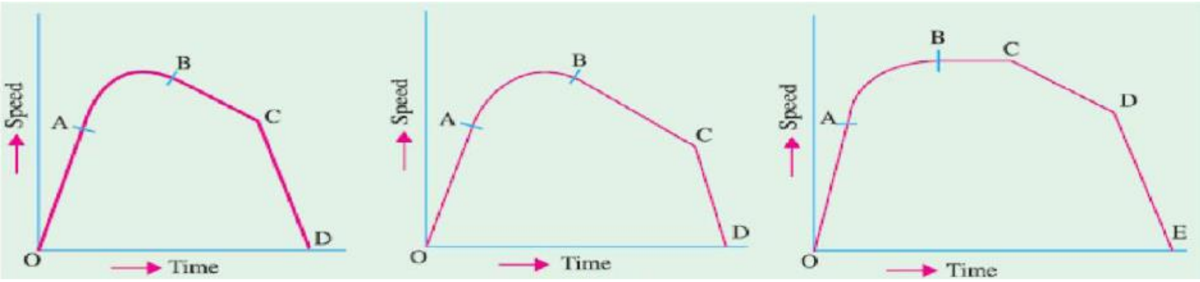


Fig 3.2 Speed/Time Curves for Different Services

3.5.2 Simplified Speed/Time Curve

For the purpose of comparative performance for a given service, the actual speed/time curve of Fig. 3.1 is replaced by a simplified speed/time curve which does not involve the knowledge of motor characteristics. Such a curve has simple geometric shape so that simple mathematics can be used to find the relation between acceleration, retardation, average speed and distance etc. The simple curve would be fairly accurate provided it **(*i*) *retains the same acceleration and retardation and (ii) has The same area as the actual speed/time curve***. The simplified speed/time curve can have either of the two shapes:

(i) trapezoidal shape *OA*1*B*1*C* of Fig. 43.10 where speed-curve running and coasting periods of the actual speed/time curve have been replaced by a constant speed period.

(ii) Quadrilateral shape *OA*2*B*2*C* where the same two periods are replaced by the extensions of initial constant acceleration and coasting periods. It is found that trapezoidal diagram *OA*1*B*1*C* gives simpler relationships between the principal quantities involved in train movement and also gives closer approximation of actual energy consumed during ***main-line service on level track***. On the other hand, quadrilateral diagram approximates more closely to the actual conditions in ***city and suburban services***.

3.5.3 Average and Schedule Speed

While considering train movement, the following three speeds are of importance :

1. Crest Speed. It is the maximum speed (*Vm*) attained by a train during the run.

2. Average Speed =distance between stops actual time of run

In this case, only running time is considered but *not the stop time*.

3. Schedule Speed = distance between stops actual time of run + stop time

Obviously, schedule speed can be obtained from average speed by including the duration of stops. For a given distance between stations, higher values of acceleration and retardation will mean lesser running time and, consequently, higher schedule speed. Similarly, for a given distance between stations and for fixed values of acceleration and retardation, higher crest speed will result in higher schedule speed. For the same value of average speed, increase in duration of stops decreases the schedule speed.

3.5.4 SI Units in Traction Mechanics

In describing various quantities involved in the mechanics of train movement, only the latest SI system will be used. Since SI system is an _absolute system‘, only absolute units will be used while gravitational units (used hitherto) will be discarded.

1. Force. It is measured in newton (N)

2. Mass. Its unit is kilogram (kg). Commonly used bigger units is tonne (*t*), 1 tonne = 1000 kg

3.Energy. Its basic unit is joule (J). Other units often employed are watt-hour (Wh) and kilowatthour (kWh).

4. Work. Its unit is the same as that of energy.

5. Power. Its unit is watt (W) which equals 1 J/s. Other units are kilowatt (kW) and megawatt (MW).

6. Distance. Its unit is metre. Other unit often used is kilometre (km).

7. Velocity. Its absolute unit is metre per second(m/s). If velocity is given in km/h (or km.ph), it can be easily converted into the SI unit of m/s by multiplying it with a factor of
8. Acceleration. Its unit is metre/second2 (m/s2). If acceleration is given in km/h/s (or kmph. ps), then it can be converted into m/s2 by simply multiplying it by the factor (1000/3600) = 5/18 = 0.2778 *i.e.* the same factor as for velocity.

3.5.5 Relationship Between Principal Quantities in Trapezoidal Diagram

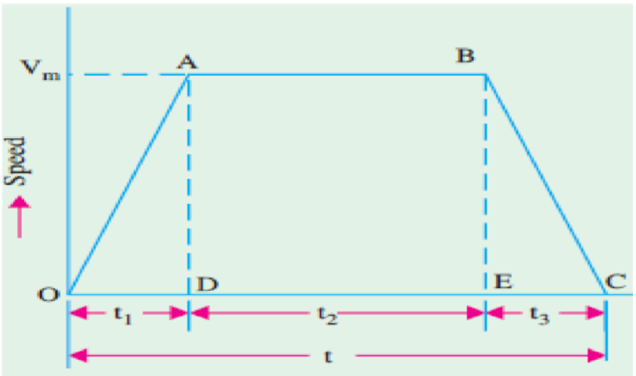


Fig 3.3 : Trapezoidal Speed time curve

$\alpha = Vm/t_1$ or $t1 = Vm/\alpha$

$\beta = Vm/t_3$ or $t_3 = Vm/\beta$

As we know, total distance D between the two stops is given by the area of trapezium $OABC$. therefore

D = area $OABC$

= area OAD + area $ABED$ + area BCE

$$=1/2Vmt_1 + Vmt_2 + 1/2Vmt_3$$

$$= \frac{1}{2} V_m t_1 + V_m[t-(t_1+t_3)] + \frac{1}{2} V_m t_3$$
$$= V_m\left[\frac{t_1}{2} + t - t_1 - t_3 + \frac{t_3}{2}\right]$$
$$= V_m\left[t - \frac{1}{2}(t_1+t_3)\right]$$
$$= V_m\left[t - \frac{V_m}{2}\left(\frac{1}{\alpha}+\frac{1}{\beta}\right)\right]$$

Let, $K = \frac{1}{2}\left(\frac{1}{\alpha}+\frac{1}{\beta}\right)$. Substituting this of K in the above equation, we get

$$D = V_m(t - KV_m)$$

or $KV_m^2 - V_m t + D = 0$

$$\therefore \quad V_m = \frac{t \pm \sqrt{t^2 - 4KD}}{2K}$$

Rejecting the positive sign which gives impracticable value, we get

$$V_m = \frac{t \pm \sqrt{t^2 - 4KD}}{2K}$$

From Eq. (*i*) above, we get

$$KV_m^2 = V_m t - D \qquad \text{or} \qquad K = \frac{t}{V_m} - \frac{D}{V_m^2} = \frac{D}{V_m^2}\left(V_m \cdot \frac{t}{D} - 1\right)$$

Now, $V_a = \frac{D}{t}$ $\quad\therefore\quad$ $K = \frac{D}{V_m^2}\left(\frac{V_m}{V_a} - 1\right)$

3.5.6 Relationship Between Principal Quantities in Quadrilateral Diagram

Let β*c* represent the retardation during coasting period

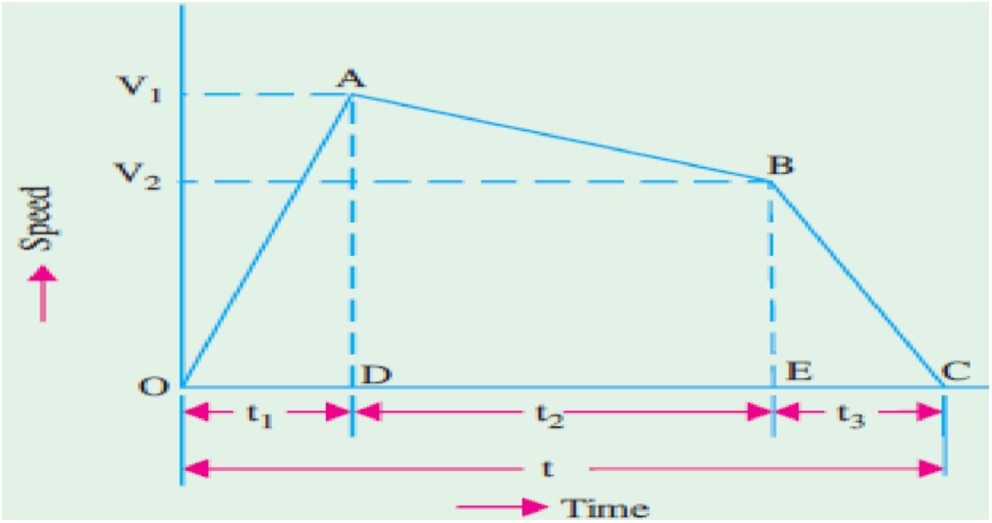


Fig 3.4 Quadrilateral speed time curve

$t_1 = V_1/\alpha,\ t_2 = (V_2 - V_1)/\beta_c$ and $t_3 = V_2/\beta$

$$
\begin{aligned}
D &= \text{area } OABC \\
&= \text{area } OAD + \text{area } ABED + \text{area } BCE \\
&= \frac{1}{2}V_1 t_1 + t_2\left(\frac{V_1 + V_2}{2}\right) + \frac{1}{2}V_2 t_3 \\
&= \frac{1}{2}V_1(t_1 + t_2) + \frac{1}{2}V_2(t_2 + t_3) \\
&= \frac{1}{2}V_1(t - t_3) + \frac{1}{2}V_2(t - t_1) \\
&= \frac{1}{2}t(V_1 + V_2) - \frac{V_1 t_1}{2} - \frac{V_1 t_3}{2} \\
&= \frac{1}{2}t(V_1 + V_2) - \frac{1}{2}V_1 V_2\left(\frac{1}{\alpha} + \frac{1}{\beta}\right) \\
&= \frac{1}{2}t(V_1 + V_2) - KV_1 V_2
\end{aligned}
$$

where $K = \frac{1}{2}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right) = \frac{\alpha + \beta}{2\alpha\beta}$ Also, $\beta_c = \frac{(V_1 - V_2)}{t_2}$

$$\therefore \quad V_2 = V_1 - \beta_c t_2 = V_1 - \beta_c(t - t_1 - t_3)$$

$$= V_1 - \beta_c\left(t - \frac{V_1}{\alpha} - \frac{V_2}{\beta}\right) = V_1\beta_c\left(t - \frac{V_1}{\alpha}\right) + \beta_c\frac{V_2}{\beta}$$

or $V_2\left(1 - \frac{\beta_c}{\beta}\right) = V_1 - \beta_c\left(t - \frac{V_1}{\alpha}\right) \qquad \therefore \quad V_2 = \frac{V_1 - \beta_c(t - V_1/\alpha)}{(1 - \beta_c/\beta)}$

3.6 Tractive Effort for Propulsion of a Train

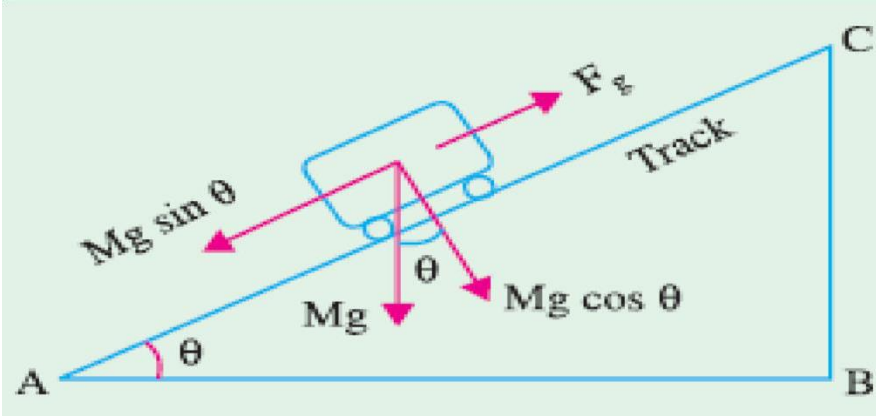


Fig 3.5 Tractive Effort for Propulsion of a Train

The tractive effort (*Ft*) is the force developed by the traction unit at the rim of the driving wheels for moving the unit itself and its train (trailing load). The tractive effort required for train propulsion on a *level track* is

Ft = *Fa* + *Fr*

If gradients are involved, the above expression becomes

Ft = *Fa* + *Fg* + *Fr* — for ascending gradient = *Fa* − *Fg* + *Fr* — for descending gradient

where *Fa* = force required for giving linear acceleration to the train

Fg = force required to overcome the effect of gravity

Fr = force required to overcome resistance to train motion.

(*a*) Value of Fa

If *M* is the dead (or stationary) mass of the train and a its linear acceleration, then

Fa = *Ma*

Since a train has rotating parts like wheels, axles, motor armatures and gearing etc., its *effective* (or accelerating) mass *Me* is more (about 8 − 15%) than its stationary mass.

These parts have to be given angular acceleration at the same time as the whole train is accelerated in the linear direction.

Hence, *Fe* = *Mea*

(*ii*) If *Me* is in tonne and α in km/h/s, then converting them into absolute units, we have *Fa* = (1000 *Me*) × (1000/3600) *a* = 277.8 *Me a* newton

(*b*) Value of Fg

As seen from Fig. 43.13, *Fg* = *W* sin θ = *Mg* sin θ

In railway practice, gradient is expressed as the rise (in metres) a track distance of 100 m and is called percentage gradient.

Therefore % *G* = 100/100

BC /*BC*

AC /*AC* = = 100 sin θ Substituting the value of sin θ in the above equation, we

Get *Fg* = *Mg G*/100 = 9.8 × 10−2 *MG*

(i) When *M* is in kg, *Fg* = 9.8 × 10−2 *MG* newton

(ii) When *M* is given in tonne, then

$F_g = 9.8 \times 10^{-2}$ (1000 M) G = 98 MG Newton

***(c)*Value of Fr**

Train resistance comprises all those forces which oppose its motion. It consists of mechanical resistance and wind resistance. Mechanical resistance itself is made up of internal and external resistances. The internal resistance comprises friction at journals, axles, guides and buffers etc. The external resistance consists of friction between wheels and rails and flange friction etc. Mechanical resistance is almost independent of train speed but depends on its weight. The wind friction varies directly as the square of the train speed. If r is specific resistance of the train *i.e.* resistance offered per unit mass of the train, then $F_r = M.r$.

(i) If r is in newton per kg of train mass and M is the train mass in kg, then
$F_r = M.r$ newton

(ii) If r is in newton per tonne train mass (N/t) and M is in tonne (t), then

$F_r = M$ tonne $\times r = Mr$ newton*
Hence, expression for total tractive effort becomes
$F_t = F_a \pm F_g + F_r = (277.8\ \alpha Me \pm 98\ MG + Mr)$ newton
Please remember that here M is in tonne, α in km/h/s, G is in metres per 100 m of track length (*i.e.* % G) and r is in newton/tonne (N/t) of train mass.

The positive sign for F_g is taken when motion is along an ascending gradient and negative sign when motion is along a descending gradient.

Power Output from Driving Axles

If F_t is the tractive effort and ν is the train velocity, then output power = $F_t \times \nu$

(i) If F_t is in newton and ν in m/s, then output power = $F_t \times \nu$ watt

(ii) If F_t is in newton and ν is in km/h , then converting ν into m/s,

* If r is in kg (wt) per tonne train mass and M is in tonne, then $F_r = M$ tonne × (r × 9.8) newton/tonne = 9.8

$$\text{output power} = F_t \times \left(\frac{1000}{3600}\right)\nu \text{ watt} = \frac{F_t\,\nu}{3600}\text{ kW}$$

If η is the efficiency of transmission gear, then power output of motors is

$$= F_t\,.\,\nu/\eta \text{ watt} \qquad \text{— }\nu\text{ in m/s}$$

$$= \frac{F_t\,\nu}{3600\,\eta}\text{ kW} \qquad \text{— }\nu\text{ in km/h}$$

Energy Output from Driving Axles

Energy (like work) is given by the product of power and time. $E = (F_t \times v) \times t = F_t \times (v \times t) = F_t \times D$ where D is the distance travelled in the direction of tractive effort.

Total energy output from driving axles for the run is

E = energy during acceleration + energy during free run

$E = F_t \times$ area $OAD + F_t' \times$ area $ABED = F_t \times 1/2 V_m t_1 + F_t' \times 1/2 V_m t_2$ where F_t is the tractive effort during accelerating period and F_t' that during free running period. Incidentally, F_t will consist of all the three components given in Art. 43.37 whereas F_t' will consist of (98 $MG + Mr$) provided there is an ascending gradient.

3.7 Specific Energy Output

It is the energy output of the driving wheel expressed in watt-hour (Wh) per tonne-km (*t*-km) of the train. It can be found by first converting the energy output into Wh and then dividing it by the mass of the train in tonne and route distance in km.

Hence, unit of specific energy output generally used in railway work is : Wh/tonne-km (Wh/t-km).

Evaluation of Specific Energy Output

We will first calculate the total energy output of the driving axles and then divide it by train mass in tonne and route length in km to find the specific energy output. It will be presumed that :

(i) there is a gradient of G throughout the run and

(ii) power remains ON upto the end of free run in the case of trapezoidal curve and upto the accelerating period in the case of quadrilateral curve

Now, output of the driving axles is used for the following purposes :

1. for accelerating the train **2.** for overcoming the gradient

3. for overcoming train resistance.

(*a*) Energy required for train acceleration (*Ea*)

As seen from trapezoidal diagram

$$E_a = F_a \times \text{distance } OAD = 277.8\,\alpha M_e \times \frac{1}{2} V_m . t_1 \text{ joules}$$

$$= 277.8\,\alpha M_e \times \frac{1}{2} V_m \times \frac{V_m}{\alpha} \text{ joules} \qquad \left(\text{फ}t_1 = \frac{V_m}{\alpha}\right)$$

$$= 277.8\,\alpha M_e \times \left[\frac{1}{2} . \frac{V_m \times 1000}{3600} \times \frac{V_m}{\alpha}\right] \text{ joules}$$

It will be seen that since V_m is in km/h, it has been converted into m/s by multiplying it with the conversion factor of (1000/3600). In the case of (V_m /t), conversion factors for V_m and a being the same, they cancel out. Since 1 Wh = 3600 J.

$$\therefore \quad E_a = 277.8\,\alpha\,M_e\left[\frac{1}{2}.\frac{V_m \times 1000}{3600}\times\frac{V_m}{\alpha}\right]\text{Wh} = 0.01072\,\frac{V_m^2}{M_e}\text{ Wh}$$

$$E = E_a + E_g + E_r$$
$$= (0.01072\,V_m^2/M_e + 27.25\,MGD' + 0.2778\,Mr\,D'\text{ Wh}$$

Specific energy output

$$E_{spo} = \frac{E}{M \times D} \qquad \text{— } D \text{ is the } \textit{total} \text{ run length}$$

$$= \left(0.01072\,\frac{V_m^2}{D}.\frac{M_e}{M} + 27.25\,G\,\frac{D'}{D} + 0.2778\,r\,\frac{D'}{D}\right)\text{Wh/t-km}$$

It may be noted that *if there is no gradient*, then

$$E_{spo} = \left(0.01072\,\frac{V_m^2}{D}.\frac{M_e}{M} + 0.2778\,r\,\frac{D'}{D}\right)\text{Wh/t-km}$$

Energy Consumption

It equals the total energy input to the traction motors from the supply. It is usually expressed in Wh which equals 3600 J. It can be found by dividing the energy output of the driving wheels with the combined efficiency of transmission gear and motor.

$$\therefore \quad \text{energy consumption} = \frac{\text{output of driving axles}}{\eta_{motor} \times \eta_{gear}}$$

Specific Energy Consumption

It is the energy consumed (in Wh) per tonne mass of the train per km length of the run.

Specific energy consumption

$$E_{spc} = \frac{\text{total energy consumed in Wh}}{\text{train mass in tonne} \times \text{run length in km}} = \frac{\text{specific energy output}}{\eta}$$

where η = overall efficiency of transmission gear and motor = $\eta_{gear} \times \eta_{motor}$

As seen from Art. 43.41, specific energy consumption is

$$E_{spc} = \left(0.01072\,.\frac{V_m^2}{\eta D}.\frac{M_e}{M} + 27.25\,\frac{G}{\eta}.\frac{D'}{D} + 0.2778\,\frac{r}{\eta}.\frac{D'}{D}\right)\text{Wh/t-km}$$

If no gradient is involved, then specific enrgy consumption is

$$E_{spc} = \left(0.01072\,.\frac{V_m^2}{\eta D}.\frac{M_e}{M} + 0.2778\,\frac{r}{\eta}.\frac{D'}{D}\right)\text{Wh/t-km}$$

3.8 Adhesive Weight

It is given by the total weight carried on the driving wheels. Its value is $Wa = x\ W$, where W is dead weight and x is a fraction varying from 0.6 to 0.8.

Coefficient of Adhesion

Adhesion between two bodies is due to interlocking of the irregularities of their surfaces in contact. The adhesive weight of a train is ***equal to the total weight to be carried on the driving wheels***

If $x = \dfrac{\text{adhesive weight, } W_a}{\text{dead weight } W}$, then, $W_a = x\,W$

Let, F_t = tractive effort to slip the wheels

or

= maximum tractive effort possible without wheel slip

Coefficient of adhesion, $\mu_a = F_t / W_a$

$\therefore$ $F_t = \mu_a\, W_a = \mu_a\, xW = \mu_a\, x\, Mg$

If M is in tonne, then

$$F_t = 1000 \times 9.8\, x\, \mu_a\, M = 9800\, \mu_a\, x\, M \text{ newton}$$

It has been found that tractive effort can be increased by increasing the motor torque but only Up to a certain point. Beyond this point, any increase in motor torque does not increase the tractive effort but merely causes the driving wheels to slip. It is seen from the above relation that for increasing Ft, it is not enough to increase the kW rating of the traction motors alone but the weight on the driving wheels has also to be increased.

Adhesion also plays an important role in braking. If braking effort exceeds the adhesive weight of the vehicle, skidding takes place.

3.8.1 Mechanism of Train Movement

The essentials of driving mechanism in an electric vehicle are illustrated in Fig. 43.14. The armature of the driving motor has a pinion which meshes with the gear wheel keyed to the axle of the driving wheel. In this way, motor torque is transferred to the wheel through the gear.

Let, T = torque exerted by the motor

$F1$ = tractive effort at the pinion Ft = tractive effort at the wheel γ = gear ratio

Here, $d1$, $d2$ = diameters of the pinion and gear wheel respectively D = diameter of the driving wheel

η = efficiency of power transmission from the motor to driving axle

Now, $T = F1 \times d1/2$ or $F1 = 2T/d1$

Tractive effort transferred to the driving wheel is

$$F_t = \eta F_1 \left(\frac{d_2}{D}\right) = \eta \cdot \frac{2T}{d_1}\left(\frac{d_2}{D}\right) = \eta\, T\left(\frac{2}{D}\right)\left(\frac{d_2}{d_1}\right) = 2\,\gamma\eta\,\frac{T}{D}$$

3.9 Control of D.C. Motors

The starting current of motor is limited to its normal rated current by starter during starting. At the instant of switching on the motor, back e.m.f. $Eb = 0$ therefore Supply voltage = $V = IR$ + Voltage drop across Rs.

At any other instant during starting

$V = IR$ + Voltage across $Rs + Eb$

At the end of accelerating period, when total Rs is cut-off $V = Eb + IR$

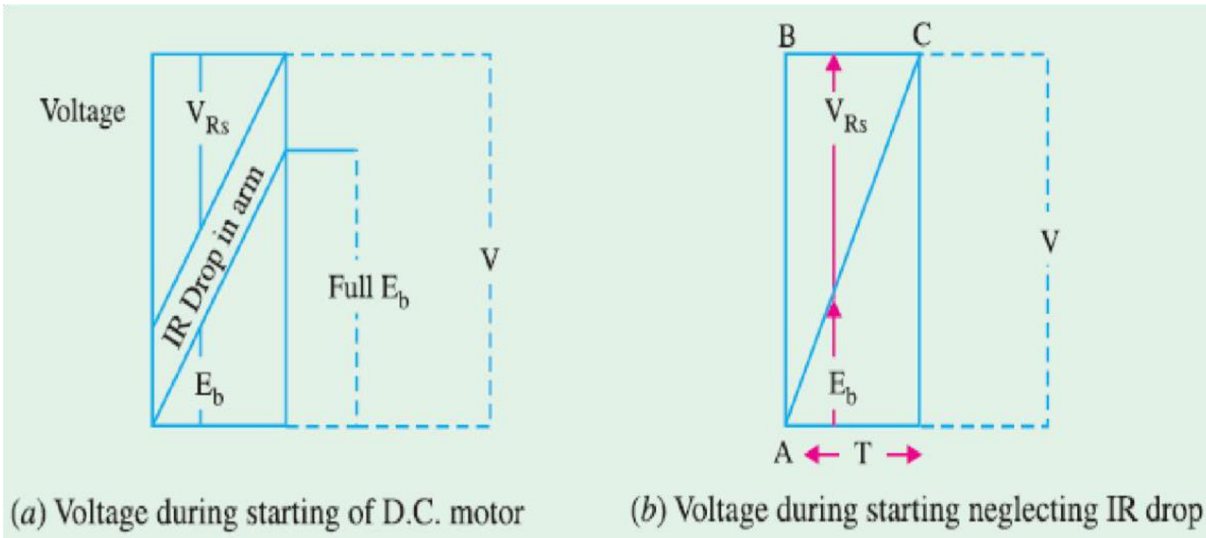


Fig 3.6 control of traction motors

Energy wasted in Rs = Area of triangle $ABC \times I$ = ½. $T.V.I.$ watt - sec. = ½ VIT watt - sec. But total energy supplied = $V.I.T$ watt - sec.

Therefore Half the energy is wasted in starting

Therefore ηstarting = 50%

3.9.1 Series - Parallel Starting

With a 2 motor equipment ½ the normal voltage will be applied to each motor at starting as shown in Fig. (Series connection) and they will run upto approximate ½ speed, at which instant they are switched on to parallel and full voltage is applied to each motor. Rs is gradually cutout, with motors in series connection and then reinserted when the motors are connected in parallel, and again gradually cut-out.

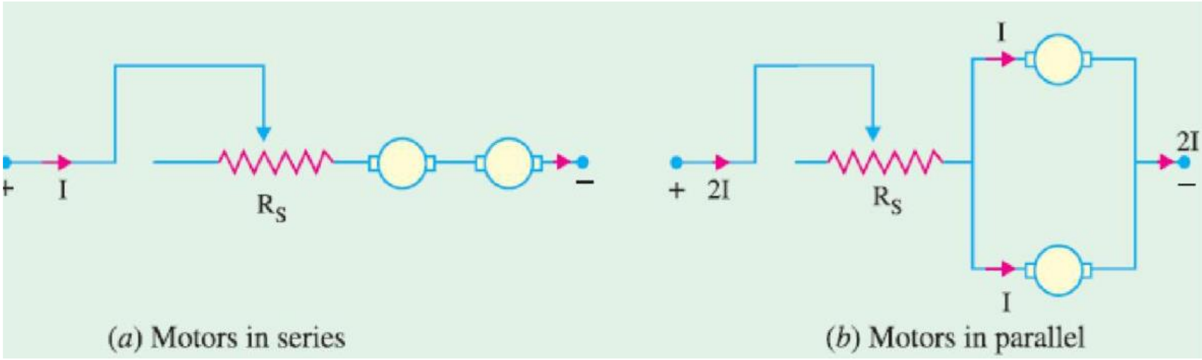


Fig 3.7: series parallel starting

In traction work, 2 or more similar motors are employed. Consider 2 series motors started by series parallel method, which results in saving of energy.

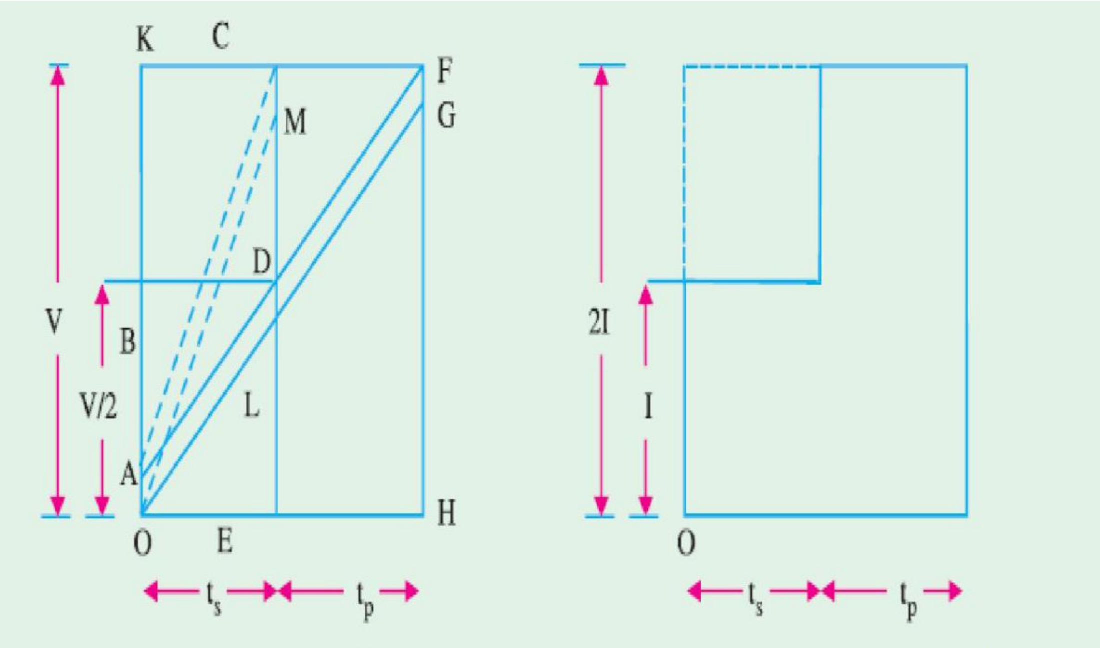
(a) Series operation. The 2 motors, are started in series with the help of *Rs*. The current during starting is limited to normal rated current ‗*I*‗ per motor. During series operation, current ‗*I*‗ is drawn from supply. At the instant of starting *OA* = *AB* = *IR* drop in each motor. *OK* = Supply voltage ‗*V*‗. The back e.m.fs. of 2 motors jointly develop along *OM* as shown in Fig. 43.30 (*a*). At point. *E*, supply voltage *V* = Back e.m.fs of 2 motors + *IR* drops of 2 motor. Any point on the line *BC* represents the sum of Back e.m.fs. of 2 motors + *IR* drops of 2 motors + Voltage across resistance *Rs* of 2 motors *OE* = time taken for series running.

At pt ‗*E*‗ at the end of series running period, each motor has developed a back e.m.f.=2*V* − *IR*

(b) Parallel operation. The motors are switched on in parallel at the instant ‗*E*‗, with *Rs* reinserted as shown in Fig. 43.29 (*b*). Current drawn is 2*I* from supply. Back e.m.f. across each motor = *EL*. So the back e.m.f. now develops along *LG*. At point ‗*H*‗ when the motors are in full parallel, (*Rs* = 0 and both the motors are running at rated speed)

Supply voltage = *V* = *HF* = *HG* + *GF*= Normal Back e.m.f. of each motor + *IR* drop in each motor.

To find ts, tp and η of starting The values of time *ts* during which the motors remain in series and *tp* during which they are in parallel



(*a*) Voltage built-up in series-parallel starting (*b*) Variation of current in series-parallel starting

Fig 3.8 Parallel operation

But total energy supplied

$= I\,V\,t + 2\,I\,V\,t$ (Series) (Parallel) $= 3\;V\,I\,t$

$$\therefore \eta \text{ of starting} = \frac{3VIt - VIt}{3VIt}$$
$$= \frac{2}{3} = 66.6\%$$

(c)Series Parallel Control by Shunt Transition Method

The various stages involved in this method of series – parallel control are shown in Fig. 43.31 In steps 1, 2, 3, 4 the motors are in series and are accelerated by cutting out the *Rs* in steps. In step 4, motors are in full series. During transition from series to parallel, *Rs* is reinserted in circuit– step 5. One of the motors is bypassed -step 6 and disconnected from main circuit – step 7. It is then connected in parallel with other motor -step 8, giving 1st parallel position. *Rs* is again cut-out in steps completely and the motors are placed in full parallel.

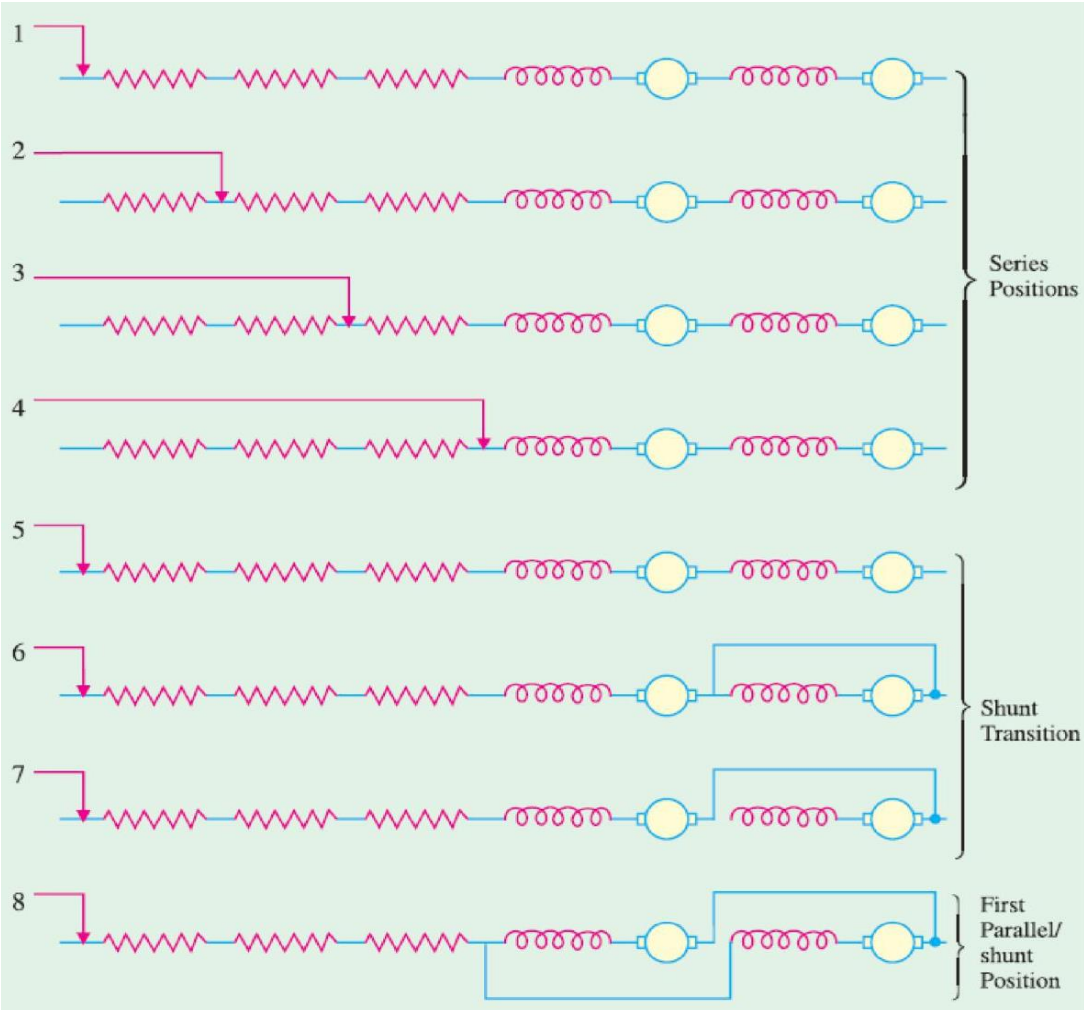


Fig 3.9 Shunt Transition

The main difficulty with series parallel control is to obtain a satisfactory method of transition from series to parallel without interrupting the torque or allowing any heavy rushes of current.

In shunt transition method, one motor is short circuited and the total torque is reduced by about 50% during transition period, causing a noticeable jerk in the motion of vehicle. The Bridge transition is more complicated, but the resistances which are connected in parallel with or _bridged' across the motors are of such a value that current through the motors is not altered in magnitude and the total torque is therefore held constant and hence it is normally used for railways. So in this method it is seen that, both motors remain in circuit through-out the transition. Thus the jerks will not be experienced if this method is employed.

(d)Series Parallel Control by Bridge Transition

(a) At starting, motors are in series with *Rs i.e.* link *P* in position = *AA′*

(b) Motors in full series with link *P* in position = *BBRs* in the circuit)

(a) The motor and *Rs* are connected in the form of Wheatstone Bridge. Initially motors are in series with full *Rs* as shown in Fig. *A* and *A* heads. In position *BBb*), with no *Rs* present in the circuit.

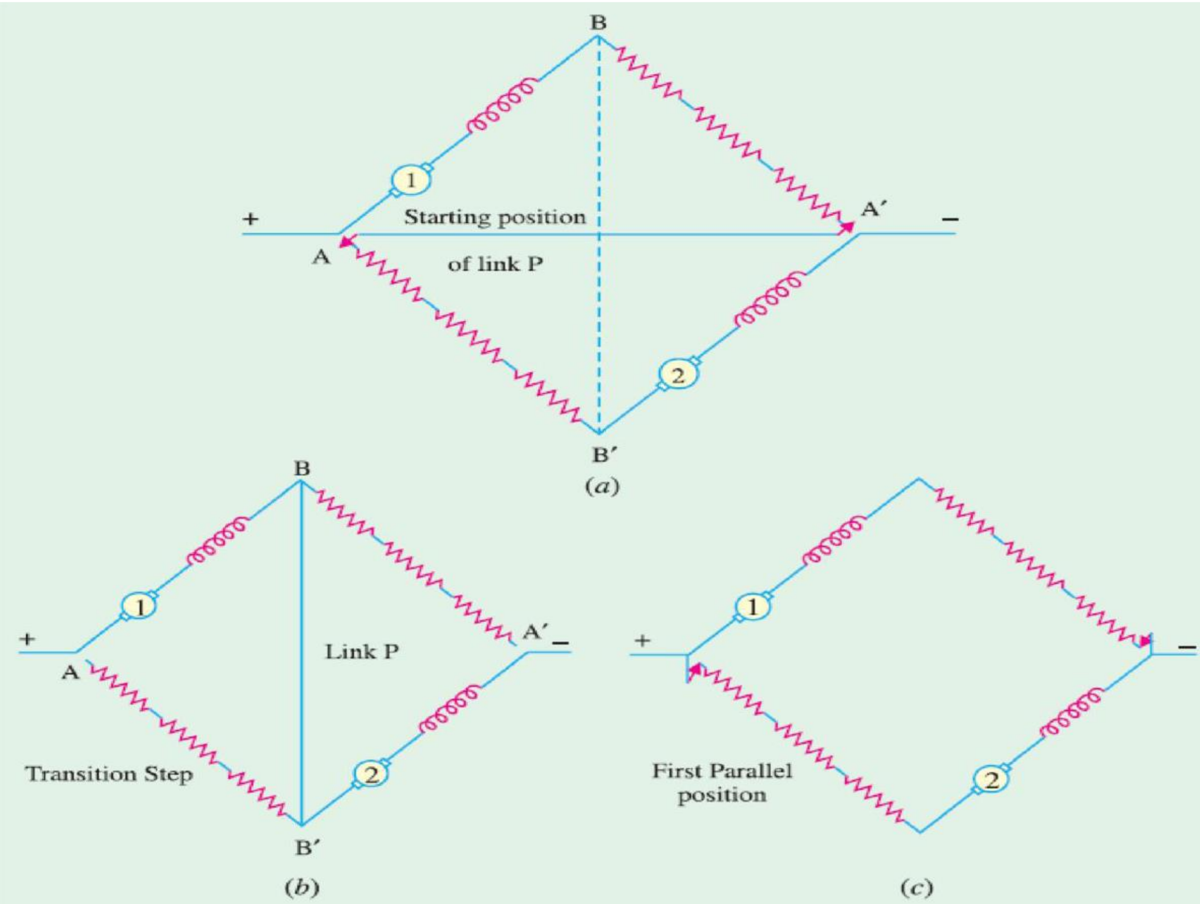


Fig 3.10 Bridge Transition

In transition step the *Rs* is reinserted.

In Ist parallel step, link *P* is removed and motors are connected in parallel with full *Rs* as shown in Fig. 43.32 (*c*). Advantage of this method is that the normal acceleration torque is available from both the motors, through - out starting period. Therefore acceleration is smoother, without any jerks, which is very much desirable for traction motors.

Module Outcomes:

1. Discuss systems of electric traction, speed time curves and mechanics of train movement.
2. Explain the motors used for electric traction and their control.

MODULE-4

ELECTRIC BRAKING

Structure

Braking:

- Introduction
- Regenerative Braking with Three Phase Induction Motors
- Braking with Single Phase Series Motors
- Mechanical braking, Magnetic Track Brake, Electro – Mechanical Drum Brakes.

Electric Traction Systems and Power Supply:

- System of Electric Traction, Electrification, AC Transmission Lines to Sub - Stations,
- Sub – Stations, Feeding and Distribution System of AC
- Traction, Feeding and Distribution System for Dc Tramways
- Electrolysis by Currents through Earth, Negative Booster
- System of Current Collection, Trolley Wires.

Trams, Trolley Buses and Diesel – Electric Traction:

- Tramways, The Trolley – Bus,
- Diesel Electric Traction and Problems

Module Objectives:

- To discuss braking of electric motors, traction systems and power supply and other traction systems

4.1 Braking in Traction

Both electrical and mechanical braking is used. Mechanical braking provides holding torque. Electric Braking reduces wear on mechanical brakes, provides higher retardation, thus bringing a vehicle quickly to rest. Different types of electrical braking used in traction are discussed.

1. Rheostatic Braking:

(a) Equalizer Connection ***(b)*** Cross Connection

(a) Equalizer Connection

For traction work, where 2 or more motors are employed, these are connected in parallel for braking, because series connection would produce too high voltage. K.E. of the vehicle is utilized in driving the machines as generators, which is dissipated in braking resistance in the form of heat.

To ensure that the 2 machines share the load equally, an equalizer connection is used as shown in Fig. 43.33 (*a*). If it is not used, the machine whose acceleration builts-up first would send a current through the 2nd machine in opposite direction, causing it to excite with reverse voltage. So that the 2 machines would be short circuited on themselves. The current would be dangerously high. Equalizer prevents such conditions. Hence Equalizer connection is important during braking in traction.

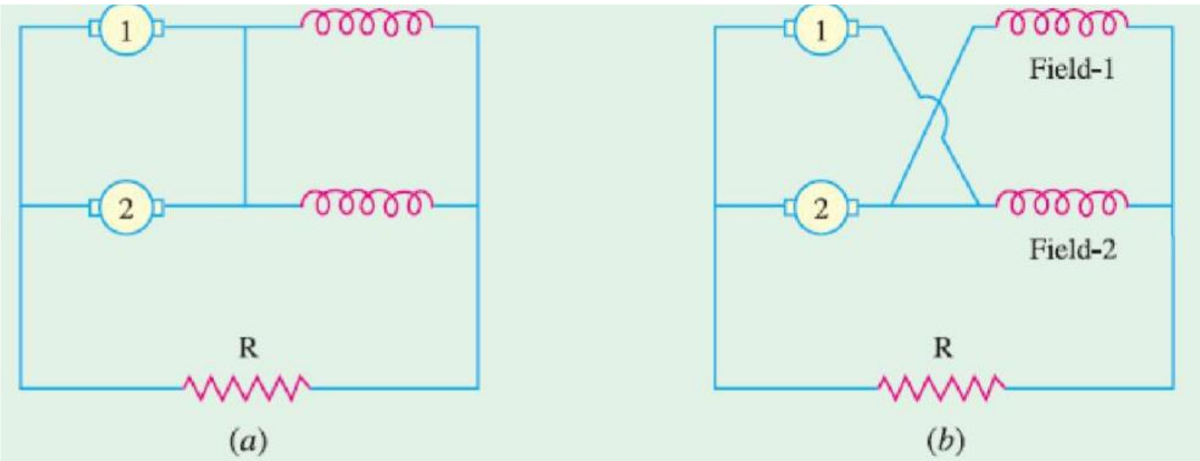


Fig 4.1 Rheostatic braking

(b) Cross Connection

In cross connection the field of machine 2 is connected in series with armature of machine 1 and the field of machine 1 is connected in series with armature of machine 2 as shown in Fig. Suppose the voltage of machine 1 is greater than that of 2. So it will send greater current through field of machine 2, causing it to excite to higher voltage. At the same time machine 1 excitation is low, because of lower voltage of machine 2. Hence machine 2 will produce more voltage and machine 1 voltage will be reduced. Thus automatic compensation is provided and the 2 machines operate satisfactorily.

Because of cross - connection during braking of traction motors, current in any of the motor will not go to a very high value.

2. Regenerative Braking with D.C. Motors

In order to achieve the regenerative braking, it is essential that **(*i*)** the voltage generated by the machine should exceed the supply voltage and **(*ii*)** the voltage should bez kept at this value, irrespective of machine speed. Fig. 43.34 (*a*) shows the case of 4 series motors connected in parallel during normal running *i.e.* motoring.

One method of connection during regenerative barking, is to arrange the machines as shunt machines, with series fields of 3 machines connected across the supply in series with suitable resistance. One of the field winding is still kept in series across the 4 parallel armatures as shown in figure

The machine acts as a compound generator. (with slight differential compounding) Such an arrangement is quiet stable; any change in line voltage produces a change in excitation which produces corresponding change in e.m.f. of motors, so that inherent compensation is provided *e.g.* let the line voltage tends to increase beyond the e.m.f. of generators. The increased voltage across the shunt circuit increases the excitation thereby increasing the generated voltage. Vice-versa is also true. The arrangement is therefore self compensating.

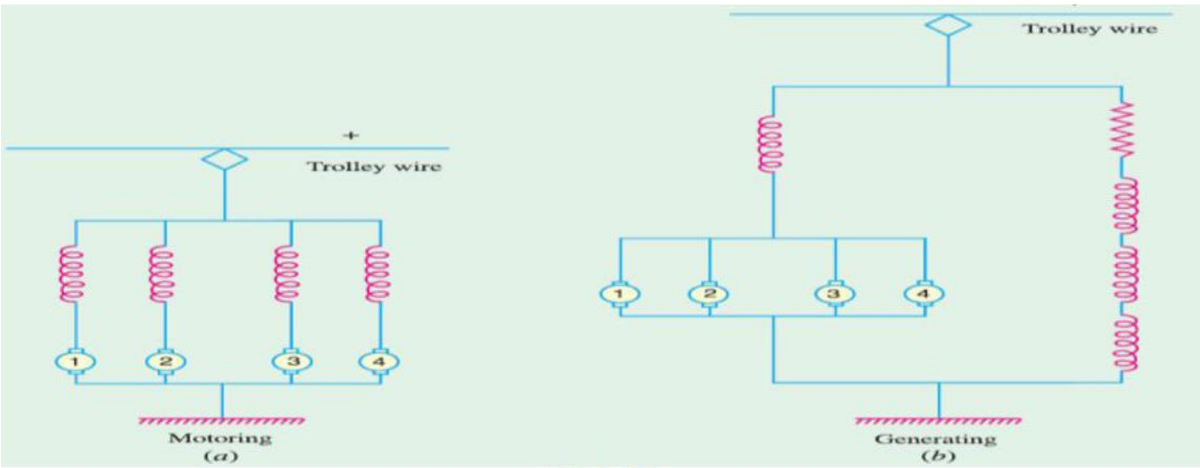


Fig 4.2 Regenerative braking

D.C. series motor can‘t be used for regenerative braking without modification for obvious reasons. During regeneration current through armature reverses; and excitation has to be maintained. Hence field connection must be reversed.

4.2 Systems of Railway Electrification

Presently, following four types of track electrification systems are available:

1. Direct current system—600 V, 750 V, 1500 V, 3000 V

2. Single-phase ac system—15-25 kV, 16 23, 25 and 50 Hz

3. Three-phase ac system—3000-3500 V at 16 2 3 Hz

4. Composite system—involving conversion of single-phase ac into 3-phase ac or dc.

Direct Current System

Direct current at 600-750 V is universally employed for tramways in urban areas and for many suburban railways while 1500-3000 V dc is used for main line railways. The current collection is from third rail (or conductor rail) up to 750 V, where large currents are involved and from

overhead wire for 1500 V and 3000 V, where small currents are involved. Since in majority of cases, track (or running) rails are used as the return conductor, only one conductor rail is required. Both of these contact systems are fed from substations which are spaced 3 to 5 km for heavy suburban traffic and40-50 km for main lines operating at higher voltages of 1500 V to 3000 V. These sub-stations themselves receive power from 110/132 kV, 3-phase network (or grid). At these substations, this high-voltage 3-phase supply is converted into low-voltage 1-phase supply with the help of Scott connected or V-connected 3-phase transformers (Art. 31.9). Next, this low ac voltage is converted into the required dc voltage by using suitable rectifiers or converters (like rotary converter, mercury arc,
metal or semiconductor rectifiers). These substations are usually automatic and are remote controlled.
The dc supply so obtained is fed via suitable contact system to the traction motors which are either dc series motors for electric locomotive or compound motors for tramway and trolley buses where regenerative braking is desired.

Single-Phase Low-frequency AC System

In this system, ac voltages from 11 to 15 kV at 23 16 or 25 Hz are used. If supply is from a generating station exclusively meant for the traction system, there is no difficulty in getting the electric supply of 23 16 or 25 Hz. If, however, electric supply is taken from the high voltage transmission lines at 50 Hz, then in addition to step-down transformer, the substation is provided with a frequency converter. The frequency converter equipment consists of a 3-phase synchronous motor which drives a I-phase alternator having or 25 Hz frequency.
The 15 kV 23 16 or 25 Hz supply is fed to the electric locomotors via a single over-head wire (running rail providing the return path).
A step-down transformer carried by the locomotive reduces the 15-kV voltage to 300-400 V for feeding the ac series motors. Speed regulation of ac series motors is achieved by applying variable voltage from the tapped secondary of the above transformer. Low-frequency ac supply is used because apart from improving the commutation properties of ac motors, it increases their efficiency and power factor. Moreover, at low frequency, line reactance is less so that line impedance drop and hence line voltage drop is reduced. Because of this reduced line drop, it is feasible to space the substations 50 to 80 k

Three-phase Low-frequency AC System

It uses 3-phase induction motors which work on a 3.3 kV, 23
16 Hz supply. Sub-stations receive power at a very high voltage from 3-phase transmission lines at the usual industrial frequency of 50 Hz. This high voltage is stepped down to 3.3 kV by transformers whereas frequency is reduced from 50 Hz to 23 16 Hz by frequency converters installed at the substations. Obviously, this system employs *two* overhead contact wires, the track rail forming the third phase (of course, this leads to insulation difficulties at the junctions). Induction motors used in the system are quite simple and robust and give trouble-free operation.
They possess the merits of high efficiency and of operating as a generator when driven at speeds above the synchronous speed. Hence, they have the property of automatic regenerative braking during the descent on gradients. However, it may be noted that despite all its advantages, this

system has not found much favor and has; in fact, become obsolete because of it‘s certain inherent limitations given below:

1. The overhead contact wire system becomes complicated at crossings and junctions.

2. constant-speed characteristics of induction motors are not suitable for traction work.

3. Induction motors have speed/torque characteristics similar to dc shunt motors. Hence, they are not suitable for parallel operation because, even with little difference in rotational speeds caused by unequal diameters of the wheels, motors will becomes loaded very unevenly.

Single-phase AC to DC System

This system combines the advantages of high-voltage ac distribution at industrial frequency with the dc series motors traction. It employs overhead 25-kV, 50-Hz supply which is stepped down by the transformer installed in the locomotive itself. The low-voltage ac supply is then converted into dc supply by the rectifier which is also carried on the locomotive. This dc supply is finally fed to dc series traction motor fitted between the wheels. The system of traction employing 25-kV, 50-Hz, 1phase ac supply has been adopted for all future track electrification in India.

Advantages of 25-kV, 50-Hz AC System

Advantages of this system of track electrification over other systems particularly the dc system are as under :

1. Light Overhead Catenary

Since voltage is high (25 kV), line current for a given traction demand is less. Hence, crosssection of the overhead conductors is reduced. Since these small-sized conductors are light, supporting structures and foundations are also light and simple. Of course, high voltage needs higher insulation which increases the cost of overhead equipment (OHE) but the reduction in the size of conductors has an overriding effect.

2. Less Number of Substations

Since in the 25-kV system, line current is less, line voltage drop which is mainly due to the resistance of the line is correspondingly less. It improves the voltage regulation of the line which fact makes larger spacing of 50-80 km between sub-stations possible as against 5-15 km with 1500 V dc system and 15-30 km with 3000 V dc sysem. Since the required number of substations along the track is considerably reduced, it leads to substantial saving in the capital expenditure on track electrification.

3. Flexibility in the Location of Substations

Larger spacing of substations leads to greater flexibility in the selection of site for their proper location. These substations can be located near the national high-voltage grid which, in our country,
fortunately runs close to the main railway routes. The substations are fed from this grid thereby saving the railway administration lot of expenditure for erecting special transmission lines for their substations. On the other hand, in view of closer spacing of dc substations and their far away location, railway administration has to erect its own transmission lines for taking feed from the national grid to the substations which consequently increases the initial cost of electrification.

4. Simplicity of Substation Design

In ac systems, the substations are simple in design and layout because they do not have to install and maintain rotary converters or rectifiers as in dc systems. They only consist of static transformers alongwith their associated switchgear and take their power directly from the high-voltage national grid running over the length and breadth of our country. Since such sub-stations are remotely controlled, they have few attending personnel or even may be unattended.

5. Lower Cost of Fixed Installations

The cost of fixed installations is much less for 25 kV ac system as compared to dc system. In fact, cost is in ascending order for 25 kV ac, 3000 V dc and 1500 V dc systems. Consequently, traffic densities for which these systems are economical are also in the ascending order

6. Higher Coefficient of Adhesion

The straight dc locomotive has a coefficient of adhesion of about 27% whereas its value for ac rectifier locomotive is nearly 45%. For this reason, a lighter ac locomotive can haul the same load as a heavier straight dc locomotive. Consequently, ac locomotives are capable of achieving higher speeds in coping with heavier traffic.

7. Higher Starting Efficiency

An ac locomotive has higher starting efficiency than a straight dc locomotive. In dc locomotive supply voltage at starting is reduced by means of ohmic resistors but by on-load primary or secondary tap-changer in ac locomotives.

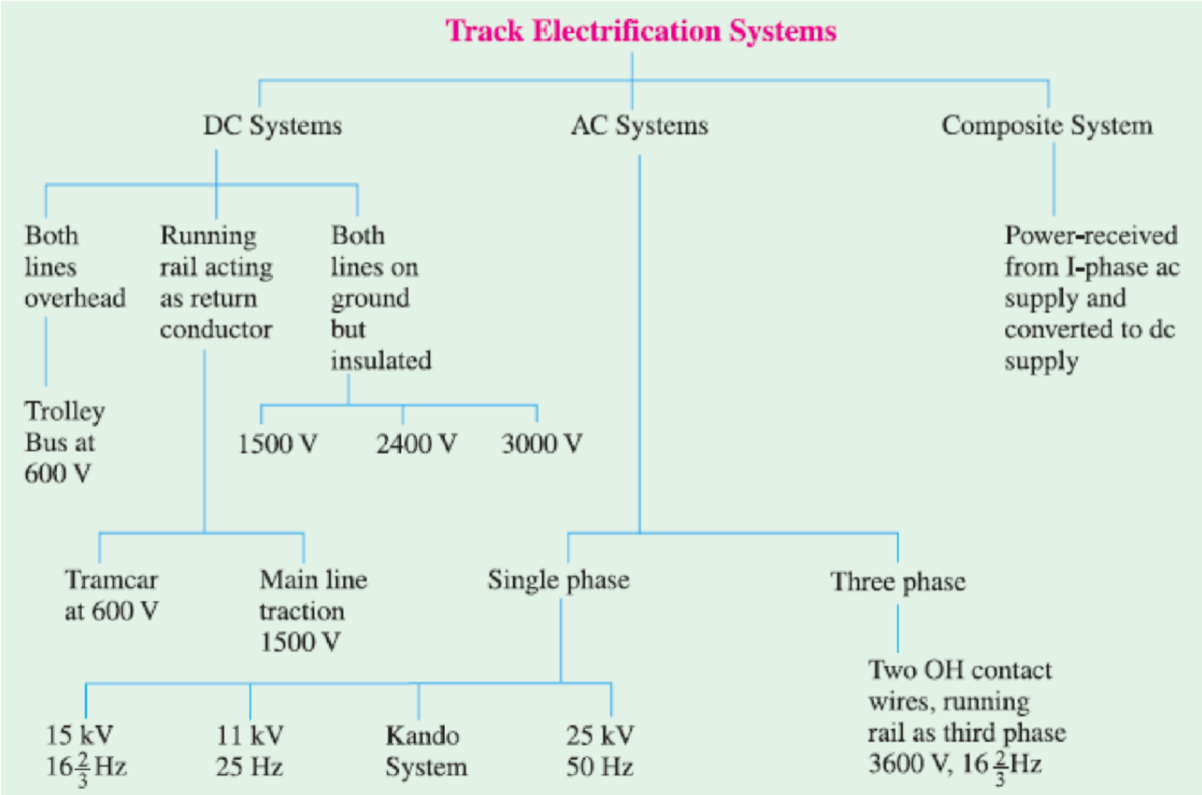


Fig 4.3 Flow diagram of AC locomotive

4.3 Components of AC locomotives:

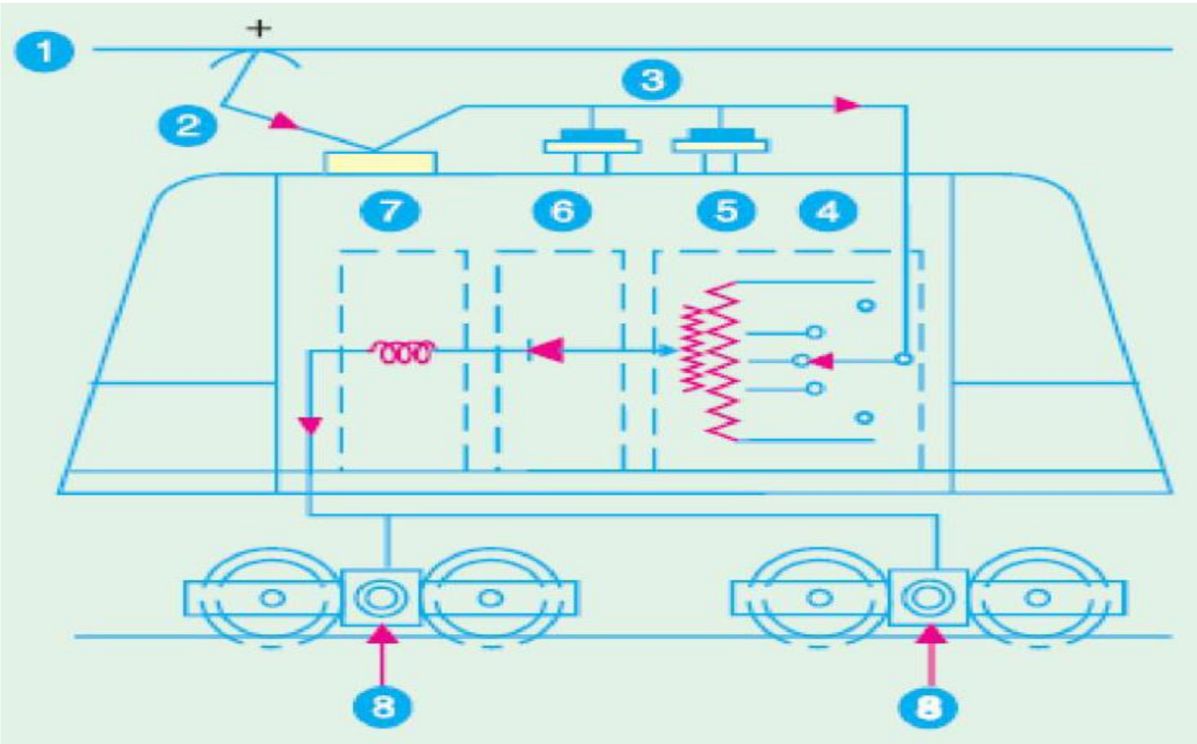


Fig 4.4 various components of an ac locomotive

The various components of an ac locomotive running on single-phase 25-kV, 50-Hz ac supply are numbered above
1. OH contact wire

2. pantograph

3. circuit breakers

4. on-load tap-changers

5. transformer

6. rectifier

7. smoothing choke

8. dc traction motors.

As seen, power at 25 kV is taken via a pantograph from the overhead contact wire and fed to the step-down transformer in the locomotive. The low ac voltage so obtained is converted into pulsating dc voltage by means of the rectifier. The pulsations in the dc voltage are then removed by the smoothing choke beforeit is fed to dc series traction motors which are mounted between the wheels. The function of circuit breakers is to immediately disconnect the locomotive from the overhead supply in case of any fault in its electrical system. The on-load tap-changer is used to change the voltage across the motors and hence regulate their speed.

4.4 The Tramways

It is the most economical means of transport for very dense traffic in the congested streets of large cities. It receives power through a bow collector or a grooved wheel from an overhead conductor at about 600 V dc, the running rail forming the return conductor. It is provided with at least two driving axles in order to **(*i*)** secure necessary adhesion **(*ii*)** start it from either end and **(*iii*)** use two motors with series-parallel control. Two drum-type controllers, one at each end, are used for controlling the tramcar. Though these controllers are connected in parallel, they have suitable interlocking arrangement meant to prevent their being used simultaneously.

Tramcars are being replaced by trolley-buses and internal-combustion-engined omnibuses because of the following reasons :

1. tramcars lack flexibility of operation in congested areas.

2. the track constitutes a source of danger to other road users.

4.5 The Trolleybus:

It is an electrically-operated pneumatic-tyred vehicle which needs ***no track in the roadway***. It receives its power at 600 V dc from two overhead contact wires. Since adhesion between a rubbertyred wheel and ground is sufficiently high, only a single driving axle and, hence, a single motor is used. The trolleybus can manoeuvre through traffic a metre or two on each side of the centre line of the trolley wires

4.6 Overhead Equipment (OHE)

Broadly speaking, there are two systems of current collection by a traction unit :
(*i*) third rail system and **(*ii*)** overhead wire system.
It has been found that current collection from overhead wire is far superior to that from the third rail. Moreover, insulation of third rail at high voltage becomes an impracticable proposition and endangers the safety of the working personnel.
The simplest type of OHE consists of a single contact wire of hard drawn copper or silico-bronze supported either by bracket or an overhead span. To facilitate connection to the supports, the wire is grooved as shown in Fig. 43.2. Because there is appreciable sag of the wire between supports, it limits the speed of the traction unit to about 30 km/h. Hence, single contact wire system is suitable for tramways and in complicated yards and terminal stations where speeds are low and simplicity of layout is desirable.
For collection of current by high-speed trains, the contact (or trolley) wire has to be kept level without any abrupt changes in its height between the supporting structures. It can be done by using the single catenary system which consists of one catenary or messenger wire of steel with high sag and the trolley (or contact) wire supported from messenger wire by means of droppers clipped to both wires as shown in Fig.

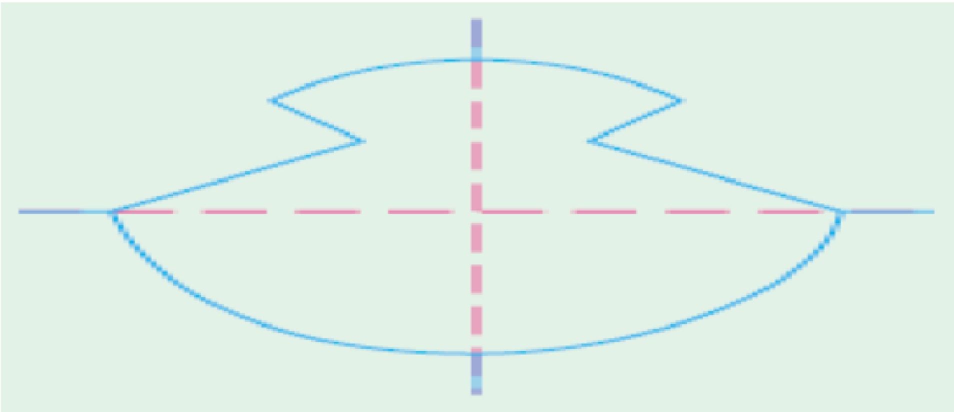


Fig 4.5 OH Equipment

4.6.1 Collector Gear for OHE

The most essential requirement of a collector is that it should keep continuous contact with trolley wire at all speeds. Three types of gear are in common use :

1. trolley collector **2.** bow collector and **3.** pantograph collector.
2. To ensure even pressure on OHE, the gear equipment must, be flexible in order to follow variations in the sag of the contact wire. Also, reasonable precautions must be taken to prevent the collectorfrom leaving the overhead wire at points and crossings.

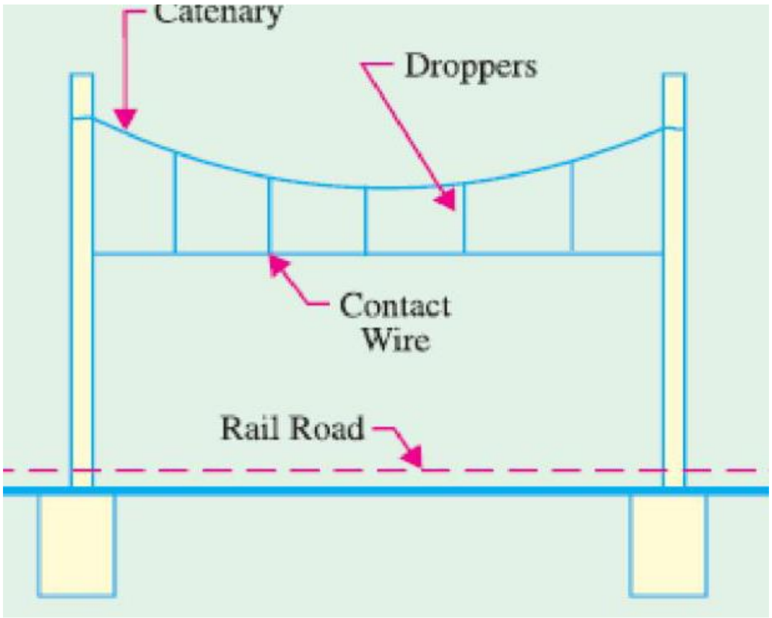


Fig 4.6 Collector Gear for OHE

4.6.2 The Trolley Collector

This collector is employed on tramways and trolley buses and is mounted on the roof of the vehicle. Contact with the OH wire is made by means of either a grooved wheel or a sliding shoe carried at the end of a light trolley pole attached to the top of the vehicle and held in contact with OH wire by means of a spring. The pole is hinged to a swivelling base so that it may be reversed for reverse running thereby making it unnecessary for the trolley wire to be accurately maintained abovethe centre of the track. Trolley collectors always operate in the trailing position. The trolley collector is suitable for low speeds upto 32 km/h beyond which there is a risk of its jumping off the OH contact wire particularly at points and crossing.

The Bow Collector It can be used for higher speeds. As shown in Fig. 43.4, it consists of two roof mounted trolley poles at the ends of which is placed a light metal strip (or bow) about one metre long for current collection. The collection strip is purposely made of soft material (copper, aluminium or carbon) in order that most of the wear may occur on it rather than on the trolley wire. The bow collector also operates in the trailing position. Hence, it requires provision of either duplicate bows or an arrangement for reversing the bow for running in the reverse direction. Bow collector is not suitable for railway work where speeds up to 120 km/h and currents up to 3000 A are encountered. It is so because the inertia of the bow collector is too high to ensure satisfactory current collection.

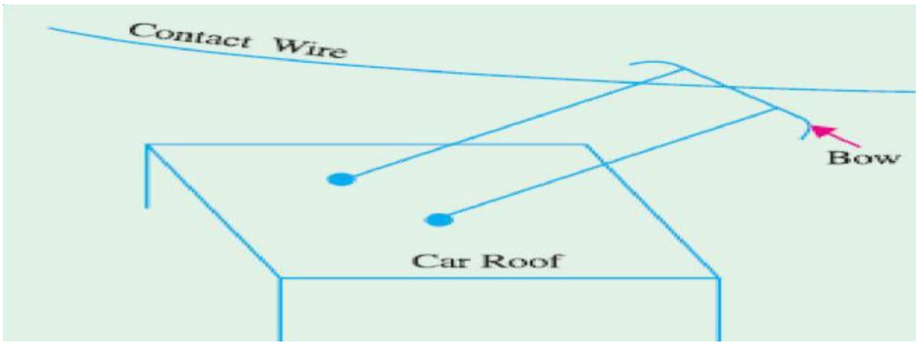


Fig 4.7 Bow collector

4.6.3 The Pantograph Collector

Its function is to maintain link between overhead contact wire and power circuit of the electric locomotive at different speeds under all wind conditions and stiffness of OHE. It means that positive pressure has to be maintained at all times to avoid loss of contact and sparking but the pressure must be as low as possible in order to minimize wear of OH contact wire. A _diamond' type single-pan pantograph is shown in Fig. 43.5. It consists of a pentagonal framework of high-tensile alloy-steel tubing. The contact portion consists of a pressed steel pan fitted with renewable copper wearing strips which are forced against the OH contact wire by the upward action of pantograph springs. The pantograph can be raised or lowered from cabin by air cylinders.

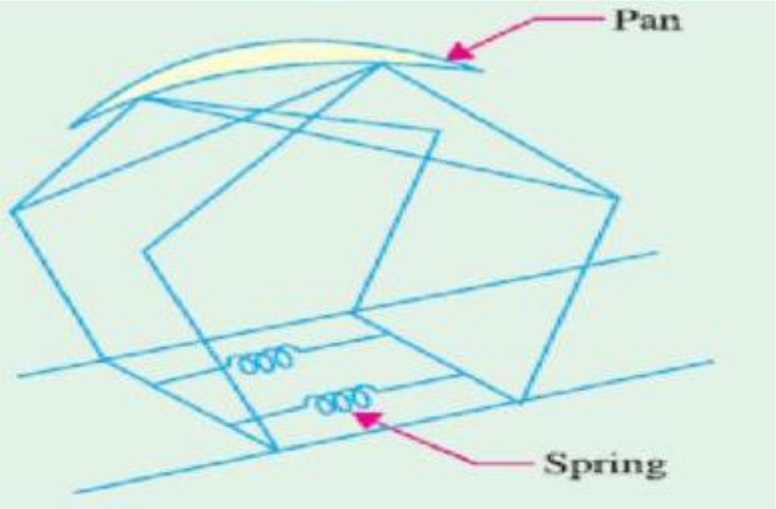


Fig 4.8 **The Pantograph Collector**

Module Outcomes:

- Discuss braking of electric motors, traction systems and power supply and other traction systems.

MODULE-5

HYBRID ELECTRIC VEHICLES

Structure

Electric Vehicles:

- Configurations of Electric Vehicles
- Performance of Electric Vehicles
- Tractive Effort in Normal Driving, Energy Consumption.

Hybrid Electric Vehicles:

- Concept of Hybrid Electric
- Drive Trains
- Architectures of Hybrid Electric Drive Trains.

Module Objectives:

- Give awareness of technology of electric and hybrid electric vehicles.

5.1 Introduction

Almost all modern industrial and commercial undertakings employ electric drive in preference to mechanical drive because it possesses the following advantages

Advantages:

1. It is simple in construction and has less maintenance cost

2. Its speed control is easy and smooth

3. It is neat, clean and free from any smoke or flue gases

4. It can be installed at any desired convenient place thus affording more flexibility in the layout

5. It can be remotely controlled

6. Being compact, it requires less space

7. It can be started immediately without any loss of time

8. It has comparatively longer life.

Disadvantages:

However, electric drive system has two inherent disadvantages:

1. It comes to stop as soon as there is failure of electric supply and

2. It cannot be used at far off places which are not served by electric supply.

However, the above two disadvantages can be overcome by installing diesel-driven dc generators and turbine-driven 3-phase alternators which can be used either in the absence of or on the failure of normal electric supply.

5.2 Configuration and performance of Electric Drives

Electric drives may be grouped into three categories : group drive, individual drive and multimotor drive.
In group drive, a single motor drives a number of machines through belts from a common shaft.
It is also called line shaft drive. In the case of an indvidual drive, each machine is driven by its own separate motor with the help of gears, pulley etc. In multi-motor drives separate motors are provided for actuating different parts of the driven mechanism. For

example, in travelling cranes, three motors are used: one for hoisting, another for long travel motion and the third for cross travel motion.

Multimotor drives are commonly used in paper mills, rolling mills, rotary printing presses and metal working machines etc.
Each type of electric drive has its own advantages and disadvantages. The group drive has following advantages :

1. It leads to saving in initial cost because one 150-kW motor costs much less than ten 15-kW motors needed for driving 10 separate machines.

2. Since all ten motors will seldom be required to work simultaneously, a single motor of even 100kW will be sufficient to drive the main shaft. This diversity in load reduces the initial cost still further.

3. Since a single large motor will always run at full-load, it will have higher efficiency and power factor in case it is an induction motor.

4. Group drive can be used with advantage in those industrial processes where there is a sequence of continuity in the operation and where it is desirable to stop these processes simultaneously as in a flour mill.

However, group drive is seldom used these days due to the following disadvantages:

1. Any fault in the driving motor renders all the driven equipment idle. Hence, this system is unreliable.

2. If all the machines driven by the line shaft do not work together, the main motor runs at reduced load. Consequently, it runs with low efficiency and with poor power factor

3. Considerable amount of power is lost in the energy transmitting mechanism.

4. Flexibility of layout of different machines is lost since they have to be so located as to suit the position of the line shaft.

5. The use of line shaft, pulleys and belts etc. makes the drive look quite untidy and less safe to operate.

6. It cannot be used where constant speed is required as in paper and textile industry.

7. Noise level at the worksite is quite high.

5.2.1 Advantages of Individual Drive

It has the following advantages:

1. Since each machine is driven by a separate motor, it can be run and stopped as desired.

2. Machines not required can be shut down and also replaced with a minimum of dislocation.

3. There is flexibility in the installation of different machines.

4. In the case of motor fault, only its connected machine will stop whereas others will continue working undisturbed.

5. The absence of belts and line shafts greatly reduces the risk of accidents to the operating personnel.

6. Ach operator has full control of the machine which can be quickly stopped if an accident occurs.

7. Maintenance of line shafts, bearings, pulleys and belts etc. is eliminated. Similarly there is no danger of oil falling on articles being manufactured–something very important in textile industry. The only disadvantage of individual drive is its initial high cost However, the use of individual drives and multimotor drives has led to the introduction of automation in production processes which, apart from increasing the productivity of various undertakings, has increased the reliability and safety of operation.

5.3 Traction motor characteristics: Selection of a Motor

The selection of a driving motor depends primarily on the conditions under which it has to operate and the type of load it has to handle. Main guiding factors for such a selection are as follows :

(*a*) Electrical characteristics

1. Starting characteristics 2. Running characteristics
3. Speed control 4. Braking

(*b*) Mechanical considerations

1. Type of enclosure 2. Type of bearings
3. Method of power transmission 4. Type of cooling
5. Noise level

(*c*) Size and rating of motors

1. Requirement for continuous, intermittent or variable load cycle
2. Overload capacity

(*d*) Cost

1. Capital cost 2. Running cost

In addition to the above factors, one has to take into consideration the type of current available whether alternating or direct. However, the basic problem is one of matching the mechanical output of the motor with the load requirement *i.e.* to select a motor with the correct speed/torque characteristics as demanded by the load. In fact, the complete selection process requires the analysis and synthesis of not only the load and the proposed motor but the complete drive assembly and the control equipment which may include rectification or frequency changing

5.3.1 Types of Enclosures

The main function of an enclosure is to provide protection not only to the working personnel but also to the motor itself against the harmful ingress of dirt, abrasive dust, vapours and liquids and solid foreign bodies such as a spanner or screw driver etc. At the same time, it should not adversely affect the proper cooling of the motor. Hence, different types of enclosures are used for different motors depending upon the environmental conditions. Some of the commonly used motor enclosures are as under:

1. Open Type. In this case, the machine is open at both ends with its rotor being supported on pedestal bearings or end brackets. There is free ventilation since the stator and rotor ends are in free contact with the surrounding air. Such, machines are housed in a separate neat and clean room. This type of enclosure is used for large machines such as d.c. motors and generators.

2. Screen Protected Type. In this case, the enclosure has large openings for free ventilation. However, these openings are fitted with screen covers which safeguard against accidental contacts and rats entering the machine but afford no protection from dirt, dust and falling water. Screen protected type motors are installed where dry and neat conditions prevail without any gases or fumes.

3. Drip Proof Type. This enclosure is used in very damp conditions. *i.e*. for pumping sets. Since motor openings are protected by over-hanging cowls, vertically falling water and dust are not able to enter the machine.

4. Splash-proof Type. In such machines, the ventilating openings are so designed that liquid or dust particles at an angle between vertical and 100° from it cannot enter the machine. Such type of motors can be safely used in rain.

5. Totally Enclosed (TE) Type. In this case, the motor is completely enclosed and no openings are left for ventilation. All the heat generated due to losses is dissipated from the outer surface which is finned to increase the cooling area. Such motors are used for dusty atmosphere *i.e.* sawmills, coalhandling plants and stone-crushing quarries etc.

6. Totally-enclosed Fan-cooled

(TEFC) Type. In this case, a fan is mounted on the shaft external to the totally enclosed casing and air is blown over the ribbed outer surfaces of the stator and endshields (Fig. 44.1). Such motors are commonly used in flour mills, cement works and sawmills etc. They require little maintenance apart from lubrication and are capable of giving years of useful service without any interruption of production.

7. Pipe-ventilated Type. Such an enclosure is used for very dusty surroundings. The motor is totally enclosed but is cooled by neat and clean air brought through a separate pipe from outside the dustladen area. The extra cost of the piping is offset by the use of a smaller size motor on account of better cooling.

8. Flame-proof (FLP) Type. Such motors are employed in atmospheres which contain inflammable gases and vapours *i.e.* in coal mines and chemical plants. They are totally enclosed but their enclosures are so constructed that any explosion within the motor due to any spark does not ignite the gases outside. The maximum operating temperature at the surface of the motor is much less than the ignition temperature of the surrounding gases.

5.3.2 Bearings

These are used for supporting the rotating parts of the machines and are of two types :

1. Ball or roller bearings **2.** Sleeve or bush bearings

(*a*) Ball Bearings

Upto about 75kW motors, ball bearings are preferred to other bearings because of their following advantages :

1. They have low friction loss

2. They occupy less space

3. They require less maintenance

4. Their use allows much smaller air-gap between the stator and rotor of an induction motor

5. Their life is long.

Their main disadvantages are with regard to cost and noise particularly at high motor speeds.

(*b*) Sleeve Bearings

These are in the form of self-aligning pourous bronze bushes for fractional kW motors and in the form of journal bearings for larger motors. Since they run very silently, they are fitted on super-silent motors used for driving fans and lifts in offices or other applications where noise must be reduced to the absolute minimum.

Fig 5.1 Three phase motor

5.4 Transmission of Power

There are many ways of transmitting mechanical power developed by a motor to the driven machine.

1. Direct Drive. In this case, motor is coupled directly to the driven machine with the help of solid or flexible coupling. Flexible coupling helps in protecting the motor from sudden jerks. Direct drive is nearly 100% efficient and requires minimum space but is used only when speed of the driven machine equals the motor speed.

2. Belt Drive. Flat belts are extensively used for line-shaft drives and can transmit a maximum power of about 250 kW. Where possible, the minimum distance between the pulley centres should be 4 times the diameter of the larger pulley with a maximum ratio between pulley diameters of 6 : 1. The power transmitted by a flat belt increases in proportion to its width and varies greatly with its quality and thickness. There is a slip of 3 to 4 per cent in the belt drive.

3. Rope Drive. In this drive, a number of ropes are run in V-grooves over the pulleys. It has negligible slip and is used when the power to be transmitted is beyond the scope of belt drive.

4. Chain Drive. Though somewhat more expensive, it is more efficient and is capable of transmitting larger amounts of power. is noiseless, slipless and smooth in operation.

5. Gear Drive. It is used when a high-speed motor is to drive a low-speed machine. The coupling between the two is through a suitable ratio gear box. In fact motors for low-speed drives are manufactured with the reduction gear incorporated in the unit itself. Fig. 44.2 shows such a unit consisting of a flange motor bolted to a high-efficiency gear box which is usually equipped with feet, the motor being overhung.

Fig 5.2 Geared motor unit

5.5 Motors for Different Industrial Drives

1. D.C. Series Motor. Since it has high starting torque and variable speed, it is used for heavy duty applications such as electric locomotives, steel rolling mills, hoists, lifts and cranes.

2. D.C. Shunt Motor. It has medium starting torque and a nearly constant speed. Hence, it is used for driving constant-speed line shafts, lathes, vacuum cleaners, wood-working machines, laundry washing machines, elevators, conveyors, grinders and small printing presses etc.

3. Cumulative Compound Motor. It is a varying-speed motor with high starting torque and is used for driving compressors, variable-head centrifugal pumps, rotary presses, circular saws, shearing machines, elevators and continuous conveyors etc.

4. Three-phase Synchronous Motor. Because its speed remains constant under varying loads, it is used for driving continuously- operating equipment at constant speed such as ammonia and air compressors, motor-generator sets, continuous rolling mills, paper and cement industries.

5. Squirrel Cage Induction Motor. This motor is quite simple but rugged and possesses high overload capacity. It has a nearly constant speed and poor starting torque. Hence, it is used for low and medium power drives where speed control is not required as for water pumps, tube wells, lathes, drills, grinders, polishers, wood planers, fans, blowers, laundry washing machines and compressors etc.

6. Double Squirrel Cage Motor. It has high starting torque, large overload capacity and a nearly constant speed. Hence, it is used for driving loads which require high starting torque such as compressor pumps, reciprocating pumps, large refrigerators, crushers, boring mills, textile machinery, cranes, punches and lathes etc.

7. Slip-ring Induction Motor. It has high starting torque and large overload capacity. Its speed can be changed up to 50% of its normal speed. Hence, it is used for those industrial drives which require high starting torque and speed control such as lifts, pumps, winding machines, printing presses, line shafts, elevators and compressors etc.

8. Single-phase Synchronous Motor. Because of its constant speed, it is used in teleprinters, clocks, all kinds of timing devices, recording instruments, sound recording and reproducing systems.

9. Single-phase Series Motor. It possesses high starting torque and its speed can be controlled over a wide range. It is used for driving small domestic appliances like refrigerators and vacuum cleaners etc.

10. Repulsion Motor. It has high starting torque and is capable of wide speed control. Moreover, it has high speed at high loads. Hence, it is used for drives which require large starting torque and adjustable but constant speed as in coil winding machines.

11. Capacitor-start Induction-run Motor. It has fairly constant speed and moderately high starting torque. Speed control is not possible. It is used for compressors, refrigerators and small portable hoists.

12. Capacitor-start-and-run Motor. Its operating characteristics are similar to the above motor except that it has better power factor and higher efficiency. Hence, it is used for drives requiring quiet operations.

5.5.2 Advantages of Electrical Braking Over Mechanical Braking

1. In mechanical braking; due to excessive wear on brake drum, liner etc. it needs frequent and costly replacement. This is not needed in electrical braking and so electrical braking is more economical than mechanical braking.

2. Due to wear and tear of brake liner frequent adjustments are needed thereby making the maintenance costly.

3. Mechanical braking produces metal dust, which can damage bearings. Electrical braking has no such problems.

4. If mechanical brakes are not correctly adjusted it may result in shock loading of machine or machine parts in case of lift, trains which may result in discomfort to the occupants.

5. Electrical braking is smooth. Heavy duty hydraulic motor for high torque and low speeds

6. In mechanical braking the heat is produced at brake liner or brake drum, which may be a source of failure of the brake. In electric braking the heat is produced at convenient place, which in no way is harmful to a braking system.

7. In regenerative braking electrical energy can be returned back to the supply which is not possible in mechanical braking.

8. Noise produced is very high in mechanical braking. Only disadvantage in electrical braking is that it is ineffective in applying holding torque.
Types of Electric Braking
There are three types of electric braking as applicable to electric motors in addition to eddy current braking.

1. Plugging or reverse-current braking.
2. Rheostatic or dynamic braking.
3. Regenerative braking.

In many cases, provision of an arrangement for stopping a motor and its driven load is as important as starting it. For example, a planning machine must be quickly stopped at the end of its stroke in order to achieve a high rate of production. In other cases, rapid stops are essential for preventing any danger to operator or damage to the product being manufactured. Similarly, in the case of lifts and hoists, effective braking must be provided for their proper functioning.

Plugging Applied to D.C. Motors

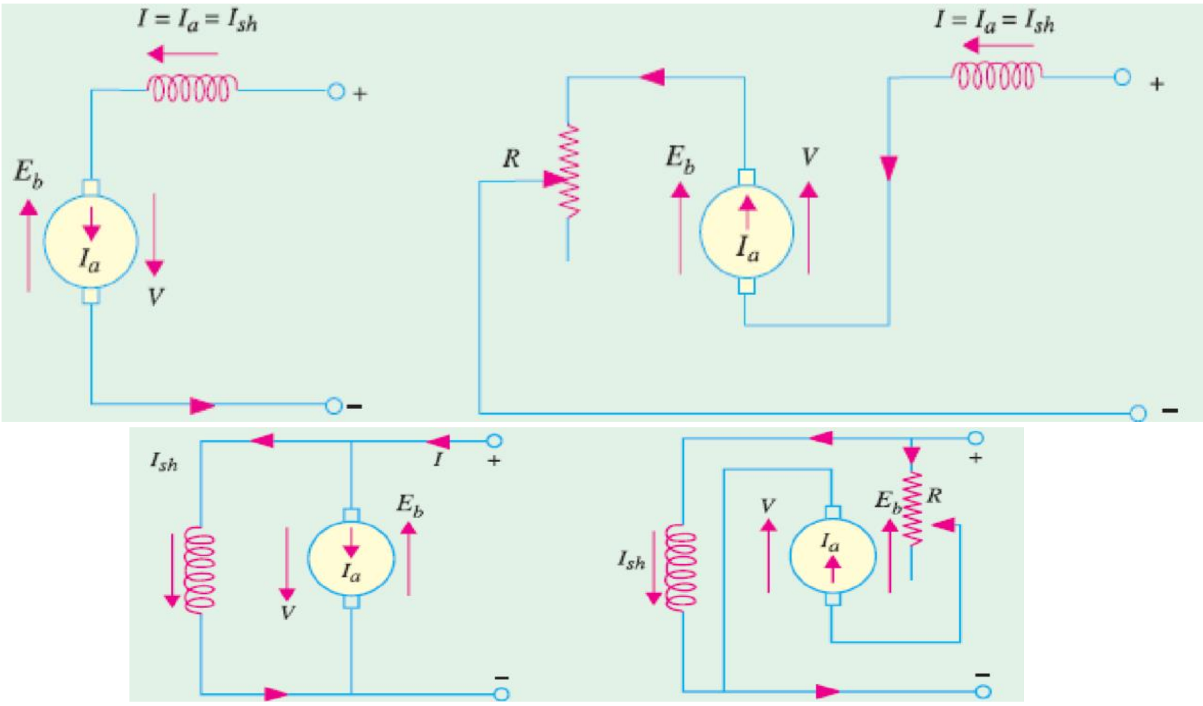


Fig 5.3 Plugging applied to dc motors

If the armature connections are reversed whereas ***field winding connections remains unchanged***. With reversed armature connections, the motor develops a torque in the ***opposite*** direction. When speed reduces to zero, motor will accelerate in the opposite direction. Hence, the arrangement is made to disconnect the motor from the supply as soon as it comes to rest. Fig. shows running and reversed connections for shunt motors and similar conditions for series motors.Since with reversed connection, *V* and *Eb* are in the same direction, voltage across the armature is almost double of its normal value. In order to avoid excessive current through the armature, additional resistance *R* is connected in series with armature.
This method of braking is wasteful because in addition to wasting kinetic energy of the moving parts, it draws additional energy from the supply during braking.

Braking torque is given by

$$T_B \propto \Phi I_a = k_1 \Phi I_a; \text{ Now, } I_a = (V + E_b)/R$$

$$T_B = K_1 \Phi \cdot \frac{V + E_b}{R} = k_1 \Phi \frac{V + k_2 \Phi N}{R} \qquad (\because E_b \propto \Phi N)$$

$$= \frac{K_1 \Phi V}{R} + \frac{k_1 k_2 \Phi^2 N}{R} = k_3 \Phi + k_4 \Phi^2 N$$

For shunt motor

Since in the case, Φ is practically constant, $T_B = k_5 + k_6 N$.

For series motor

$$T_B = k_3 \Phi + k_4 \Phi^2 N = k_5 I_a + k_6 N I_a^2$$

5.6 Vehicle Performance and Energy :Energy Saving in Regenerative Braking

We will now compute the amount of energy recuperated between any two points on a level track during which regenerative braking is employed. The amount of energy thus recovered and then returned to the supply lines depends on :
(*i*) initial and final velocities of the train during braking **(*ii*)** efficiency of the system and **(*iii*)** train resistance.
Suppose regenerative braking is applied when train velocity is *V*1 km/h and ceases when it is *V*2 km/h. If *Me* tonne is the effective mass of the train, then

$$\text{K.E. of the train at } V_1 = \frac{1}{2} M_e V_1^2 = \frac{1}{2}(1000\, M_e) \times \left(\frac{1000\, V_1}{3600}\right)^2 \text{ joules}$$

$$= \frac{1}{2}(1000\, M_e)\left(\frac{1000\, V_1}{3600}\right)^2 \times \frac{1}{3600} \text{ Wh}$$

$$= 0.01072\, M_e V_1^2 \text{ Wh} = 0.01072\, \frac{M_e}{M} V_1^2 \text{ Wh/tonne}$$

$$\text{K.E. at } V_2 = 0.01072\, \frac{M_e}{M} V_2^2 \text{ Wh/tonne}$$

Hence, energy available for recovery is = $0.01072\ \frac{M_e}{M}\ (V_1^2 - V_2^2)$ Wh/tonne

If r N/t is the specific resistance of the train, then total resistance = rM newton.

If d km is the distance travelled during braking, then

energy spent = $rM \times (1000\ d)$ joules = $rMd \propto \frac{1000}{3600}$ Wh = $0.2778\ rd$ Wh/tonne

Hence, net energy recuperated during regenerative braking is

$$= 0.01072\ \frac{M_e}{M}\ (V_1^2 - V_2^2) - 0.2778\ rd \text{ Wh/tonne}$$

Gradient. If there is a *descending* gradient of G per cent over the same distance of d km, then downward force is = 98 MG newton

Energy provided during braking

$$= 98\ MG \times (1000\ d) \text{ joules} = 98\ MG\ d\ (1000 / 3600) \text{ Wh} = 27.25\ Gd \text{ Wh/tonne}$$

Hence, net energy recuperated in this case is

$$= \left[0.01072\frac{M_e}{M}(V_1^2 - V_2^2) - 0.2778\ rd + 2725\ Gd\right] \text{ Wh/tonne}$$

$$= 0.01072\frac{M_e}{M}(V_1^2 - V_2^2) + d\ (27.75\ G - 0.2778\ r) \text{ Wh/tonne}$$

If η is the system efficiency, net energy returned to the line is

(*i*) level track

$$= \eta\left[0.01072\frac{M_e}{M}(V_1^2 - V_2^2) - 0.2778\ rd\right] \text{ Wh/tonne}$$

(*ii*) **descending gradient**

$$= \eta\left[0.01072\frac{M_e}{M}(V_1^2 - V_2^2) + d\ (27.25\ G - 0.2778\ r)\right] \text{ Wh/tonne}$$

Module Outcomes:

- Explain the working of electric hybrid vehicles