INDUSTRIAL AND ALLIED ELECTRICAL SYSTEMS LECTURE NOTES

B.TECH
(IV YEAR –I SEM)
(2020-21)

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MALLAREDDY COLLEGE OF ENGINEERING & TECHNOLOGY
(Autonomous Institution – UGC, Govt. of India)
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MALLA REDDY COLLEGE OF ENGINEERING AND TECHNOLOGY

IV B.Tech EEE I Sem **L T/P/D**

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(R17A0220) INDUSTRIAL AND ALLIED ELECTRICAL SYSTEMS

COURSE OBJECTIVES:

- To give a basic knowledge on residential, commercial and wiring systems.
- To understand the different applications like heating, welding and illumination.
- To gives a comprehensive idea on UPS, Electric Traction and industrial electrical systems.

UNIT - I

ILLUMINATION: Introduction, terms used in illumination, laws of illumination, polar curves, photometry. Sources of light Discharge lamps: Mercury Vapor and Sodium Vapor lamps – comparison between tungsten filament lamps and fluorescent lamps. Basic principles of light control, Types and design of lighting and flood lighting.

UNIT - II

RESIDENTIAL AND COMMERCIAL ELECTRICAL SYSTEMS: Types of residential and commercial wiring systems, general rules and guidelines for installation, load calculation and sizing of wire, rating of main switch, distribution board and protection devices, earthing system calculations, requirements of commercial installation, deciding lighting scheme and number of lamps, earthing for commercial installations. Selection and sizing of components.

UNIT - III

ELECTRIC HEATING AND WELDING: Electric Heating: Advantages and methods of electric heating, resistance heating, induction heating and dielectric heating. Electric welding: resistance and arc welding, electric welding equipment, comparison between A.C. and D.C. Welding.

UNIT - IV

INDUSTRIAL ELECTRICAL SYSTEMS: Industrial loads, motors, starting of motors, Lightning Protection, methods of earthing, UPS System, Electrical Systems for the elevators, Battery banks, Selection of UPS and Battery Banks.

UNIT - V

ELECTRIC TRACTION: Traction Systems: types, overview of existing electric traction systems in India. Special features of traction motor. Speed-time curves for different services – trapezoidal and quadrilateral speed time curves.

TEXT BOOKS:

1. J.B. Gupta, “Utilization of Electric Power and Electric Traction”, Kataria & Sons publishers, Delhi,
IX Edtion, 2004.
2. C.L. Wadhwa, “Generation, Distribution and Utilization of electrical Energy”, New Age International
(P) Limited Publishers, 3rd Edition, 2010
3. S. L.Uppal and G.C.Garg,” Electrical wiring Estimating & costing” Khanna publishers,2008
4. Utilization of electric Energy by E. Openshaw Taylor, Orient Longman Private Limited,1971.

REFERENCE BOOKS:

1. N.V. Suryanarayana, “Utilization of Electrical Power including Electric drives and Electric traction”, New Age International (P) Limited Publishers, 1st Edition, 1994.
2. E. Open Shaw Taylor, “Utilization of Electric Energy”, Orient Longman,1st Edition,1937

COURSE OUTCOMES:

After completion of the course, the student will be able to

- Maintain/Troubleshoot various lamps and fittings in use.
- Understand various types of Heating, Welding and traction system.
- Design Illumination systems for various applications.
- Work in the areas of UPS systems and traction systems production, commissioning and maintenance.

UNIT-1
ILLUMINATION

INTRODUCTION:

Study of illumination engineering is necessary not only to understand the principles of light control as applied to interior lighting design such as domestic and factory lighting but also to understand outdoor applications such as highway lighting and flood lighting. Now a day, the electrically produced light is preferred to the other source of illumination because of an account of its cleanliness, ease of control, steady light output, low cost, and reliability. The best illumination is that it produces no strain on the eyes. Apart from its esthetic and decorative aspects, good lighting has a strictly utilitarian value in reducing the fatigue of the workers, protecting their health, increasing production, etc.The science of illumination engineering is therefore becoming of major importance.

NATURE OF LIGHT

Light is a form of electromagnetic energy radiated from a body and human eye is capable of receiving it. Light is a prime factor in the human life as all activities of human being ultimately depend upon the light. Various forms of incandescent bodies are the sources of light and the light emitted by such bodies depends upon their temperature. A hot body about 500–800°C becomes a red hot and about 2,500–3,000°C the body becomes white hot. While the body is red hot, the wavelength of the radiated energy will be sufficiently large and the energy available in the form of heat. Further, the temperature increases, the body changes from red-hot to white-hot state, the wavelength of the radiated energy becomes smaller and enters into the range of the wavelength of light. The wavelength of the light waves varying from 0.0004 to 0.00075 mm, i.e. 4,000-7,500 Å (1 Angstrom unit = 10–10 mm). The eye discriminates between different wavelengths in this range by the sensation of color.

The whole of the energy radiated out is not useful for illumination purpose. Radiations of very short wavelength varying from 0.0000156 × 10–6m to 0.001 × 10–6 m are not in the visible range are called as rontgen or x-rays, which are having the property of penetrating through opaque bodies.

TERMS USED IN ILLUMINATION

The following terms are generally used in illumination.

Color:

The energy radiation of the heated body is monochromatic, i.e. the radiation of only one wavelength emits specific color. The wavelength of visible light lies between 4,000 and 7,500 Å. The color of the radiation corresponding to the wavelength is shown in Fig. 1.1.

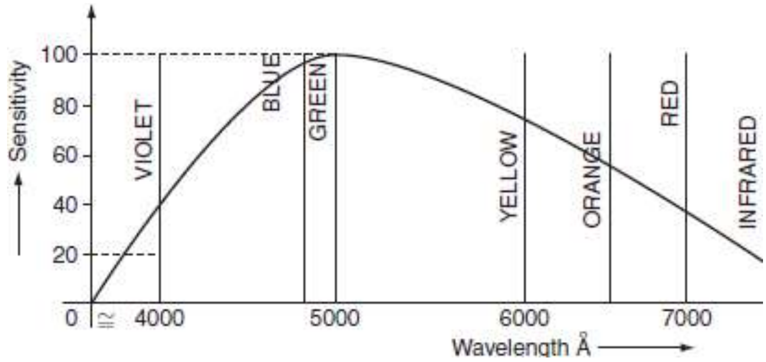


Fig. 1.1.Wavelength

Relative sensitivity:

The reacting power of the human eye to the light waves of different wavelengths varies from person to person, and also varies with age. The average relative sensitivity is shown in Fig. 1.2. The eye is most sensitive for a wavelength of 5,500 Å. So that, the relative sensitivity according to this wavelength is taken as unity. Referred from Fig. 1.1, blue and violet corresponding to the short wavelengths and red to the long wavelengths, orange, yellow, and green being in the middle of the visible region of wavelength. The color corresponding to 5,500 Å is not suitable for most of the applications since yellowish green. The relative sensitivity at any particular wavelength (λ) is known as relative luminous factor (Kλ).

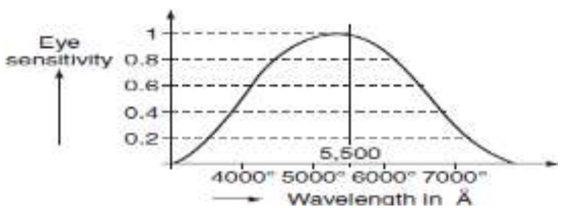


Fig. 1.2 The average relative sensitivity

Light:

It is defined as the radiant energy from a hot body that produces the visual sensation upon the human eye. It is expressed in lumen-hours and it analogous to watthours,which denoted by the symbol 'Q'.

Luminous flux:

It is defined as the energy in the form of light waves radiated per second from a luminous body. It is represented by the symbol 'φ' and measured in lumens.

Ex: Suppose the luminous body is an incandescent lamp. The total electrical power input to the lamp is not converted to luminous flux, some of the power lost through conduction, convection, and radiation, etc. Afraction of the remaining radiant flux is in the form of light waves lies in between the visual range of wavelength, i.e. between 4,000 and 7,000 Å, as shown in Fig. 1.3.

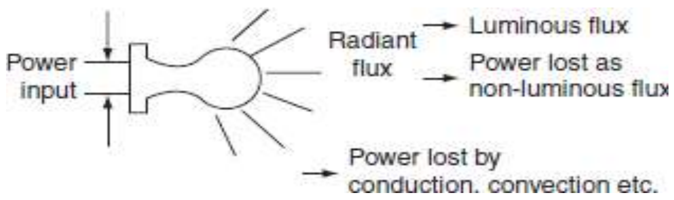


Fig. 1.3 Flux diagram

Radiant efficiency

When an electric current is passed through a conductor, some heat is produced to I^2R loss, which increases its temperature of the conductor. At low temperature, conductor radiates energy in the form of heat waves, but at very high temperatures, radiated energy will be in the form of light as well as heat waves. 'Radiant efficiency is defined as the ratio of energy radiated in the form of light, produces sensation of vision to the total energy radiated out by the luminous body'.

$$\text{Radiant Efficiency} = \frac{\textbf{Energy radiated in the form of light}}{\textbf{Total energy radiated by the body}}$$

Plane angle

A plane angle is the angle subtended at a point in a plane by two converging lines (Fig.1.4). It is denoted by the Greek letter 'θ' (theta) and is usually measured in degrees or radians. One radian is defined as the angle subtended by an arc of a circle whose length by an arc of a circle whose length is equals to the radius of the circle.

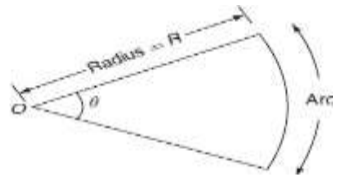


Fig. 1.4 Plane angle

$$\therefore \text{Plane angle } (\theta) = \frac{\text{arc}}{\text{radius}}. \qquad (1.1)$$

Plane angle (θ) = $\frac{Arc}{Radius}$

Solid angle

Solid angle is the angle subtended at a point in space by an area, i.e., the angle enclosed in the volume formed by numerous lines lying on the surface and meeting at the point (Fig. 1.5). It is usually denoted by symbol 'ω' and is measured in steradian.

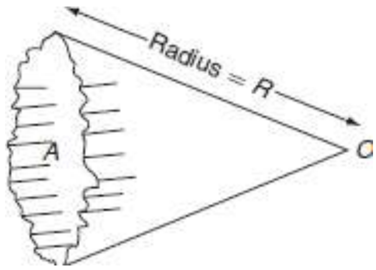


Fig.1.5 Solid angle

Solid angle (ω) = $\frac{area}{radius2}$ (1.2)

The largest solid angle subtended at the center of a sphere:

$$\omega = \frac{area\ of\ sphere}{radius\ 2} = \frac{4\pi r^2}{R^2} = \mathbf{4\prod\ steradians}$$

Relationship between plane angle and solid angle

Let us consider a curved surface of a spherical segment ABC of height 'h' and radius of the sphere 'r' as shown in Fig. 1.6. The surface area of the curved surface of the spherical segment ABC = 2πrh. From the Fig. 1.6:

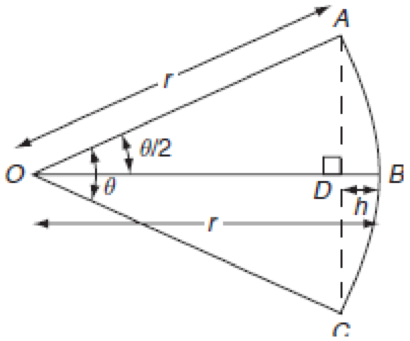


Fig.1.6 Sectional view for solid angle

$$h = r - r\cos\left(\frac{\theta}{2}\right) \quad [\because \text{From } \Delta ODA, OD = r\cos\theta/2]$$

$$= r\left(1 - \cos\frac{\theta}{2}\right).$$

$$h = r - r\cos(\tfrac{\theta}{2})$$

BD = OB – OD From

The surface area of the segment = 2∏**rh**

$$= 2\prod r^2[1 - \cos(\tfrac{\theta}{2})]$$

$$\text{Solid angle } (\omega) = \frac{area}{radius2}$$

=

$$= \frac{2\prod r2[1 - \cos(\frac{\theta}{2})]}{r2}$$

$$= 2\prod[1 - \cos(\tfrac{\theta}{2})]$$

$\therefore$ The surface area of the segment $= 2\pi rh$

$$= 2\pi r^2 \left[r - \cos\frac{\theta}{2} \right].$$

$$\text{We know solid angle } (\omega) = \frac{\text{area}}{(\text{radius})^2}$$

$$= \frac{2\pi r^2 \left(1 - \cos\frac{\theta}{2}\right)}{r^2} \qquad \textbf{(1.3)}$$

$$= 2\pi \left(1 - \cos\frac{\theta}{2}\right).$$

From the Equation (1.3), the curve shows the variation of solid angle with plane angle is shown in Fig. 1.7.

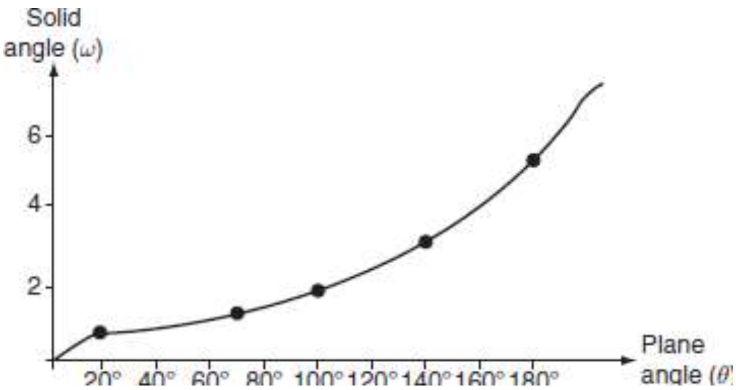


Fig. 1.7 Relation between solid angle and plane angle

Luminous intensity

Luminous intensity in a given direction is defined as the luminous flux emitted by the source per unit solid angle (Fig. 1.8).

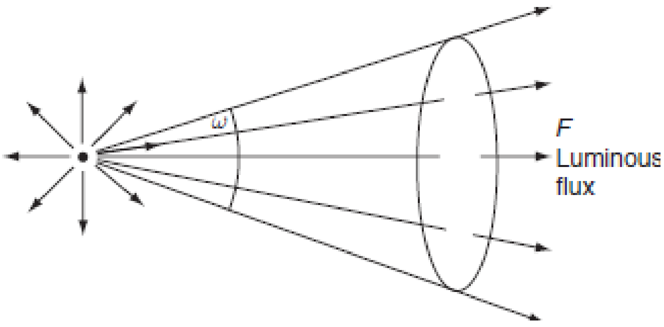


Fig. 1.8 Luminous flux emitting from the source

It is denoted by the symbol 'I' and is usually measured in 'candela'. Let 'F' be the luminous

$$I = \frac{\emptyset}{\boldsymbol{\omega}}$$

flux crossing a spherical segment of solid angle 'ω'. Then luminous intensity lumen/steradian or candela.

Lumen:

It is the unit of luminous flux. It is defined as the luminous flux emitted by a source of one candle power per unit solid angle in all directions.

Lumen = candle power of source × solid angle. Lumen = CP × ω

Total flux emitted by a source of one candle power is 4π lumens.

Candle power (CP)

The CP of a source is defined as the total luminous flux lines emitted by that source in a unit solid angle.

$$CP = \frac{\boldsymbol{lumen}}{\boldsymbol{\omega}} \text{ lumen/steradian or candela}$$

Illumination

Illumination is defined as the luminous flux received by the surface per unit area.It is usually denoted by the symbol 'E' and is measured in lux or lumen/m2 or meter

$$\text{Illumination } E = \frac{\boldsymbol{luminous\ flux}}{\boldsymbol{area}}$$

$$= \frac{\emptyset}{\boldsymbol{A}}$$

$$= \frac{\boldsymbol{CP\ X\ \omega}}{\boldsymbol{A}} \text{ Lux}$$

Lux or meter candle

It is defined as the illumination of the inside of a sphere of radius 1 m and a source of 1 CP is fitted at the center of sphere.

Foot candle

It is the unit of illumination and is defined as the illumination of the inside of a sphere of radius 1 foot, and a source of 1 CP is fitted at the center of it.

We know that 1 lux = 1 foot candle = 1 lumen/(ft)2

$$1 \text{ foot candle } = \frac{\text{lumen}}{\left(\frac{1}{3.28}\right)^2 \text{m}^2} = 10.76 \text{ lux or m-candle}$$

$$\therefore 1 \text{ foot candle} = 10.76 \text{ lux.}$$

Brightness

Brightness of any surface is defined as the luminous intensity pen unit surface area of the projected surface in the given direction. It is usually denoted by symbol 'L'.If the luminous intensity of source be 'I' candela on an area A, then the projected area is Acos θ.

The unit of brightness is candela/m2 or candela/cm2 or candela/(ft)2.

$$\textbf{Brightness, L} = \frac{I}{A\cos\theta}$$

Relation between I, E, and L

Let us consider a uniform diffuse sphere with radius r meters, at the center a source of 1 CP, and luminous intensity I candela.

$$\text{Brightness , L} = \frac{I}{\prod r\,2}$$

$$\text{and Illumination } (E) = \frac{\phi}{A} = \frac{CP \times \omega}{A}$$

$$= \frac{I}{4\pi r^2} \times 4\pi = \frac{I}{r^2} \qquad (1.4)$$

$$\therefore E = \frac{I}{r^2} = \frac{I}{\pi r^2} \times \pi = \pi L$$

$$\therefore E = \pi L = \frac{I}{r^2}.$$

Mean horizontal candle power (MHCP)

MHCP is defined as the mean of the candle power of source in all directions in horizontal plane.

Mean spherical candle power (MSCP)

MSCP is defined as the mean of the candle power of source in all directions in all planes.

Mean hemispherical candle power (MHSCP)

MHSCP is defined as the mean of the candle power of source in all directions above or below the horizontal plane.

Reduction factor

Reduction factor of the source of light is defined as the ratio of its mean spherical candle power to its mean horizontal candle power.

$$\textbf{Reduction factor} = \frac{MSCP}{MHCP}$$

Lamp efficiency

It is defined as the ratio of the total luminous flux emitting from the source to its electrical power input in watts. It is expressed in lumen/W.

$$\textbf{Lamp Efficiency} = \frac{luminious\ flux}{power\ input}$$

Specific consumption

It is defined as the ratio of electric power input to its average candle power.

Space to height ratio

It is defined as ratio of horizontal distance between adjacent lamps to the height of their Mountings.

$$\text{Space to height ratio} = \frac{\text{horizontal distance between two adjacent lamps}}{\text{mounting height of lamps above the working plane}}$$

Coefficient of utilization or utilization factor

It is defined as the ratio of total number of lumens reaching the working plane to the Total number of lumens emitting from source.

$$\text{Utilization factor} = \frac{\text{total lumens reaching the working plane}}{\text{total lumens emitting from source}}$$

Maintenance factor

It is defined as the ratio of illumination under normal working conditions to the illumination when everything is clean. Its value is always less than 1, and it will be around 0.8. This is due to the accumulation of dust, dirt, and smoke on the lamps that emit less light than that they emit when they are so clean. Frequent cleaning of lamp will improve the maintenance factor.

$$\text{Maintanance factor} = \frac{\text{illumination under normal working condition}}{\text{illumination under every thing is clean}}$$

Depreciation factor

It is defined as the ratio of initial illumination to the ultimate maintained illumination on the working plane. Its values is always more than 1.

$$\textbf{Depreciation factor} = \frac{\mathbf{1}}{\boldsymbol{Maintence\ factor}}$$

Waste light factor

When a surface is illuminated by several numbers of the sources of light, there is certain amount of wastage due to overlapping of light waves; the wastage of light is taken into account depending upon the type of area to be illuminated. Its value for rectangular area is 1.2 and for irregular area is 1.5 and objects such as statues, monuments, etc.

Absorption factor

Normally, when the atmosphere is full of smoke and fumes, there is a possibility of absorption of light. Hence, the total lumens available after absorption to the total lumens emitted by the lamp are known as absorption factor.

$$\text{Absorption factor} = \frac{\text{the total lumens available after absorption}}{\text{the total lumens given out by the lamp}}$$

Reflection factor or coefficient of reflection

When light rays impinge on a surface, it is reflected from the surface at an angle of incidence shown in Fig. 1.9. A portion of incident light is absorbed by the surface. The ratio of luminous flux leaving the surface to the luminous flux incident on it is known as reflection factor. Its value will be always less than 1.

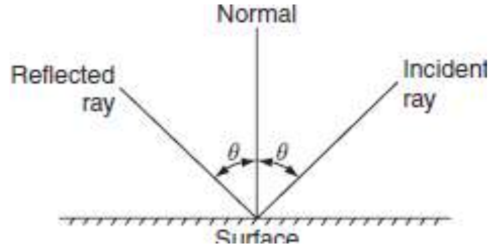


Fig.1.9 Reflected ray

Beam factor

It is defined as the ratio of 'lumens in the beam of a projector to the lumens given out by lamps'. Its value is usually varies from 0.3 to 0.6. This factor is taken into account for the absorption of light by reflector and front glass of the projector lamp.

Example 1.1: A 200-V lamp takes a current of 1.2 A, it produces a total flux of 2,860 lumens. Calculate: 1. the MSCPofthe lamp and 2. the efficiency of the lamp.

Solution:

Given V = 200 V

I = 1.2 A, flux = 2,860 lumens.

$$\text{(i) MSCP} = \frac{\text{total flux}}{4\pi} = \frac{2860}{4\pi} = 227.59.$$

Example 1.2: A room with an area of 6 × 9 m is illustrated by ten 80-W lamps. The luminous efficiency of the lamp is 80 lumens/W and the coefficient of utilization is 0.65.Find the average illumination.

Solution:

Room area = 6 × 9 = 54 m2.

Total wattage = 80 × 10 = 800 W.

Total flux emitted by ten lamps = 80 × 800 = 64,000 lumens.

Flux reaching the working plane = 64,000 × 0.65 = 41,600 lumens

$$\therefore \text{Illumination, } E = \frac{\phi}{A} = \frac{41{,}600}{54} = 770.37 \text{ lux.}$$

Example 1.3: The luminous intensity of a lamp is 600 CP. Find the flux given out. Also find the flux in the hemisphere containing the source of light and zero above the horizontal.

Solution:

Flux emitted by source (lumen)

= Intensity (I) × solid angle (ω)

= 600 × 2 π = 3,769.911 lumens

∴ Flux emitted in the lower hemisphere = 3,769.911 lumens.

Example 1.4: The flux emitted by 100-W lamp is 1,400 lumens placed in a frosted globe of 40 cm diameter and gives uniform brightness of 250 milli-lumens/m2 in all directions. Calculate the candel power of the globe and the percentage of light absorbed by the globe.

Solution:

Flux emitted by the globe

= brightness × globe area

$$= \left[\frac{250}{1{,}000}\right] \times \left[4\pi\left(\frac{40}{2}\right)^2\right]$$

= 1,256.63 lumens

Flux absorbed by the globe

= flux emitted by source – flux emitted by globe

= 1,400 – 1,256.63

= 143.36 lumens.

$$\therefore \text{The percentage of light absorbed by the globe } = \frac{143.36}{1{,}400} \times 100 = 10.24\%.$$

Example 1.5: A surface inclined at an angle 40° to the rays is kept 6 m away from 150 candle power lamp. Find the average intensity of illumination on the surface.

Solution:

From the Fig. P.1.1:

θ = (90° – 40°) = 50°.

∴ Average illumination:

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

$$= \frac{150}{(4)^2} \times \cos 50^{\circ}$$

$$= 6.026 \text{ lux.}$$

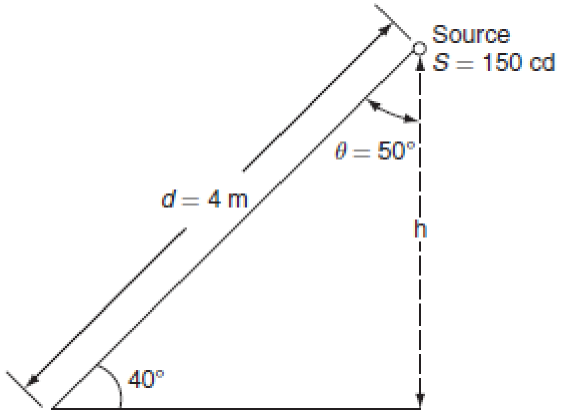


Fig. P.1.1

LAWS OF ILLUMINATION

Mainly there are two laws of illumination.

1. Inverse square law.
2. Lambert's cosine law.

I Inverse square law

This law states that 'the illumination of a surface is inversely proportional to the square of distance between the surface and a point source'.

Proof:

Let, 'S' be a point source of luminous intensity 'I' candela, the luminous flux emitting from source crossing the three parallel plates having areas A1 A2, and A3 square meters, which are separated by a distances of d, 2d, and 3d from the point source respectively as shown in Fig. 1.10.

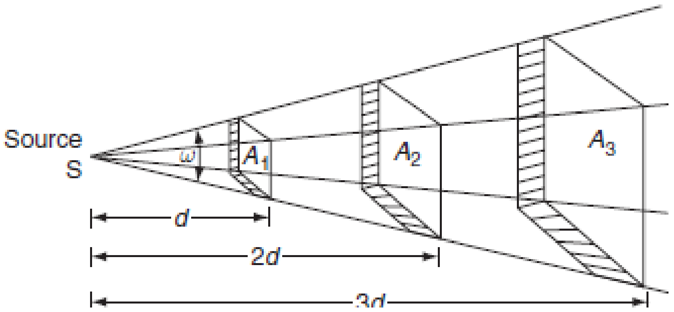


Fig. 1.10 Inverse square law

For area A_1, solid angle $\omega = \frac{A_1}{d^2}$

Luminous flux reaching the area A1 = luminous intensity × solid angle

$$= I \times \omega = I \times \frac{A_1}{d^2}$$

$$E_1 = \frac{\text{flux}}{\text{area}} = \frac{IA_1}{d^2} \times \frac{1}{A_1} \qquad (1.5)$$

$$\therefore E_1 = \frac{I}{d^2} \quad \text{lux.}$$

∴ Illumination 'E1' on the surface area 'A1' is:

Similarly, illumination 'E2' on the surface area A2 is:

$$E_2 = \frac{I}{(2d)^2} \quad \text{lux} \qquad (1.6)$$

and illumination 'E3' on the surface area A3 is:

$$E_3 = \frac{I}{(3d)^2} \quad \text{lux.} \qquad (1.7)$$

From Equations (1.5), (1.6), and (1.7)

$$E_1 : E_2 : E_3 = \frac{1}{d^2} : \frac{1}{(2d)^2} : \frac{1}{(3d)^2}. \qquad (1.8)$$

Hence, from Equation (1.8), illumination on any surface is inversely proportional to the square of distance between the surface and the source.

Lambert's cosine law

This law states that 'illumination, E at any point on a surface is directly proportional to the cosine of the angle between the normal at that point and the line of flux'.

Proof:

While discussing, the Lambert's cosine law, let us assume that the surface is inclined at an angle 'θ' to the lines of flux as shown in Fig. 1.11.

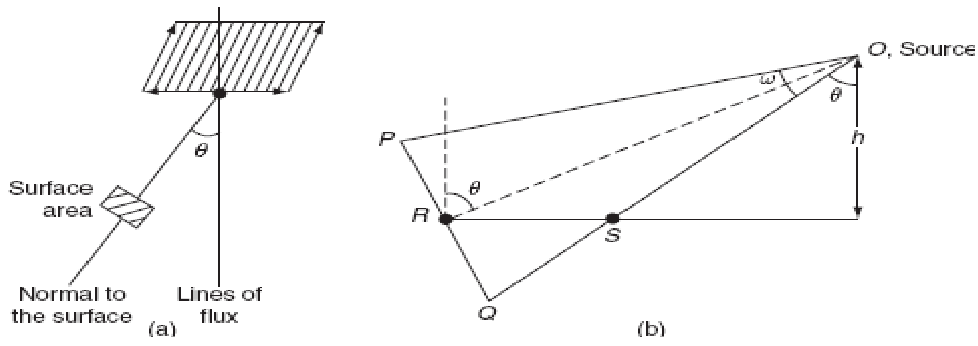


Fig. 1.11 Lambert's cosine law

Let

PQ = The surface area normal to the source and inclined at ‘θ’ to the vertical axis.

RS = The surface area normal to the vertical axis and inclined at an angle θ to the source ‘O’.

Therefore, from Fig. 1.11:

$PQ = RS\cos\theta.$

$$\therefore \text{The illumination of the surface } PQ, E_{PQ} = \frac{\text{flux}}{\text{area of } PQ} \qquad (1.9)$$

$$= \frac{I \times \omega}{\text{area of } PQ} = \frac{I}{\text{area of } PQ} \times \frac{\text{area of } PQ}{d^2} \quad [\therefore \omega = \text{area}/(\text{radius})^2]$$

$$= \frac{I}{d^2}.$$

$$\therefore \text{The illumination of the surface } RS, E_{RS} = \frac{\text{flux}}{\text{area of } RS} = \frac{\text{flux}}{\text{area of } PQ/\cos\theta} \qquad (1.10)$$

$$[\therefore PQ = RS\cos\theta]$$

$$= \frac{I}{d^2}\cos\theta.$$

From Fig. 1.11(b):

$$\cos\theta = \frac{h}{d}$$

$$\text{or } d = \frac{h}{\cos\theta}$$

Substituting ‘d' from the above equation in Equation (1.10):

Where

$$\therefore E_{RS} = \frac{I}{(h/\cos\theta)^2} \times \cos\theta = \frac{I}{h^2}\cos^3\theta \qquad (1.11)$$

$$\therefore E_{RS} = \frac{I}{d^2}\cos\theta = \frac{I}{h^2}\cos^3\theta \qquad (1.12)$$

where d is the distance between the source and the surface in m, h is the height of source from the surface in m, and I is the luminous intensity in candela. Hence, Equation (1.11) is also known as ‘cosine cube’ law. This law states that the ‘illumination at any point on a surface is dependent on the cube of cosine of the angle between line of flux and normal at that point’.

Note:

*From the above laws of illumination, it is to be noted that inverse square law is only applicable for the surfaces if the surface is normal to the line of flux. And Lambert's cosine law is applicable for the surfaces if the surface is inclined an angle ‘θ’ to the line of flux.

Example 1.6: The illumination at a point on a working plane directly below the lamp is to be 60 lumens/m2. The lamp gives 130 CP uniformly below the horizontal plane. Determine: 1. The height at which lamp is suspended. 2. The illumination at a point on the working plane 2.8 m away from the vertical axis of the lamp.

Solution:

Given data:

Candle power of the lamp = 130 CP.

The illumination just below the lamp, E = 60 lumen/m2.

From the Fig. P.6.2, the illumination just below the lamp, i.e., at point A:

$$E_A = \frac{I}{h^2}$$

$$\therefore h = \sqrt{\frac{I}{EA}} = \sqrt{\frac{130}{60}} = 1.471\,\text{m}.$$

The illumination at point ‘B':

$$E_B = \frac{I}{h^2}\cos^3\theta$$

$$= \frac{130}{(2.8)^2}\left\{\frac{2.8}{\sqrt{2.8^2 + 1.471^2}}\right\}^3 = 11.504 \text{ lux.}$$

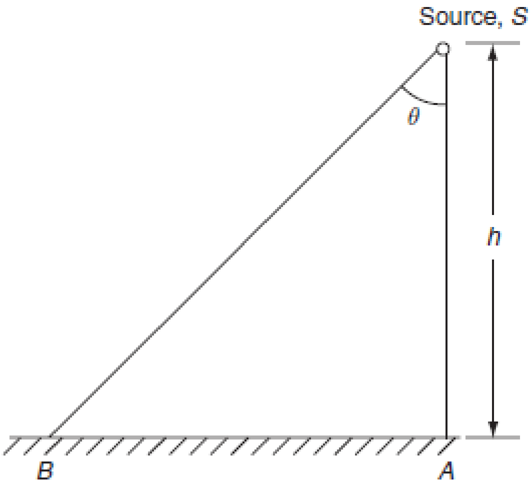


Fig. P.1.2

POLAR CURVES

The luminous flux emitted by a source can be determined using the intensity distribution curve. Till now we assumed that the luminous intensity or the candle power from a source is distributed uniformly over the surrounding surface. But due to its s not uniform in all directions. The luminous intensity or the distribution of the light can be represented with the help of the polar curves. The polar curves are drawn by taking luminous intensities in various directions at an equal angular displacement in the sphere. A radial ordinate pointing in any particular direction on a polar curve represents the luminous intensity of the source when it is viewed from that direction. Accordingly, there are two different types of polar curves and they are:

A curve is plotted between the candle power and the angular position, if the luminous intensity, i.e., candle power is measured in the horizontal plane about the vertical axis, called 'horizontal polar curve.

curve is plotted between the candle power, if it is measured in the vertical plane and the angular position is known as 'vertical polar curve'. Figure 1.12 shows the typical polar curves for an ordinary lamp.

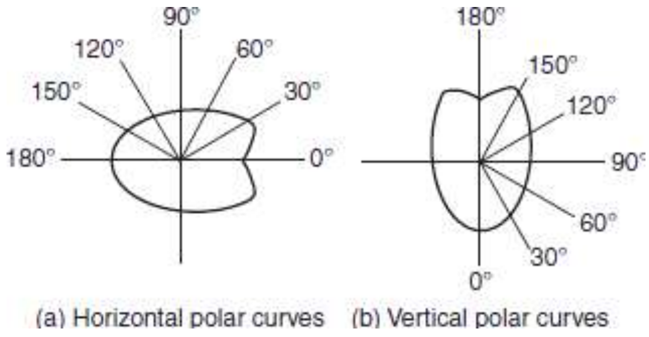


Fig 1.12 Polar

Depression at 180° in the vertical polar curve is due to the lamp holder. Slight depression at 0° in horizontal polar curve is because of coiled coil filament. Polar curves are 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. These are also used to determine mean horizontal candle power (MHCP) and mean spherical candle power (MSCP). The mean horizontal candle power of a lamp can be determined from the horizontal polar curve by considering the mean value of all the candle powers in a horizontal direction. The mean spherical candle power of a symmetrical source of a light can be found out from the polar curve by means of a Rousseau's construction.

Rousseau's construction

Let us consider a vertical polar curve is in the form of two lobes symmetrical about XOX1 axis. A simple Rousseau's curve is shown in Fig. 1.13.

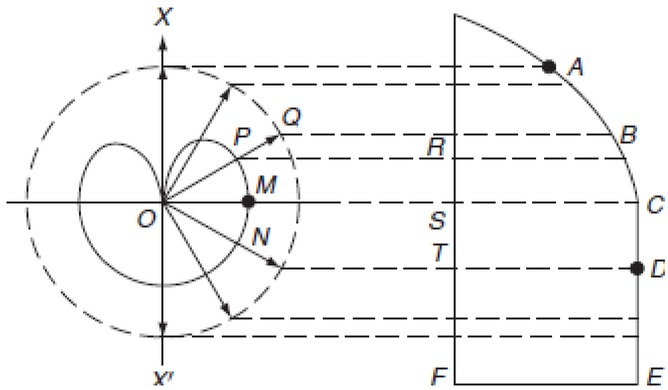


Fig. 1.13 Rousseau's curve

Rules for constructing the Rousseau's curve are as follows:

Draw a circle with any convenient radius and with ‘O’ as center.

Draw a line 'AF’ parallel to the axis XOX1 and is equal to the diameter of the circle.

Draw any line ‘OPQ' in such a way that the line meeting the circle at point ‘Q’. Now let the projection be ‘R’ onto the parallel line 'AF’.

Erect an ordinate at ‘R’ as, RB = OP.

Now from this line 'AF' ordinate equals to the corresponding radius on the polar curve are setup such as SC = OM, TD = ON, and so on.

The curve ABC DEFA so obtained by joining these ordinates is known as Rousseau's curve. The mean ordinate of this curve gives the mean spherical candle power (MSCP) of the lamp having polar curve given in Fig. 6.13. The mean ordinate of the curve:

$$= \frac{\text{area of } ABCDEFA}{\text{length of } AF}.$$

The area under the Rousseau's curve can be determined by Simpson's rule. PHOTOMETRY

Photometry involves the measurement of candle power or luminous intensity of a given source. Now, we shall discuss the comparison and measurement of the candle powers. The candle power of a given source in a particular direction can be measured by the comparison with a standard or substandard source. In order to eliminate the errors due to the reflected light, the experiment is conducted in a dark room with dead black walls and ceiling. The comparison of the test lamp with the standard lamp can be done by employing a photometer bench and some form of photometer.

Principle of simple photometer

The photometer bench essentially consists of two steel rods with 2- to 3-m long. This bench carries stands or saddles for holding two sources (test and standard lamps), the carriage for the photometer head and any other apparatus employed in making measurements. Graduated scale in centimeters or millimeters in one of the bar strips. The circular table is provided with a large graduated scale in degrees round its edge so that the angle of the rotation of lamp from the axis of bench can be measured. The photometer bench should be rigid so that the source being compared may be free from vibration. The photometer head should be capable of moving smoothly and the photometer head acts as screen for the comparison of the illumination of the

standard lamp and the test lamp. The principle methods of measurement are based upon the inverse square law. The photometer bench consists of two sources, the standard source ‘S’ whose candle power is known and the other source ‘T’ whose candle power is to be determined. The photometer head acts as screen is moved in between the two fixed sources until the illumination on both the sides of screen is same. A simple arrangement for the measurement of the candle power of the test source is shown in Fig. 1.14.

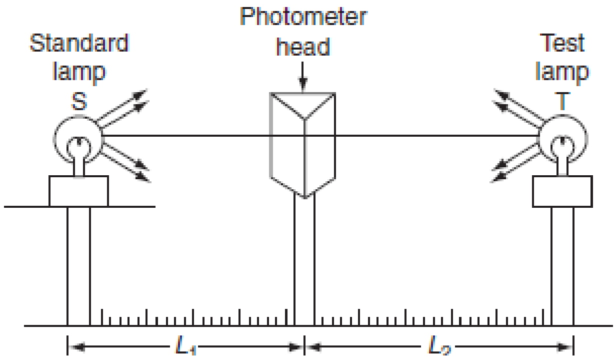


Fig.1.14 Measurement of candle power

Discharge lamps

In this method, the application of suitable voltage, known as ignition voltage, across the two electrodes results in a discharge through the gas, this is accompanied by electromagnetic radiation. Here, candle power, i.e., the color intensity of the light emitted depends upon the nature of the gas. These sources do not depend on the temperature for higher efficiencies. Ex: Neon lamp, sodium vapor lamp, mercury vapor lamp, and florescent lamp.

Various Illumination Methods

INTRODUCTION

Light plays major role in human life. Natural light restricted for some duration in a day, it is very difficult to do any work by human being without light. So, it is necessary to have substitute for natural light. Light from incandescent bodies produced electrically, which playing important role in everyday life due to its controlled output, reliability, and cleanliness nowadays; various sources are producing artificial light. Each source has its own characteristics and specific importance.

TYPES OF SOURCES OF ILLUMINATION

Usually in a broad sense, based upon the way of producing the light by electricity, the sources of light are classified into following four types.

Electric arc lamps

The ionization of air present between the two electrodes produces an arc and provides intense light.

Incandescent lamps

When the filaments of these lamps are heated to high temperature, they emit light that falls in the visible region of wavelength. Tungsten-filament lamps are operating on this principle. Gaseous

discharge lamps

When an electric current is made to pass through a gas or metal vapor, it produces visible radiation by discharge takes place in the gas vapor. Sodium and mercury vapor lamps operate on this principle.

Fluorescent lamps

Certain materials like phosphor powders exposed to ultraviolet rays emits the absorbed energy into visible radiations fall in the visible range of wavelength. This principle is employed in fluorescent lamps.

ARC LAMPS

In arc lamps, the electrodes are in contact with each other and are separated by some distance apart; the electric current is made to flow through these two electrodes. The discharge is allowed to take place in the atmosphere where there are the production of a very intense light and a considerable amount of UV radiation, when an arc is struck between two electrodes. The arcs maintain current and is very efficient source of light. They are used in search lights, projection lamps, and other special purpose lamps such as those in flash cameras.

Generally, used arc lamps are:

1 carbon arc lamp,
2 flame arc lamp, and
3 magnetic arc lamp.

1. Carbon arc lamp

Carbon arc lamp consists of two hard rod-type electrodes made up of carbon. Two electrodes are placed end to end and are connected to the DC supply. The positive electrode is of a large size than that of the negative electrode. The carbon electrodes used with AC supply are of the same size as that of the DC supply. The DC supply across the two electrodes must not be less than 45 V. When electric current passes through the electrodes are in contact and then withdrawn apart about 2–3 mm an arc is established between the two rods. The two edges of the rods becomes incandescence due to the high resistance offered by rods as shown in Fig. 1.15 by transfer of carbon particles from one rod to the other. It is observed that carbon particles transfer from the positive rod to the negative one. So that the positive electrode gets consumed earlier than the negative electrode. Hence, the positive electrode is of twice the diameter than that of the negative electrode.

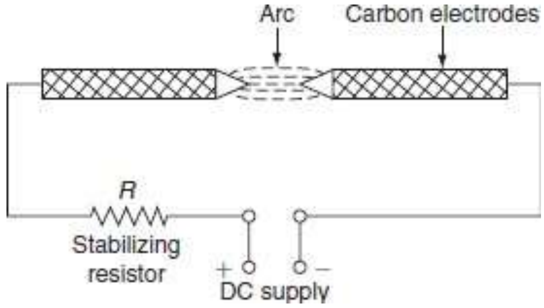


Fig 1.15 Carbon arc lamp

In case of AC supply, the rate of consumption of the two electrodes is same; therefore, the cross-section of the two electrodes is same. A resistance ‘R’ is connected in series with the electrode for stabilizing the arc. As current increases, the vaporizing rate of carbon increases, which decreases the resistance so much, then voltage drop across the arc decreases. So, to maintain the arc between the two electrodes, series resistance should be necessarily connected. For maintaining the arc, the necessary voltage required is:

$V = (39 + 2.8\,l)$ V,

where l is the length of the arc. The voltage drop across the arc is 60 V, the temperature of the positive electrode is 3,500 – 4,200°C, and the temperature of the negative electrode is 2,500°C. The luminous efficiency of such lamps is 9–12 lumens/W. This low luminous efficiency is due to the service resistance provided in DC supply while in case of AC supply, an inductor is used in place of a resistor. In carbon arc lamps, 85% of the light is given out by the positive electrode, 10% of the light is given out by the negative electrodes, and 5% of the light is given out by the air.

Flame arc lamp

The electrodes used in flame arc lamp are made up of 85% of carbon and 15% of fluoride. This fluoride is also known as flame material; it has the efficient property that radiates light energy from high heated arc stream. Generally, the core type electrodes are used and the cavities are filled with fluoride. The principle of operation of the flame arc lamp is similar to the carbon arc lamp. When the arc is established between the electrodes, both fluoride and carbon get vaporized and give out very high luminous intensities. The color output of the flame arc lamps depends upon the flame materials. The luminous efficiency of such lamp is 8 lumens/W. A simple flame arc lamp is shown in Fig. 1.16. Resistance is connected in service with the electrodes to stabilize the arc.

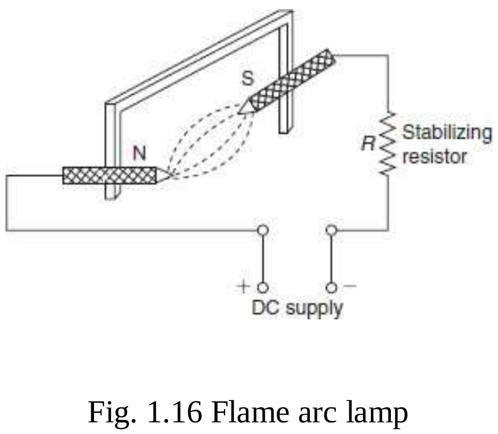


Fig. 1.16 Flame arc lamp

Magnetic arc lamp

The principle of the operation of the magnetic arc lamp is similar to the carbon arc lamp. This lamp consists of positive electrode that is made up of copper and negative electrode that is made up of magnetic oxide of iron. Light energy radiated out when the arc is struck between the two electrodes. These are rarely used lamps.

INCANDESCENT LAMP

These lamps are temperature-dependent sources. When electric current is made to flow through a fine metallic wire, which is known as filament, its temperature increases. At low temperatures, it emits only heat energy, but at very high temperature, the metallic wire emits both heat and light energy. These incandescent lamps are also known as temperature radiators. Choice of material for filament The materials commonly used as filament for incandescent lamps are carbon, tantalum, tungsten, and osmium.

The materials used for the filament of the incandescent lamp have the following properties.

1 The melting point of the filament material should be high.
2 The temperature coefficient of the material should be low.
3 It should be high resistive material.
4 The material should possess good mechanical strength to withstand vibrations.
5 The material should be ductile.

1.4.2 Comparisons of carbon, osmium, tantalum, and tungsten used for making the filament Carbon

Carbon has high melting point of 3,500°C; even though, its melting point is high, carbon starts disintegration at very fast rate beyond its working temperature of 1,800°C.

Its resistance decreases with increase in temperature, i.e., its temperature coefficient of resistivity is negative, so that it draws more current from the supply.

The temperature coefficient (α) is –0.0002 to – 0.0008.

The efficiency of carbon filament lamp is low; because of its low operating tem perature, large electrical input is required. The commercial efficiency of carbon lamp is 3 – 4.5 lumens/W approximately.

Carbon has high resistivity (ρ), which is about 1,000–7,000 μΩ-cm and its density is 1.7–3.5.

Osmium

1 The melting point of osmium is 2,600°C.

2 It is very rare and expensive metal.

3 The average efficiency of osmium lamp is 5 lumens/W.

Tantalum

1 The melting point of tantalum is 3,000°C. 2 Resistivity (ρ) is 12.5 μΩ-cm.

The main drawback of the negative temperature coefficient of carbon is overcome in tantalum. It has positive temperature coefficient (α) and its value is 0.0036.

The density of tantalum is 16.6.

The efficiency of tantalum lamp is 2 lumens/W.

Tungsten

1 The working temperature of tungsten is 2,500–3,000°C.

2 Its resistance at working temperature is about 12–15 times the cold resistance.

4 It has positive temperature coefficient of resistance of 0.0045.

3 Its resistivity is 5.6 12.5 μΩ-cm.

4 The density of tungsten is 19.3.

5 The efficiency of tantalum when working at 2,000°C is 18 lumens/W.

6 Its vapor pressure is low when compared to carbon.

In fact, the carbon lamp is the first lamp introduced by Thomas Alva Edison in 1879, owing to two drawbacks, tungsten radiates more energy in visible spectrum and somewhat less in

infrared spectrum so that there was a switch over in infrared spectrum so that there was a switch over from carbon filament to tungsten filament. Nowadays, tungsten filament lamps are widely used incandescent lamps.

The chemically pure tungsten is very strong and fragile. In order to make it into ductile, tungsten oxide is first reduced in the form of gray power in the atmosphere of hydrogen and this powder is pressed in steel mold for small bars; the mechanical strength of these bars can be improved by heating them to their melting point and then hammered at red-hot position and rerolled into wires.

Construction

Figure 1.17 shows the construction of the pure tungsten filament incandescent lamp. It consists of an evacuated glass bulb and an aluminum or brass cap is provided with two pins to insert the bulb into the socket. The inner side of the bulb consists of a tungsten filament and the support wires are made of molybdenum to hold the filament in proper position. A glass button is provided in which the support wires are inserted. A stem tube forms an air-tight seal around the filament whenever the glass is melted.

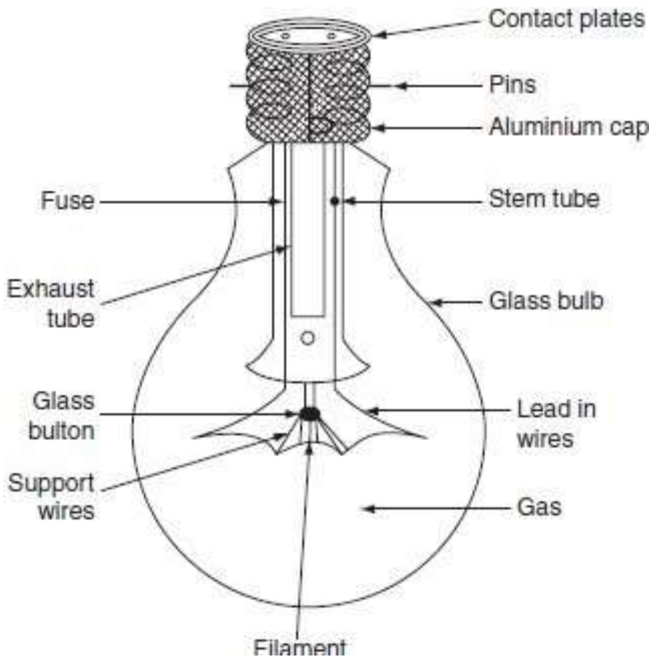


Fig. 1.17 Incandescent lamp

Operation

When electric current is made to flow through the fine metallic tungsten filament, its temperature increases. At very high temperature, the filament emits both heat and light radiations, which fall in the visible region. The maximum temperature at which the filament can be worked without oxidization is 2,000°C, i.e., beyond this temperature, the tungsten filament blackens the inside of the bulb. The tungsten filament lamps can be operated efficiently beyond 2,000°C, it can be attained by inserting a small quantity of inert gas nitrogen with small quantity of organ. But if gas is inserted instead of vacuum in the inner side of the bulb, the heat of the lamp is conducted away and it reduces the efficiency of the lamp. To reduce this loss of heat by conduction and convection, as far as possible, the filament should be so wound that it takes very little space.

This is achieved by using a single-coil filament instead of a straight wire filament as shown in Fig. 1.18(a) This single-coil filament is used in vacuum bulbs up to 25 W and gas filled bulbs from 300 to 1,000 W.

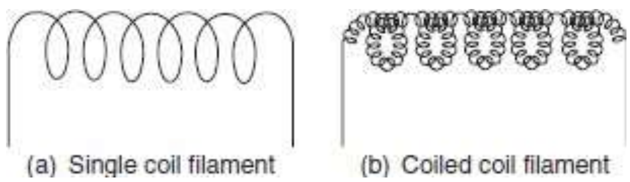


Fig. 1.18 Various filaments used in incandescent lamps

On further development of the incandescent lamps, the shortening of the length of the filament was achieved by adopting a coiled coil or a double coil filament as shown in Fig. 1.18(b). The use of coiled coil filament not only improves the efficiency of the lamp but also reduces the number of filament supports and thus simplified interior construction because the double coil reduces the filament mounting length in the ratio of 1:25 as compared to the straight wire filaments. Usually, the tungsten filament lamp suffers from 'aging effect', the output of the light an incandescent lamp decreases as the lamp ages. The output of the light of the lamp decreases due to two reasons.

At very high temperature, the vaporization of filament decreases the coil diameter so that resistance of the filament increases and hence its draws less current from the supply, so the temperature of the filament and the light output of the bulb decrease.

The current drawn from the mains and the power consumed by the filament decrease, which decrease the efficiency of the lamp with the passage of time. In addition, the evaporation of the filament at high temperature blackens the inside of the bulb.

The effects of voltage variations

The variations in normal supply voltages will affect the operating characteristics of incandescent lamps. The performance characteristic of an incandescent lamp, when it is subjected to voltage other than normal voltage, is shown in Fig. .

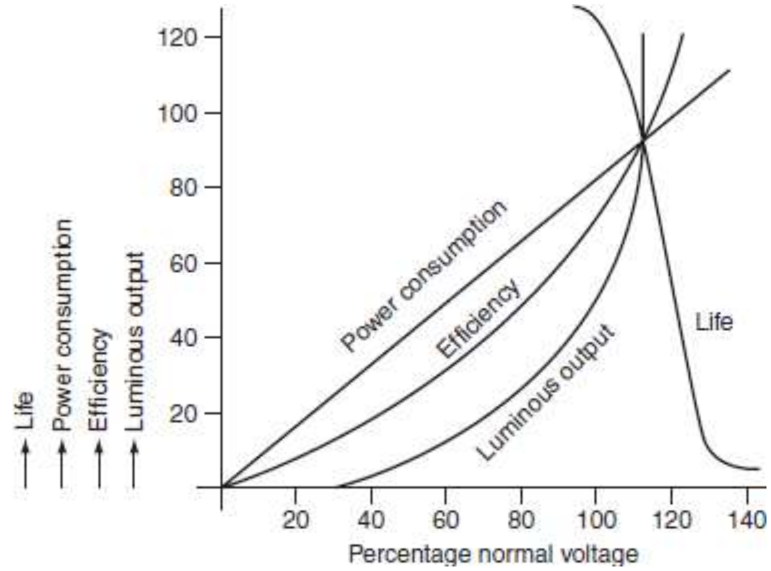


Fig.1.19. Performance characteristics of incandescent lamp

With an increase in the voltage owing to the increase in the temperature, the luminous output

of the incandescent lamps, and the efficiency and power consumption, but its life span decreases. The depreciation in the light output is around 15% over the useful life of the lamp. The above stated factors are related to the variations of voltage are given as:

Lumens output ∝ (voltage)3.55.

Power consumption ∝ (voltage)1.55. 3 Luminous efficiency ∝ (voltage)2.

4 Life ∝ (voltage)–13 (for vacuum lamps). 5 Life ∝ (voltage)–14 (for gas filled lamps).

The advantages of the incandescent lamps

1. These lamps are available in various shapes and sizes.
2. These are operating at unity power factor.
3. These lamps are not affected by surrounding air temperature.
4. Different colored light output can be obtained by using different colored glasses.

Filament dimensions

Let us consider a lamp, which is connected to the mains, is given the steady light output, i.e. whatever the heat produced, it is dissipated and the filament temperature is not going to be increase further. It is found to be the existence of a definite relation between the diameter of a given filament and the current through it.

The input wattage to the lamp is expressed as:

$$I^2R = I^2\frac{\rho l}{a} \qquad \left(\because R = \rho\frac{l}{a}\right)$$

$$= \frac{I^2 \times \rho l}{(\pi d^2/4)} \qquad (1.13)$$

$$= I^2 \times \frac{4\rho l}{\pi d^2}.$$

where I is the current taken by the lamp A, a is the filament cross-section, sq. m, ρ is the resistivity of the filament at working temperature Ω-m, l is the length of the filament m, andd is the diameter of the filament. Let the emissivity of the material be 'e'. Total heat dissipated will depend upon the surface area and the emissivity of the material

$$\propto \pi dl \times e. \qquad (1.14)$$

∴ Heat dissipated ∝ surface area × emissivity:

At the steady state condition, the power input should be equal to the heat dissipated. From Equations (1.13) and (1.14), we can write that:

$$I^2\frac{4\rho l}{\pi d^2} \propto \pi dl \times e$$

$$I^2 \propto d^3 \quad \text{or} \quad I \propto d^{3/2}. \qquad \mathbf{(1.15)}$$

If two filaments are made up of same material, working at same temperature and efficiency but with different diameters, then from Equation (1.15):

$$\frac{I_1}{I_2} = \left(\frac{d_1}{d_2}\right)^{3/2} \qquad (1.16)$$

If two filaments are working at the same temperature, then their luminous output must be same even though their lengths are different.

$$\therefore \text{Lumen output} \propto l_1 d_1 \propto l_2 d_2 \qquad (1.17)$$

$$\therefore l_1 d_1 \propto l_2 d_2 = \text{constant.}$$

Limitations

The incandescent lamp suffers from the following drawbacks:

Low efficiency.

Colored light can be obtained by using different colored glass enclosures only. DISCHARGE LAMPS

Discharge lamps have been developed to overcome the drawbacks of the incandescent lamp.

The main principle of the operation of light in a gaseous discharge lamp is illustrated as below. In all discharge lamps, an electric current is made to pass through a gas or vapor, which produces its illuminance. Normally, at high pressures and atmospheric conditions, all the gases are poor conductors of electricity. But on application of sufficient voltage across the two electrodes, these ionized gases produce electromagnetic radiation. In the process of producing light by gaseous conduction, the most commonly used elements are neon, sodium, and mercury. The wavelength of the electromagnetic radiation depends upon the nature of gas and the gaseous pressure used inside the lamp. A simple discharge lamp is shown in Fig. 1.20.

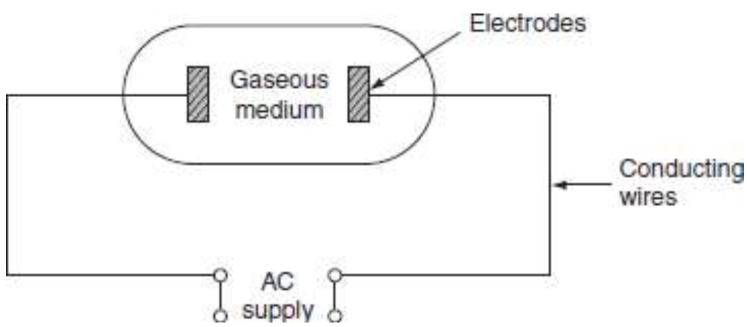


Fig.1.20. Discharge lamps

The production of light in the gaseous discharge lamps is based on the phenomenon of excitation and ionization of gas or metal vapor present between the two electrodes of a discharge tube. When the potential between the two electrodes is equals to ionizing potential, gas or metal vapor starts ionizing and an arc is established between the two electrodes. Volt– ampere characteristics of the arc is negative, i.e., gaseous discharge lamp possess a negative resistance characteristics. A choke or ballast is provided to limit high currents to a safe value. Here, the choke serves two functions.

It provides ignition voltage initially.

Limits high currents

The use of choke will reduce the power factor (0.3–0.4) of all the gaseous lamps so that all the discharge lamps should be provided with a condenser to improve the power factor. The nature of the gas and vapor used in the lamp will affect the color affected of light.

Types of discharge lamps

Generally used discharge lamps are of two types. They are:

The lamps that emit light of the color produced by discharge takes place through the gas or vapor present in the discharge tube such as neon gas, sodium vapor, mercury vapor, etc.

Ex: Neon gas, sodium vapor lamp, and mercury vapor lamp.

The lamp that emits light of color depends upon the type of phosphor material coated inside the walls of the discharge tube. Initially, the discharge takes place through the vapor produces UV radiation, then the invisible UV rays absorbed by the phosphors and radiates light energy falls in the visible region. This UV light causes fluorescence in certain phosphor materials, such lamps are known as fluorescent lamps.

Ex: Fluorescent mercury vapor tube.

In general, the gaseous discharge lamps are superior to the tungsten filament lamps.

Drawbacks

1. The discharge lamps suffer from the following drawbacks.
2. The starting of the discharge lamps requires starters and transformers; therefore, the lamp circuitry is complex.
3. High initial cost.
4. Poor power factor; therefore, the lamps make use of the capacitor.
5. Time required to give its full output brilliancy is more.
6. These lamps must be placed in particular position.
7. These lamps require stabilizing choke to limit current since the lamps have negative resistance
8. characteristics.

NEON DISCHARGE LAMP

This is a cold cathode lamp, in which no filament is used to heat the electrode for starting. Neon lamp consists of two electrodes placed at the two ends of a long discharge tube is shown in Fig. 1.21

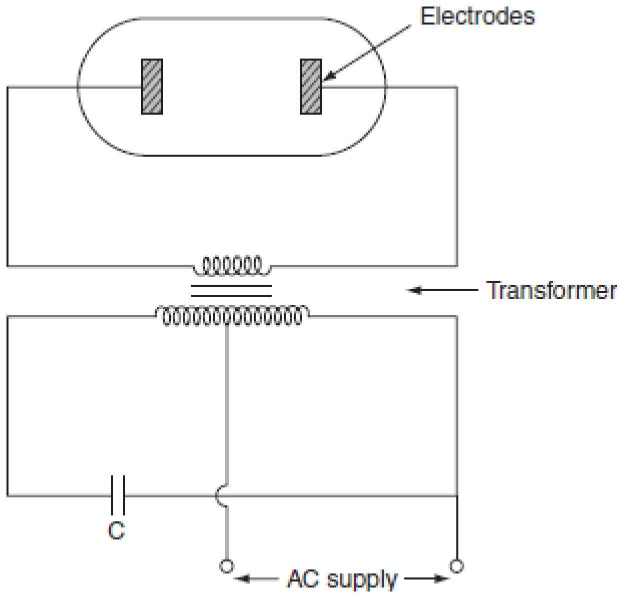


Fig.1.21. Neon lamps

The discharge tube is filled with neon gas. A low voltage of 150 V on DC or 110 V on AC is impressed across the two electrodes; the discharge takes place through the neon gas that emits light or electro magnetic radiation reddish in color. The sizes of electrodes used are equal for both AC and DC supplies. On DC, neon glow appear nearer to the negative electrode; therefore, the negative electrode is made larger in size. Neon lamp electric circuit consists of a transformer with high leakage reactance in order to stabilize the arc. Capacitor is used to improve the power factor. Neon lamp efficiency is approximately 15–40 lumens/W. The power consumption of the neon lamp is 5 W. If the helium gas is used instead of neon, pinkish white light is obtained. These lamps are used as night lamps and as indicator lamps and used for the determination of the polarity of DC mains and for advertising purpose.

SODIUM VAPOR LAMP

A sodium vapor lamp is a cold cathode and low-pressure lamp. A sodium vapor discharge lamp consists of a U-shaped tube enclosed in a double-walled vacuum flask, to keep the temperature of the tube within the working region. The inner U-tube consists of two oxide-coated

electrodes, which are sealed with the ends. These electrodes are connected to a pin type base construction of

sodium vapor lamp is shown in Fig.1.22 .

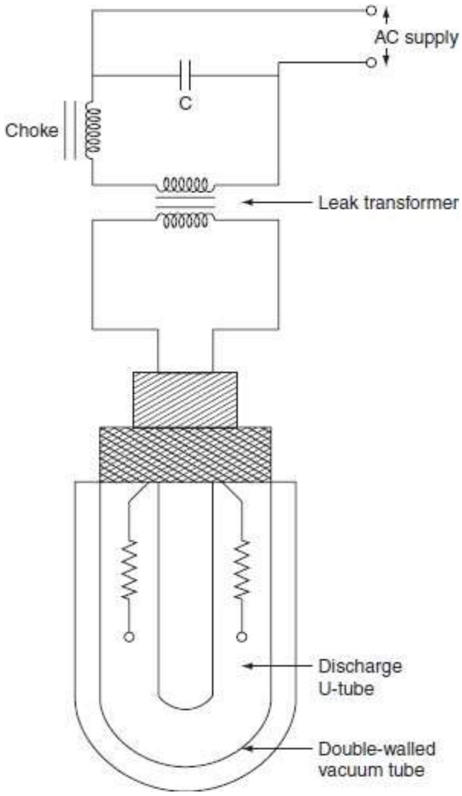


Fig.1.22 Sodium vapor lamp

This sodium vapor lamp is low luminosity lamp, so that the length of the lamp should be more. In order to get the desired length, it is made in the form of a U-shaped tube. This longUtube consists of a small amount of neon gas and metallic sodium. At the time of start, the neon gas vaporizes and develops sufficient heat to vaporize metallic sodium in the U-shaped tube. Working Initially, the sodium is in the form of a solid, deposited on the walls of inner tube. When sufficient voltage is impressed across the electrodes, the discharge starts in the inert gas, i.e., neon; it operates as a low-pressure neon lamp with pink color. The temperature of the lamp

increases gradually and the metallic sodium vaporizes and then ionizes thereby producing the monochromatic yellow light. This lamp takes 10–15 min to give its full light output. The yellowish output of the lamp makes the object appears gray. In order to start the lamp, 380 – 450 V of striking voltage required for 40- and 100-W lamps. These voltages can be obtained from a high reactance transformer or an auto transformer. The operating power factor of the lamp is very poor, so that a capacitor is placed to improve the power factor to above 0.8. More care should be taken while replacing the inner tube, if it is broken, then sodium comes in contact with the moisture; therefore, fire will result. The lamp must be operated horizontally or nearly so, to spread out the sodium well along the tube. The efficiency of sodium vapor lamp is lies between 40 and 50 lumens/W. Normally, these lamps are manufactured in 45-, 60-, 85- and 140-W ratings. The normal operating temperatures of these lamps are

300°C. In general, the average life of the sodium vapor lamp is 3,000 hr and such bulbs are not affected by voltage variations.

Following are the causes of failure to operate the lamp, when:

1. The cathode fails to emit the electrons.
2. The filament breaks or burns out.
3. All the particles of sodium are concentrated on one side of the inner tube.
4. The life of the lamp increases due to aging.
5. The average light output of the lamp is reduced by 15% due to aging. These lamps are mainly used for highway and street lighting, parks, railway yards, general outdoor lighting, etc.

HIGH-PRESSURE MERCURY VAPOR LAMP

The working of the mercury vapor discharge lamp mainly depends upon the pressure, voltage, temperature, and other characteristics that influence the spectral quality and the efficiency of the lamp. Generally used high-pressure mercury vapor lamps are of three types. They are:

MA type: Preferred for 250- and 400-W rating bulbs on 200–250-V AC supply.

MAT type: Preferred for 300- and 500-W rating bulbs on 200–250-V AC supply.

MB type: Preferred for 80- and 125-W rating bulbs and they are working at very high pressures.

MA type lamp

It is a high-pressure mercury vapor discharge lamp that is similar to the construction of sodium vapor lamp. The construction of MA type lamp is shown in Fig. 1.23.

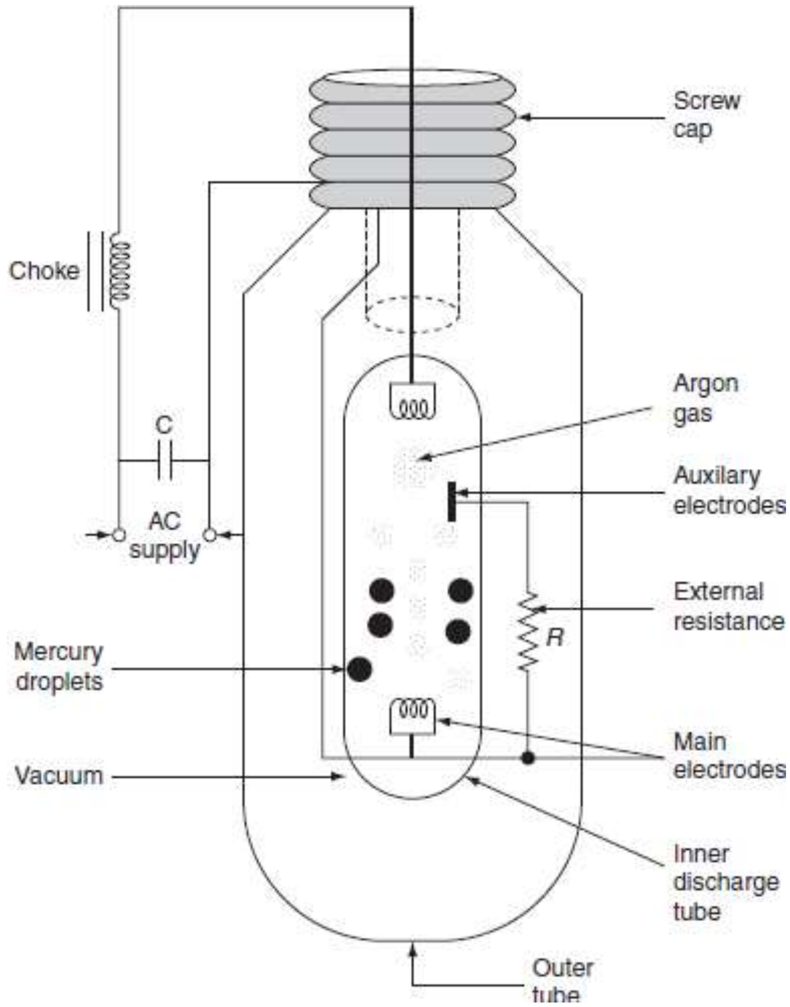


Fig. 1.23. MA type lamp

MA type lamp consists of a long discharge tube in 'U' shape and is made up of hard glass or quartz. This discharge tube is enclosed in an outer tube of ordinary glass. To prevent the heat loss from the inner bulb, by convection, the gap between the two tubes is completely evacuated. The inner tube contains two main electrodes and an auxiliary starting electrode, which is connected through a high resistance of about 50 kΩ. It also contains a small quantity of argon gas and mercury. The two main electrodes are tungsten coils coated with electron emitting material (such as thorium metal).

Working

Initially, the tube is cold and hence the mercury is in condensed form. Initially, when supply is given to the lamp, argon gas present between the main and the auxiliary electrodes gets ionized, and an arc is established, and then discharge takes place through argon for few minutes between the main and the auxiliary electrodes. As a result, discharge takes place through argon for few minutes in between the main and the auxiliary electrodes. The discharge can be controlled by using high resistance that is inserted in-series with the auxiliary electrode. After few minutes, the argon gas, as a whole, gets ionized between the two main electrodes. Hence, the discharge shifts from the auxiliary electrode to the two main electrodes. During the discharge process, heat is produced and this heat is sufficient to vaporize the mercury. As a result, the pressure inside the discharge tube becomes high and the voltage drop across the two main electrodes will increases from 20 to 150 V. After 5–7 min, the lamp starts and gives its full output. Initially, the discharge through the argon is pale blue glow and the discharge through the mercury vapors is greenish blue light; here, choke is provided to limit high currents and capacitor is to improve the power factor of the lamp. If the supply is interrupted, the lamp must cool down and the vapor pressure be reduced before it will start. It takes approximately 3 – 4 min. The operating temperature of the inner discharge tube is about 600°C. The efficiency of this type of lamp is 30–40 lumens/W. These lamps are manufactured in 250 and 400 W ratings for use on 200–250 V on AC supply. Generally, the MA type lamps are used for general industrial lighting, ports, shopping centers, railway yards, etc.

MAT type lamp

This is another type of mercury vapor lamp that is manufactured in 300 and 500 W rating for use on AC as well as DC supplies. The construction of the MAT type lamp is similar to the MA type lamp except the outer tube being empty; it consists of tungsten filament so that at the time of starting, it works as a tungsten filament lamp. Here, the filament itself acts as a choke or ballast to limit the high currents to safer value. When the supply is switched on, it works as a tungsten filament lamp, its full output is given by the outer tube. At this time, the temperature of the inner discharge tube increases gradually, the argon gas present in it starts ionizing in the discharge tube at any particular temperature is attained then thermal switch gets opened, and the part of the filament is detached and voltage across the discharge tube increases. Now, the discharge takes place through the mercury vapor. Useful color effect can be obtained by this lamp. This is because of the combination of light emitted from the filament and blue radiations from the discharge tube. In this type of lamp, capacitor is not required since the overall power

factor of the lamp is 0.95; this is because the filament itself acts as resistance. Fig. 1.24 shows the construction of MAT type lamp.

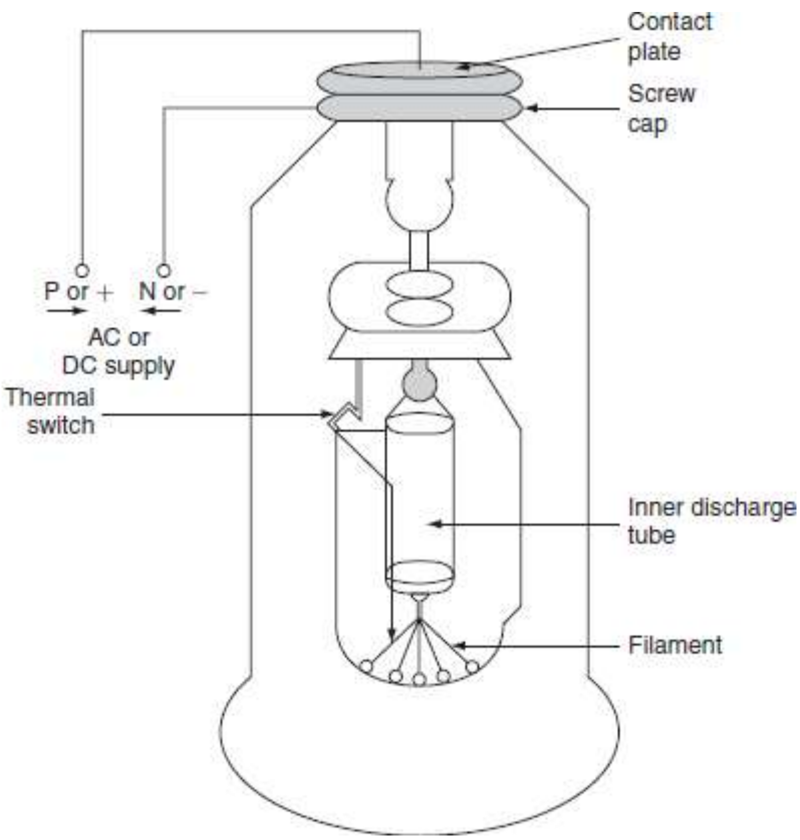


Fig.1.24. MAT type lamp MB type lamp

Schematic representation of MB type lamp is shown in Fig.1.25 .

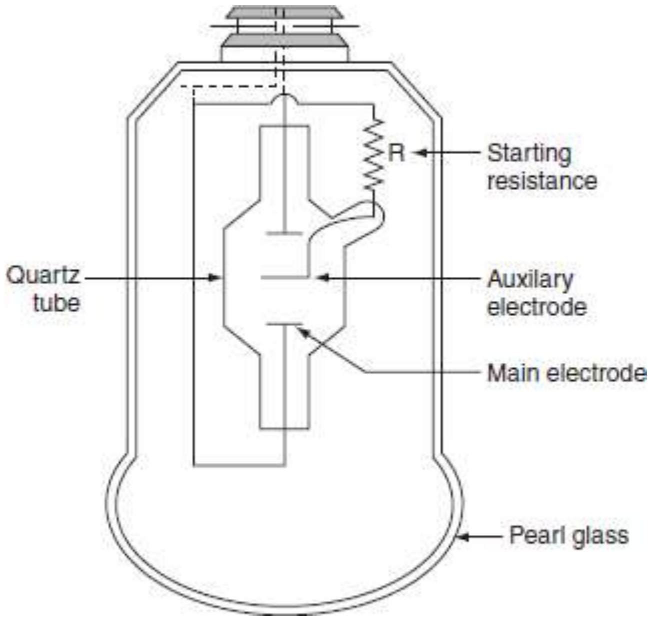


Fig.1.25 MB type lamp

The MB type lamp is also similar to the MA type lamp. The inner discharge tube for the MB type lamp is about 5 -cm long and is made up of quartz material. It has three electrodes; two main and one auxiliary electrodes. There are three electrodes present in the MB type lamp, namely two main electrodes and one auxiliary electrode. Relatively, very high pressure is maintained inside the discharge tube and it is about 5–10 times greater than atmospheric pressure. The outer tube is made with pearl glass material so as to withstand high temperatures. We can use these tubes in any position, because they are made up of special glass material. The working principle of the MB type lamp is similar to the MA type lamp. These lamps are manufactured in 300 and 500 W rating for use in AC as well as DC supplies. An MB type lamp consists a bayonet cap with three pins, so it may not be used in an ordinary sense. A choke coil and a capacitor are necessary for working with these types of lamps.

FLUORESCENT LAMP (LOW-PRESSURE MERCURY VAPOR LAMP)

Fluorescent lamp is a hot cathode low-pressure mercury vapor lamp; the construction and working of the fluorescent lamp are explained as follows.

Construction

It consists of a long horizontal tube, due to low pressure maintained inside of the bulb; it is made in the form of a long tube. The tube consists of two spiral tungsten electrode coated with electron emissive material and are placed at the two edges of long tube. The tube contains small quantity of argon gas and certain amount of mercury, at a pressure of 2.5 mm of mercury. The construction of fluorescent lamp is shown in Fig. 1.26. Normally, low-pressure mercury vapor lamps suffer from low efficiency and they produce an objectionable colored light. Such drawback is overcome by coating the inside of the tube with fluorescent powders. They are in the form of solids, which are usually knows as phosphors.

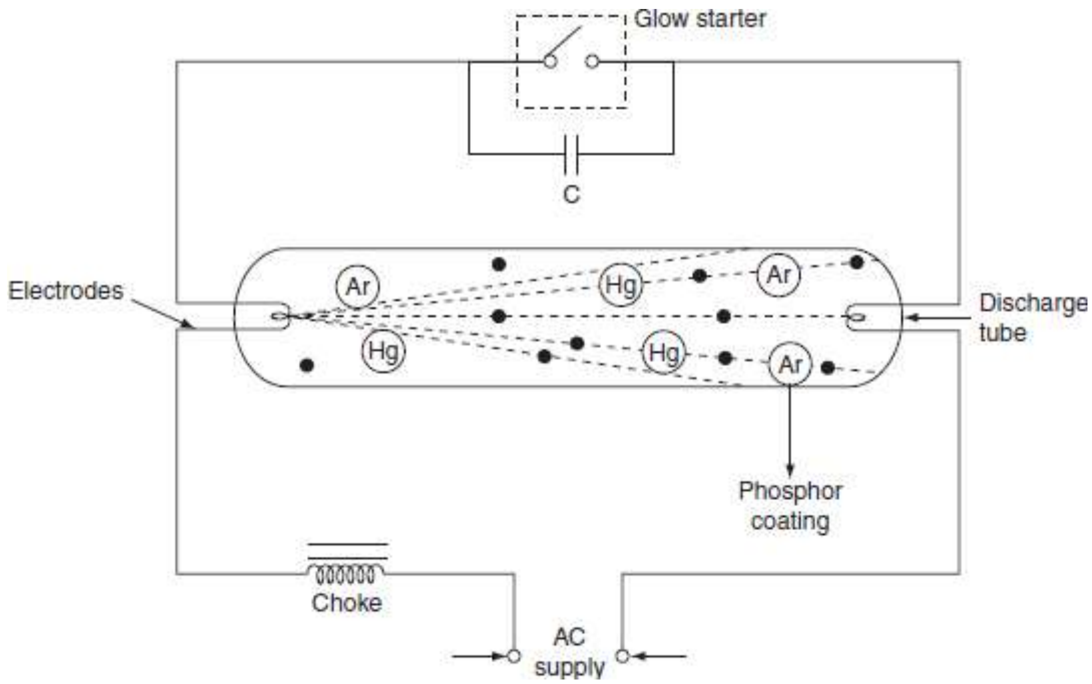


Fig.1.26. Fluorescent lamp

A glow starter switch contains small quantity of argon gas, having a small cathode glow lamp with bimetallic strip is connected in series with the electrodes, which puts the electrodes directly across the supply at the time of starting. A choke is connected in series that acts as ballast when the lamp is running, and it provides a voltage impulse for starting. A capacitor of 4μF is connected across the starter in order to improve the power factor.

Working At the time of starting, when both the lamp and the glow starters are cold, the mercury is in the form of globules. When supply is switched on, the glow starter terminals are open circuited and full supply voltage appeared across these terminals, due to low resistance of electrodes and choke coil. The small quantity of argon gas gets ionized, which establishes an arc with a

Starting glow. This glow warms up the bimetallic strip thus glow starts gets short circuited. Hence, the two electrodes come in series and are connected across the supply voltage. Now, the two electrodes get heated and start emitting electrons due to the flow of current through them.

These electrons collide with the argon atoms present in the long tube discharge that takes place through the argon gas. So, in the beginning, the lamp starts conduction with argon gas as the temperature increases, the mercury changes into vapor form and takes over the conduction of current. In the mean time, the starter potential reaches to zero and the bimetallic strip gets cooling down. As a result, the starter terminals will open. This results breaking of the series circuit. A very high voltage around 1,000 V is induced, because of the sudden opening of starter terminals in the series circuit. But in the long tube, electrons are already present; this induced voltage is quite sufficient to break down the long gap. Thus, more number of electrons collide with argon and mercury vapor atoms. The excited atom of mercury gives UV radiation, which will not fall in the visible region. Meanwhile, these UV rays are made to strike phosphor material; it causes the re-emission of light of different wavelengths producing illumination. The phenomenon of the emission is called as luminescence.

This luminescence is classified into two ways. They are:

Fluorescence: In this case, the excitation presents for the excited periods only.

Phosphorescence: In this case, even after the exciting source is removed, the excitation will present. In a lamp, the re-emission of light causes fluorescence, then such lamp is known as fluorescent lamp. Depending upon the type of phosphor material used, we get light of different colors as given in Table.

. Table Colors of light

Phosphor material Color effect

1.	Zinc silicate	Green
2.	Calcium tungstate	Green
3.	Magnesium tungstate	Bluish while

4	4Cadmium silicate	Yellowish pink
5	Zinc beryllium silicate	Yellowish while
6	Cadmium borate	Pink

Advantages of fluorescent lamp

The fluorescent lamp has the following advantages:

High efficiency.

The life of the lamp is three times of the ordinary filament lamp.

The quality of the light obtained is much superior.

Less chances of glare.

These lamps can be mounted on low ceiling, where other light sources would be unsatisfactory.

Although the fluorescent lamp has the above advantages, it sufferers form the following disadvantages:

The initial cost is high because of choke and starter.

The starting time as well as the light output of the lamp will increases because of low ambient temperature.

Because of the presence of choke, these lamps suffer from magnetic humming and may cause disturbance.

The stroboscopic effect of this lamp is objectionable.

BASIC PRINCIPLES OF LIGHT CONTROL

When light strikes the surface of an object, based on the properties of that surface, some portion of the light is reflected, some portion is transmitted through the medium of the surface, and the remaining is absorbed. The method of light control is used to change the direction of light through large angle. There are four light control methods. They are:

1. reflection,
2. refraction,
3. riffusion, and
4. absorption.

Reflection

The light falling on the surface, whole of the light will not absorbed or transmitted through the surface, but some of the light is reflected back, at an angle equals to the angle of incidence. The ratio of reflected light energy to the incident light energy is known as reflection factor. The two basic types of reflection are:

mirror or specular reflection and

diffuse reflection.

Specular reflection

When whole of the light falling on a smooth surfaces will be reflected back at an angle equal to he angle of incidence. Such a reflection is known as specular reflection. With such reflection, observer will be able to see the light source but not the illuminated surface. Most of the surfaces causing the specular reflection are silvered mirrors, highly polished metal surfaces. Specular reflection is shown in Fig. 1.27.

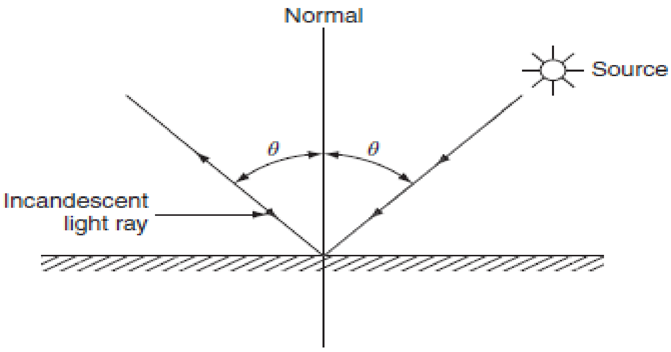


Fig. 1.27 Specular reflection

A surface that is almost free from reflection is called a matt surface.

Diffuse reflection

When the light ray falling on any surface, it is scattered in all directions irrespective of the angle of incidence. Such type of reflector is known as diffuse reflection and is shown in Fig. 1.28. Most of the surfaces causing the diffuse reflection are rough or matt surfaces such as blotting paper, frosted glass, plaster, etc.

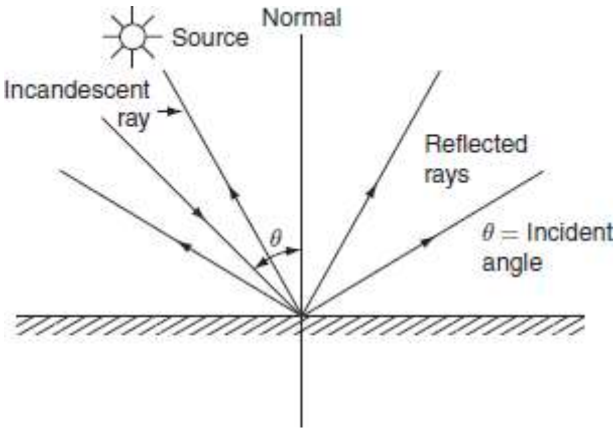


Fig. 1.28 Diffuse reflection

In this reflection, observer will be able to see the illuminated surface but not the light source. Refraction When a beam of light passes through two different mediums having different densities, the light ray will be reflected. This phenomenon is known as refraction. Figure 1.29 shows the refraction of light ray from dense medium to rare medium where μ1 andμ2 are the refractive indices of two medium, θ is the angle of incidence, and α is the angle of reflection.

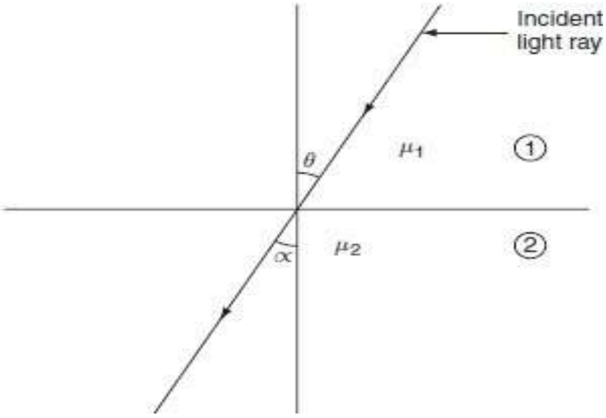


Fig. 1.29 Refraction

The angle of light ray with normal is comparatively less in dense medium than in rare medium.

Diffusion

When a ray of light falling on a surface is reflected in all possible directions, so that such surface appears luminous from all possible directions. This can be achieved with a diffusing glass screen introduced between the observer and the light source. The normally employed diffusing glasses are opal glass and frosted glass. Both are ordinary glasses, but frosted glass is an ordinary glass coated with crystalline substance. Although frosted glass is cheaper than opal glass, the disadvantage of frosted glass is, it collects more dust particles and it is difficult to clean.

Absorption

In some of the cases, whole of the light emitted by tungsten filament lamp will be excessive, so that it is necessary to avoid that the amount of unwanted wavelengths without interference. This can be achieved by using a special bluish colored glass for the filament lamp to absorb the unwanted radiation.

TYPES OF LIGHTING SCHEMES

Usually, with the reflector and some special diffusing screens, it is possible to control the distribution of light emitted from lamps up to some extent. A good lighting scheme results in an attractive and commanding presence of objects and enhances the architectural style of the interior of a building. Depending upon the requirements and the way of light reaching the surface, lighting schemes are classified as follows:

1. direct lighting,
2. semidirect lighting,
3. indirect lighting,
4. semi-indirect lighting, and

5. general lighting.

1. Direct lighting schemes

Direct lighting scheme is most widely used for interior lighting scheme. In this scheme, by using deep reflectors, it is possible to make 90% of light falls just below the lamp. This scheme is more efficient but it suffers from hard shadows and glare. Hence, while designing such schemes, all the possibilities that will cause glare on the eye have to be eliminated. It is mainly used for industrial and general outdoor lighting. Semidirect lighting schemes In semidirect lighting scheme, about 60–90% of lamps luminous flux is made to fall downward directly by using some reflectors and the rest of the light is used to illuminate the walls and ceiling. This type of light scheme is employed in rooms with high ceiling. Glare can be avoided by employing diffusing globes. This scheme will improve not only the brightness but also the efficiency. Indirect lighting schemes In this lighting scheme, 90% of total light is thrown upwards to the ceiling. In such scheme, the ceiling acts as the lighting source and glare is reduced to minimum. This system provides shadowless illumination, which is very useful for
drawing offices and in workshops where large machines and other difficulties would cause trouble some shadows if direct lighting schemes were used. Semi-indirect lighting schemes In semi-indirect lighting scheme, about 60–90% of light from the lamp is thrown upwards to the ceiling and the remaining luminous flux reaches the working surface. Glare will be completely eliminated with such type of lighting scheme. This scheme is widely preferred for indoor lighting decoration purpose. General lighting scheme. This scheme of lighting use diffusing glasses to produce the equal illumination in all directions. Mounting height of the source should be much above eye level to avoid glare. Lamp fittings of various lighting schemes are shown in Fig. 1.30.

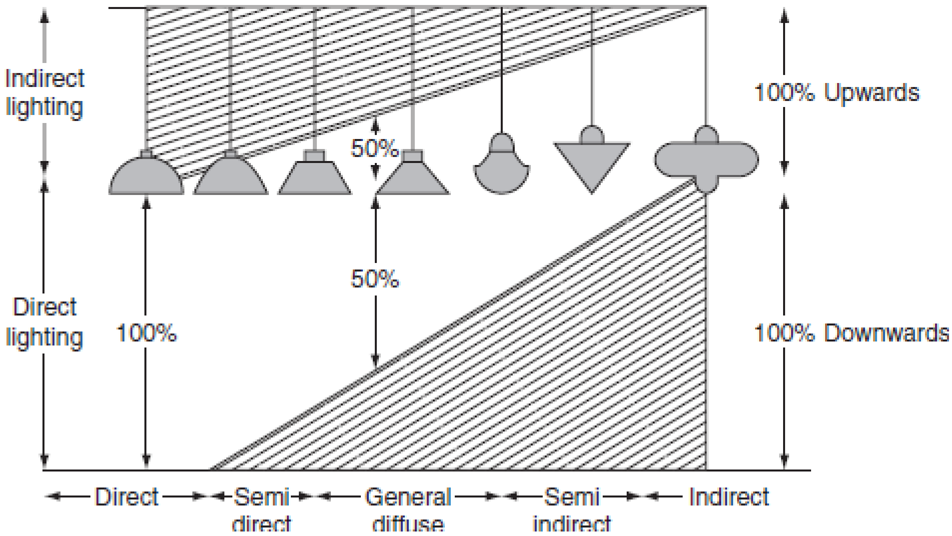


Fig. 1.30 Lighting schemes

DESIGN OF LIGHTING SCHEMES

- The lighting scheme should be such that:
- It should be able to provide sufficient illumination.
- It should be able to provide the uniform distribution of light throughout the working plane.
- It should be able to produce the light of suitable color.
- It should be able to avoid glare and hard shadows as much as possible.

While designing a lighting scheme, the following factors should be taken into consideration.

- Illumination level.
- The size of the room.
- The mounting height and the space of fitting.

STREET LIGHTING

Street lighting not only requires for shopping centers, promenades, etc. but also necessary for the following. o In order to make the street more attractive, so that obstructions on the road clearly visible to the drivers of vehicles.

- To increase the community value of the street.
- To clear the traffic easily in order to promote safety and convenience.

The basic principles employed for the street lighting are given below.

Diffusion principle.

The specular reflection principle. Diffusion principle

In this method, light is directed downwards from the lamp by the suitably designed reflectors. The design of these reflectors are in such a way that they may reflect total light over the road surface uniformly as much as possible. The reflectors are made to have a cutoff between 30° and

45°, so that the filament of the lamp is not visible expect just below the source, which results in eliminating glare. Illumination at any point on the road surface is calculated by applying inverse square low or point-by-point method.

Specular reflection principle

The specular reflection principle enables a motorist to see an object about 30 m ahead. In this case, the reflectors are curved upwards, so that the light is thrown on the road at a very large angle of incidence. This can be explained with the help of Fig. 1.31. An object resides over the road at 'P' in between the lamps S1, S2, and S3 and the observer at 'Q'.

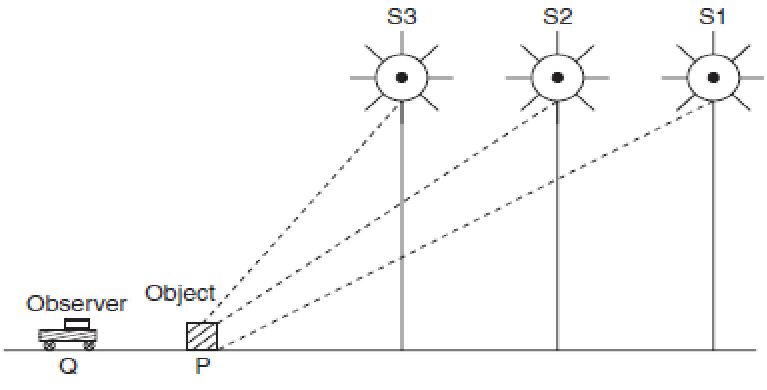


Fig. 1.31 Specular reflection for street lighting

Thus, the object will appear immediately against the bright road surface due to the lamps at a longer distance. This method of lighting is only suitable for straight sections along the road. In this method, it is observed that the objects on the roadway can be seen by a smaller expenditure of power than by the diffusion method of lighting. Illumination level, mounting height, and the types of lamps for street lighting Normally, illumination required depends upon the class of street lighting installation. 1. Road junctions and important shopping centers. 30

Poorly lighted sub-urban streets. 4

Average well-lighted street. 8–15

Mercury vapor and sodium vapor discharge lamps are preferable for street lighting since the overall cost of the installation of discharge lamps are less than the filament lamps and also the less power consumption for a given amount of power output. Normal spacing for the standard lamps is 50 m with a mounting height of 8 m. Lamp posts should be fixed at the junctions of roads.

FLOODLIGHTING

Floodlighting means flooding of large surface areas with light from powerful projectors. A special reflector and housing is employed in floodlighting in order to concentrate the light emitted from the lamp into a relatively narrow beam, which is known as floodlight projector. This projector consists of a reflecting surface that may be a silvered glass or chromium plate or stainless steel. The efficiency of silvered glass and polished metal are 85–90% and 70%, respectively. Usually metal reflectors are robust; therefore, they can be preferred. An important application of illumination engineering is the floodlighting of large and open areas. It is necessary to employ floodlighting to serve one or more.

UNIT-2

RESIDENTIAL AND COMMERCIAL ELECTRICAL SYSTEMS

Syllabus: Types of residential and commercial wiring systems, General rules and guidelines for installation, load calculation and sizing of wire, rating of main switch,Distribution board and protection devices, earthling system calculations, requirements of commercialinstallation, deciding lighting scheme and number of lamps, earthing for commercial installations. Selection and sizing of components.

2.0 What is Electrical Wiring?

Electrical Wiring is a process of connecting cables and wires to the related devices such as fuse, switches, sockets, lights, fans etc to the main distribution board is a specific structure to the utility pole for continues power supply.

2.1 Methods of Electrical Wiring Systems w.r.t Taking Connection

Wiring (a process of connecting various accessories for distribution of electrical energy from supplier's meter board to home appliances such as lamps, fans and other domestic appliances is known as Electrical Wiring) can be done using two methods which are

(i) Joint box system or Tee system

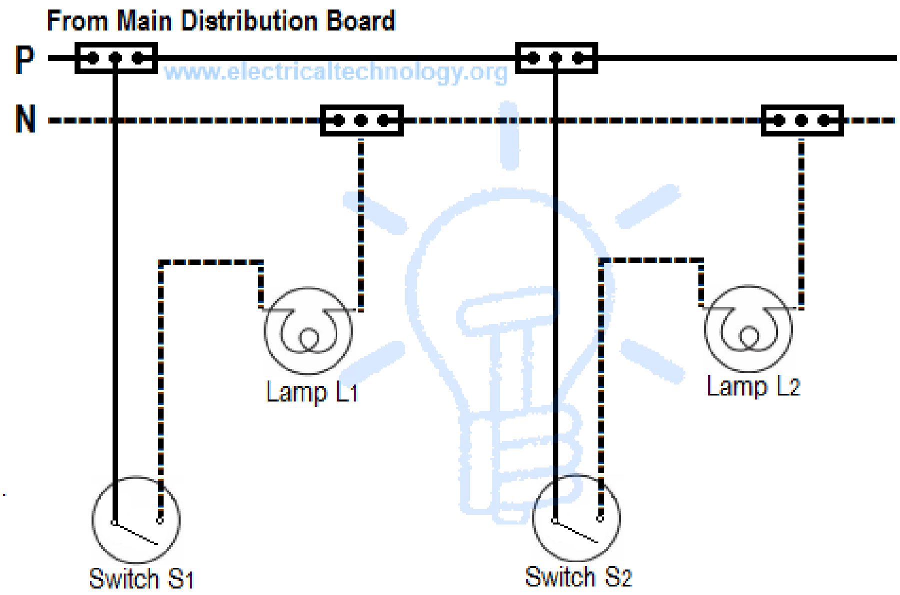
(ii) Loop – in system

They are discussed as follows:

2.1.1 Joint Box or Tee or Jointing System

In this method of wiring, connections to appliances are made through joints. These joints are made in joint boxes by means of suitable connectors or joints cutouts. This method of wiring doesn't consume too much cables size.

You might think because this method of wiring doesn't require too much cable it is therefore cheaper. It is of course but the money you saved from buying cables will be used in buying joint boxes, thus equation is balanced. This method is suitable for temporary installations and it is cheap.

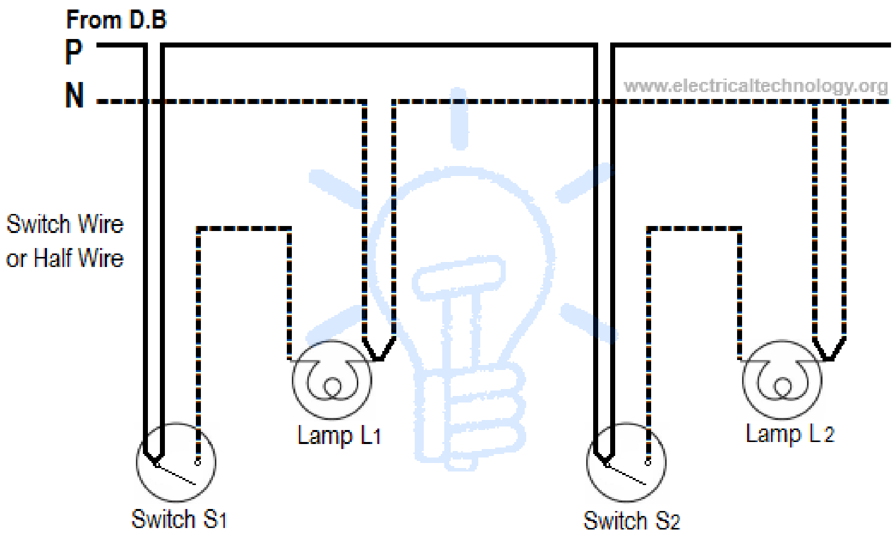


Joint Box System

2.1.2 Loop-in or Looping System

This method of wiring is universally used in wiring. Lamps and other appliances are connected in parallel so that each of the appliances can be controlled individually. When a connection is required at a light or switch, the feed conductor is looped in by bringing it directly to the terminal and then carrying it forward again to the next point to be fed.

The switch and light feeds are carried round the circuit in a series of loops from one point to another until the last on the circuit is reached. The phase or line conductors are looped either in switchboard or box and neutrals are looped either in switchboard or from light or fan. Line or phase should never be looped from light or fan.



Loop-In System

Advantages of Loop-In Method of Wiring

- It doesn't require joint boxes and so money is saved

- In loop – in systems, no joint is concealed beneath floors or in roof spaces.
- Fault location is made easy as the points are made only at outlets so that they are accessible.

Disadvantages of Loop-In Method of Wiring

- Length of wire or cables required is more and voltage drop and copper losses are therefore more
- Looping – in switches and lamp holders is usually difficult.

2.2 **Different Types of Electrical Wiring Systems**

The types of internal wiring usually used are

I. **Cleat wiring**
II. **Wooden casing and capping wiring**
III. **CTS or TRS or PVC sheath wiring**
IV. **Lead sheathed or metal sheathed wiring**
V. **Conduit wiring**

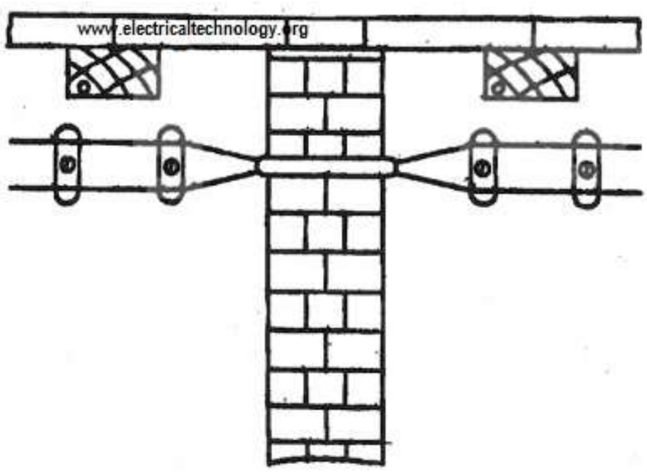
There are additional types of conduit wiring according to Pipes installation (Where steel and PVC pipes are used for wiring connection and installation).

I. Surface or open Conduit type
II. Recessed or concealed or underground type Conduit

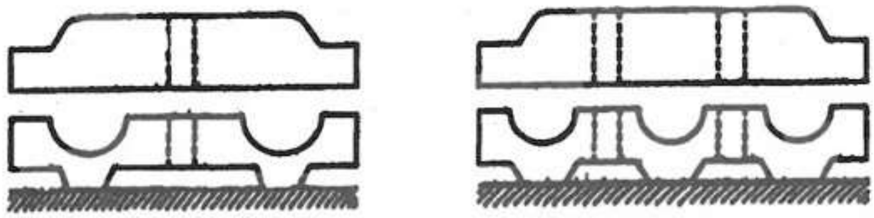
2.2.1 Cleat Wiring

This system of wiring comprise of ordinary VIR or PVC insulated wires (occasionally, sheathed and weather proof cable) braided and compounded held on walls or ceilings by means of porcelain cleats, Plastic or wood.

Cleat wiring system is a temporary wiring system therefore it is not suitable for domestic premises. The use of cleat wiring system is over nowadays.



Use of Wall tube, wires are drawn from one room into the other through partition wall.



i. Cleat with two grooves

ii. Cleat with three grooves

Cleat Wiring

Advantages of Cleat Wiring:

- It is simple and cheap wiring system
- Most suitable for temporary use i.e. under construction building or army camping
- As the cables and wires of cleat wiring system is in open air, Therefore fault in cables can be seen and repair easily.
- Cleat wiring system installation is easy and simple.
- Customization can be easily done in this wiring system e.g. alteration and addition.
- Inspection is easy and simple.

Disadvantages of Cleat Wiring:

- Appearance is not so good.
- Cleat wiring can't be use for permanent use because, Sag may be occur after sometime of the usage.
- In this wiring system, the cables and wiring is in open air, therefore, oil, Steam, humidity, smoke, rain, chemical and acidic effect may damage the cables and wires.
- it is not lasting wire system because of the weather effect , risk of fire and wear & tear.
- it can be only used on 250/440 Volts on low temperature.
- There is always a risk of fire and electric shock.
- it can't be used in important and sensitive location and places.
- It is not lasting, reliable and sustainable wiring system.

2.2.2 Casing and Capping wiring

Casing and Capping wiring system was famous wiring system in the past but, it is considered obsolete this days because of Conduit and sheathed wiring system. The cables used in this kind of wiring were either VIR or PVC or any other approved insulated cables.

The cables were carried through the wooden casing enclosures. The casing is made up of a strip of wood with parallel grooves cut length wise so as to accommodate VIR cables. The grooves were made to separate opposite polarity. the capping (also made of wood) used to cover the wires and cables installed and fitted in the casing.

Advantages of Casing Capping Wiring:

I. It is cheap wiring system as compared to sheathed and conduit wiring systems.

II. It is strong and long-lasting wiring system.

III. Customization can be easily done in this wiring system.

IV. If Phase and Neutral wire is installed in separate slots, then repairing is easy.

V. Stay for long time in the field due to strong insulation of capping and casing..

VI. It stays safe from oil, Steam, smoke and rain.

VII. No risk of electric shock due to covered wires and cables in casing & capping.

Disadvantages Casing Capping Wiring:

I. There is a high risk of fire in casing & capping wiring system.

II. Not suitable in the acidic, alkalies and humidity conditions

III. Costly repairing and need more material.

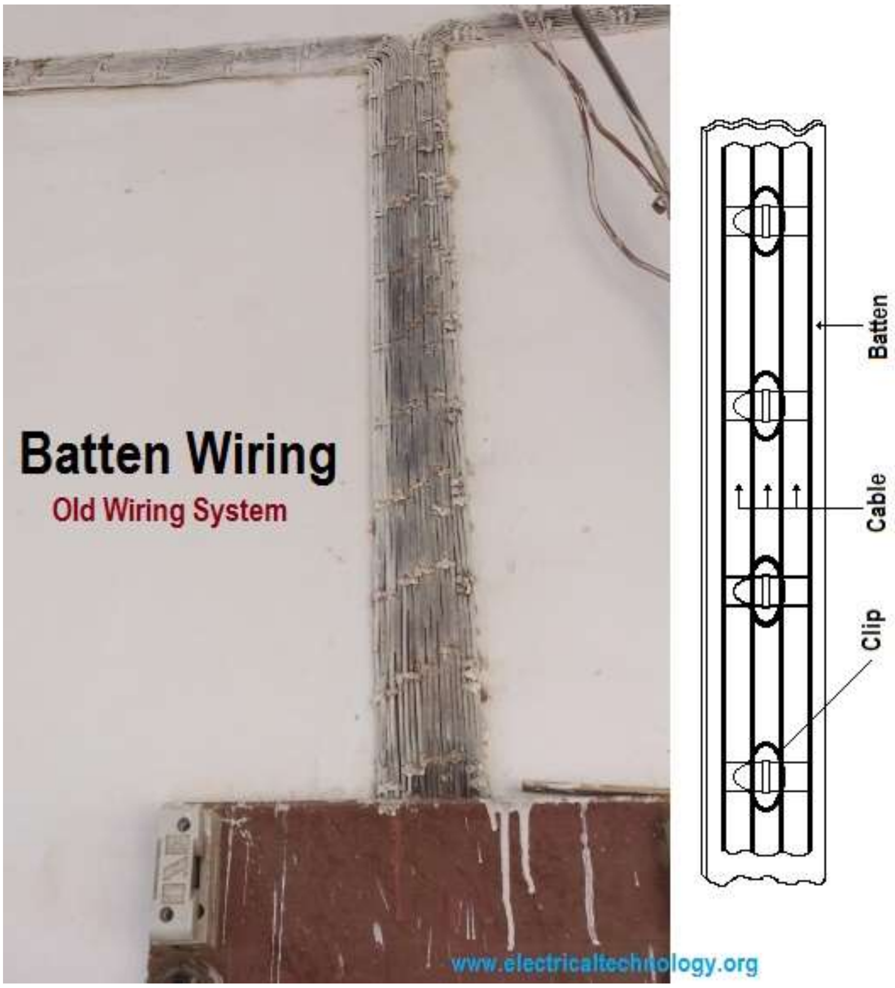
IV. Material can't be found easily in the contemporary

V. White ants may damage the casing & capping of wood.

2.2.3 Batten Wiring (CTS or TRS)

Single core or double core or three core TRS cables with a circular oval shape cables are used in this kind of wiring. Mostly, single core cables are preferred. TRS cables are chemical proof, water proof, steam proof, but are slightly affected by lubricating oil. The TRS cables are run on well seasoned and straight teak wood batten with at least a thickness of 10mm.

The cables are held on the wooden batten by means of tinned brass link clips (buckle clip) already fixed on the batten with brass pins and spaced at an interval of 10cm for horizontal runs and 15cm for vertical runs.



Advantages of Batten Wiring

- Wiring installation is simple and easy
- cheap as compared to other electrical wiring systems
- Paraphrase is good and beautiful
- Repairing is easy
- strong and long-lasting
- Customization can be easily done in this wiring system.
- less chance of leakage current in batten wiring system

Disadvantages of Batten Wiring

- Can’t be install in the humidity, Chemical effects, open and outdoor areas.
- High risk of firs

- Not safe from external wear & tear and weather effects (because, the wires are openly visible to heat, dust, steam and smoke.
- Heavy wires can't be used in batten wiring system.
- Only suitable below then 250V.
- Need more cables and wires.

2.2.4 Lead Sheathed Wiring

The type of wiring employs conductors that are insulated with VIR and covered with an outer sheath of lead aluminum alloy containing about 95% of lead. The metal sheath given protection to cables from mechanical damage, moisture and atmospheric corrosion.

The whole lead covering is made electrically continuous and is connected to earth at the point of entry to protect against electrolytic action due to leaking current and to provide safety in case the sheath becomes alive. The cables are run on wooden batten and fixed by means of link clips just as in TRS wiring.

2.2.5 Conduit Wiring

There are two additional types of conduit wiring according to pipe installation

(i) Surface Conduit Wiring

(ii) Concealed Conduit Wiring

2.2.5.1Surface Conduit Wiring

If conduits installed on roof or wall, It is known as surface conduit wiring. in this wiring method, they make holes on the surface of wall on equal distances and conduit is installed then with the help of rawal plugs.

2.2.5.2 Concealed Conduit wiring

If the conduits is hidden inside the wall slots with the help of plastering, it is called concealed conduit wiring. In other words, the electrical wiring system inside wall, roof or floor with the help of plastic or metallic piping is called concealed conduit wiring. obliviously, It is the most popular, beautiful, stronger and common electrical wiring system nowadays.

In conduit wiring, steel tubes known as conduits are installed on the surface of walls by means of pipe hooks (surface conduit wiring) or buried in walls under plaster and VIR or PVC cables are afterwards drawn by means of a GI wire of size if about 18SWG.

In Conduit wiring system, The conduits should be electrically continuous and connected to earth at some suitable points in case of steel conduit. Conduit wiring is a professional way of wiring a building. Mostly PVC conduits are used in domestic wiring.

The conduit protects the cables from being damaged by rodents (when rodents bites the cables it will cause short circuit) that is why circuit breakers are in place though but hey! Prevention is better than cure. Lead conduits are used in factories or when the building is prone to fire accident. Trunking is more of like surface conduit wiring. It's gaining popularity too.

It is done by screwing a PVC trunking pipe to a wall then passing the cables through the pipe. The cables in conduit should not be too tight. Space factor have to be put into consideration.

2.3Types of Conduit

Following conduits are used in the conduit wiring systems (both concealed and surface conduit wiring) which are shown in the above image.

- Metallic Conduit
- Non-metallic conduit

2.3.1Metallic Conduit:

Metallic conduits are made of steel which are very strong but costly as well.

There are two types of metallic conduits.

- Class A Conduit: Low gauge conduit (Thin layer steel sheet conduit)
- Class B Conduit: High gauge conduit (Thick sheet of steel conduit)

2.3.2 Non-metallic Conduit:

A solid PVC conduit is used as non-metallic conduit now a days, which is flexible and easy to bend.

Size of Conduit:

The common conduit pipes are available in different sizes genially, 13, 16.2, 18.75, 20, 25, 37, 50, and 63 mm (diameter) or 1/2, 5/8, 3/4, 1, 1.25, 1.5, and 2 inch in diameter.

Advantage of Conduit Wiring Systems

I. It is the safest wiring system (Concealed conduit wring)

II. Appearance is very beautiful (in case of concealed conduit wiring)

III. No risk of mechanical wear & tear and fire in case of metallic pipes.

IV. Customization can be easily done according to the future needs.

V. Repairing and maintenance is easy.

VI. There is no risk of damage the cables insulation.

VII. it is safe from corrosion (in case of PVC conduit) and risk of fire.

VIII. It can be used even in humidity , chemical effect and smoky areas.

IX. No risk of electric shock (In case of proper earthing and grounding of metallic pipes).

X. It is reliable and popular wiring system.

XI. sustainable and long-lasting wiring system.

Disadvantages of Conduit Wiring Systems

I. It is expensive wiring system (Due to PVC and Metallic pipes, Additional earthing for metallic pipes Tee(s) and elbows etc.

II. Very hard to find the defects in the wiring.

III. installation is not easy and simple.

IV. Risk of electric shock (In case of metallic pipes without proper earthing& grounding system)

V. Very complicated to manage additional connection in the future.

2.4 Comparison between Different Wiring Systems

Below is the table which shows the comparison between all the above mentioned wiring systems.

S.No	Particulars	Cleat Wiring	Casing Capping Wiring	Batten Wiring	Conduit Wiring
1	Life	Short	Fairly long	Long	Very long
2	Cost	Low	Medium	Medium	Highest
3	Mechanical Protection	None	Fair	None	Very good
4	Possibility of fire	Nil	Good	Good	Nil
5	Protection from dampness	None	Slight / a little	None	Good
6	Type of labor required	Semi-Skilled	Highly Skilled	Semi-skilled	Highly Skilled
7	Installation	Very Easy	Difficult	Easy	Difficult
8	Inspection	Easy	Easy	Easy	Difficult
9	Repair	Easy	Little bit difficult	Easy	Difficult
10	Popularity	Nil	Fair	Nil	Very High

Comparison of Different Wiring Systems

Electrical connection of neutral point of a supply system or the non-current carrying part of electrical equipment's to the general mass of earth in such a manner that all times on immediate discharge of

Electrical energy

- The potential of an installation is measured with respect to the general mass of earth or commonly called Earth
- Why is the practice of earthing electrical system?

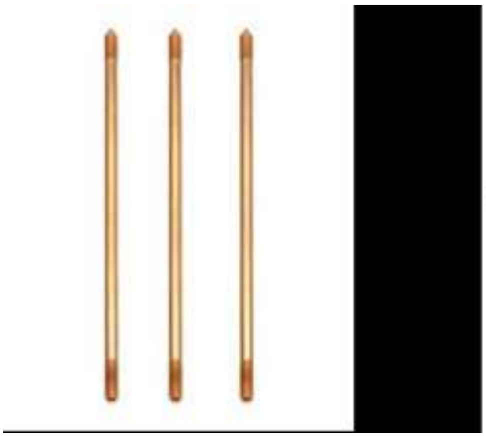
✓ To provide a sufficiently low impedance

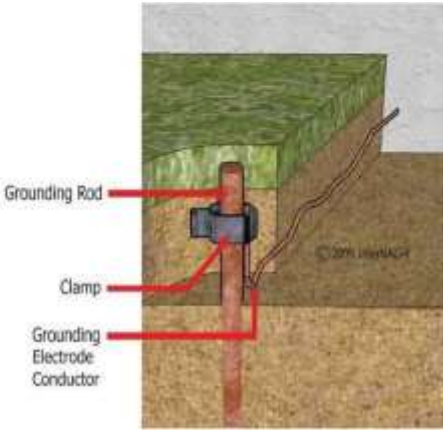
✓ To retain system voltages with in reasonable limits under faultcondition (Lightning\, switching surges, or contact with highervoltages system)

✓ The potential of an installation is measured with respect to thegeneral mass of earth or commonly called Earth

Earthing Conductors:

A protecting conductor connecting the main earthing terminal of an installation to an earth electrode or other means of earthing.





2.5 Installation methods

There are three common types of installation:

1. Buried ring
2. Earthing rods
3. Vertical plates

Buried ring

- Most of the time used for new building, the electrode should be buried around the perimeter of the excavation made for the foundations.
- It is important that the bare conductor be in intimate contact with the soil (and not placed in the gravel or aggregate hard-core, often forming a base for concrete).

The conductors may be:

- Copper: Bare cable (≥ 25 mm 2) or multiple-strip (≥ 25 mm 2and ≥ 2 mm thick)
- Aluminum : with lead jacket: Cable (≥ 35 mm 2)
- Galvanized-steel cable: Bare cable (≥ 95 mm 2) or multiple-strip (≥ 100mm 2 and ≥ 3 mm thick)

$R = 2p/R$

The approximate resistance R of the electrode in ohms:

Where: ρ = resistivity of the soil in ohm –meter

L = length of the conductor in meter

2. Earthing rods

Vertically driven earthing rods are often used for existing buildings, and for improving (i.e. reducing the resistance of) existing earth electrodes

The rods may be:

Copper or (more commonly) copper-clad steel. The latter are generally 1 or 2 metres long and provided with screwed ends and sockets in order to reach considerable depths, if necessary (for instance, the water-table level in areas of high soil resistivity)

Galvanised steel pipe ≥ 25 mm diameter or rod u15 mm diameter, ≥ 2 meters long in each case

It is often necessary to use more than one rod, in which case the spacing between them should exceed the depth to which they are driven, by a factor of 2 to 3.

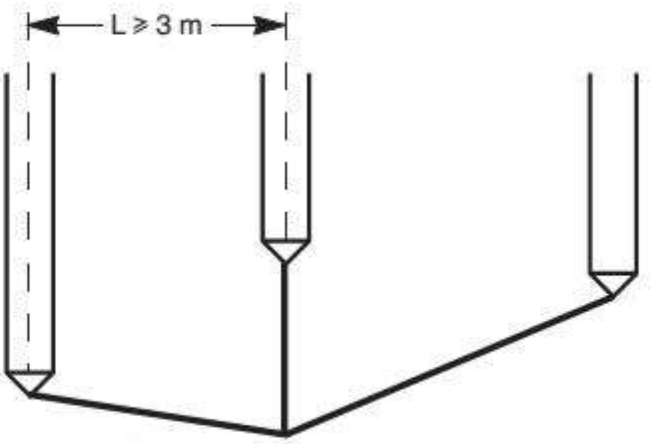
The total resistance (in homogeneous soil) is then equal to the resistance of one rod, divided by the number of rods in question. The approximate resistance R obtained is:

$$R = \rho / nL$$

if the distance separating the rods > 4L Where: ρ = resistivity of the soil in ohm –meter

L = length of the rod in meter

n = Number of rods



Rods connected in parallel

3. Vertical plates

Rectangular plates, each side of which must be ≥0.5 metres, are commonly used as earth electrodes, being buried in a vertical plane such that the centre of the plate is at least 1 metre below the surface of the soil. The plates may be:

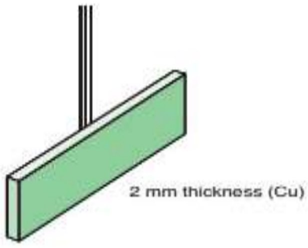
Copper of 2 mm thickness

Galvanised steel of 3 mm thickness

$$R = 0.8 \rho / L$$

The resistance R in ohms is given (approximately), by:

Where: ρ = resistivity of the soil in ohm –meter



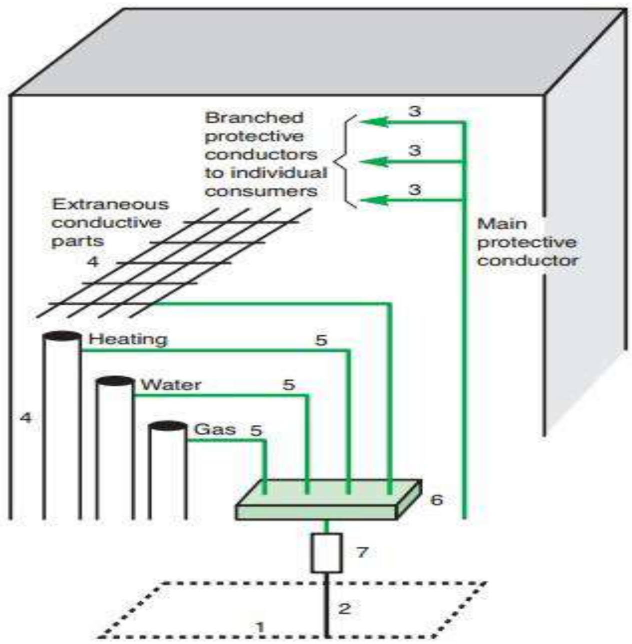
L = perimeter length of the rod in meter

Bonding

Is the practice of intentionally electrically connecting all exposed metallic parts not designed to carry electricity in a room or building to protect from electric shock.

Equipotential Bonding

Electrical Connection maintaining various exposed conductive parts and extraneous conductive parts as substantially the same bonding



Bonding Conductor:

A protective conductor providing equipotential bonding

There are different earthing arrangements:

- IT system
- TT system
- TN system

- TN-C-S

The first letter defines the situation of the neutral point inrelation to earth

T: Solidily earthed to neutral

I: unearthed or high impendence earth to neutral

The Second letter defines the connection method of electrical installation exposed conductive path

T: The exposed conductive parts are interconnected and solidly earthed, regardless of whether the neutral part is earthed or not

N: The exposed conductive parts are directly connected to neutral conductor

The third and Fourth letter indicates the arrangement ofearthed supply conductor system

C: Combined S: Separate

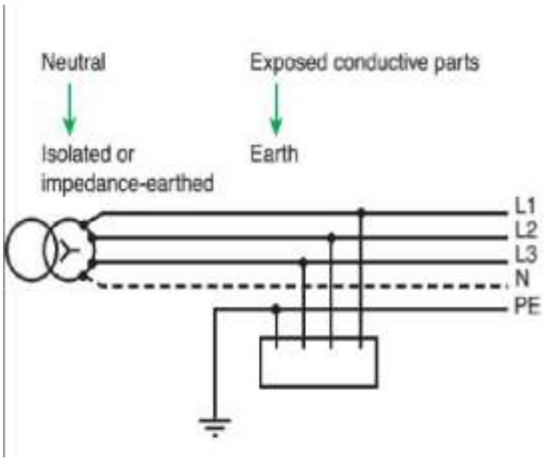
IT system earthing

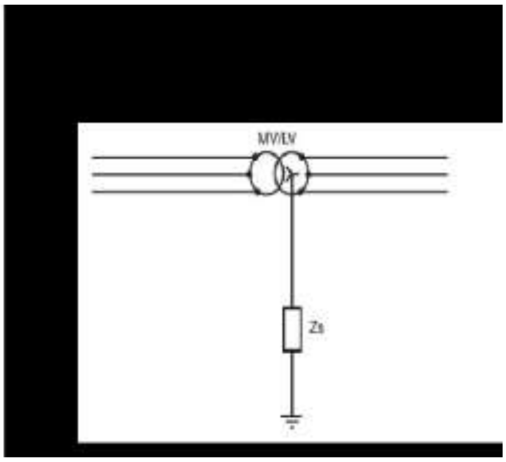
The neutral is earthed or unearthed via high impendence

No intentional connection is made between the neutral point of the supply source and earth

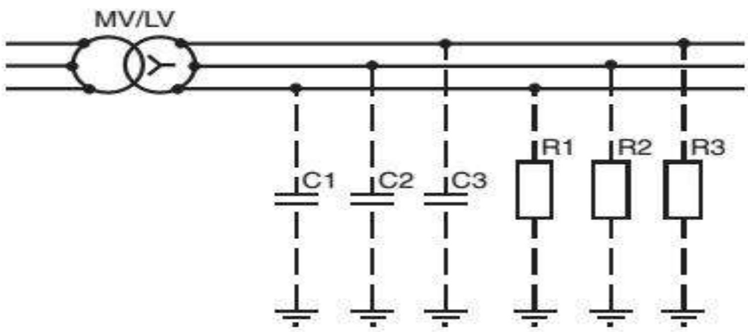
Exposed- and extraneous-conductive-parts of the installation are connected to an earth electrode.

An impendence b/n 1 kohm and 2 kohm are frequently used





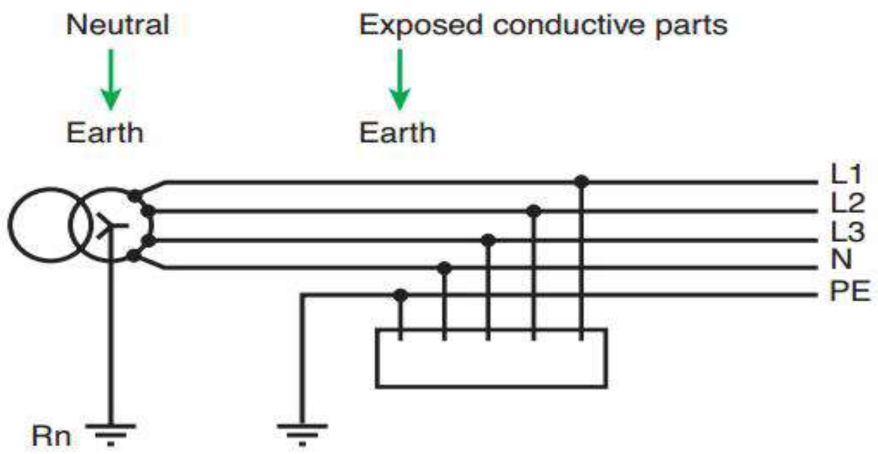
In practice all circuits have a leakage impedance to earth, since no insulation is perfect. In parallel with this (distributed) resistive leakage path, there is the distributed capacitive current path, the two paths together constituting the normal leakage impedance to earth In a LV 3-phase 3-wire system, 1 km of cable will have a leakage impedance due to C1, C2, C3 and R1, R2 and R3 equivalent to a neutral earth impedance Zct of 3,000 to 4,000 Ω, without counting the filtering capacitances of electronic devices.



TT Earthing system

The neutral is directly earthed,

The exposed conductive parts of the loads are interconnected, either together or in groups or individually earthed



TN Earthing system

The neutral point is directly earthed

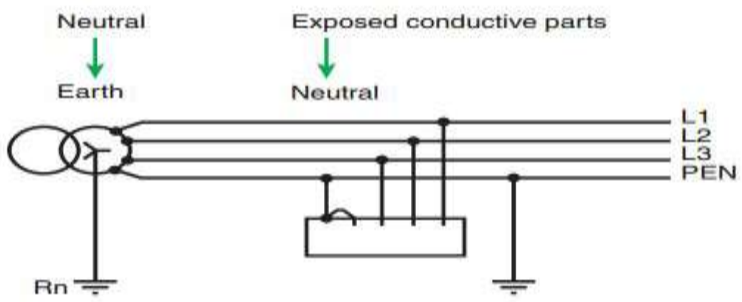
The exposed conductive parts of the loads are connected to the neutral conductor.

There are two possible system depending on whether the neutral conductor (N) and protective conductor (PE) are on the same or not

TN – C Earthing system

The Neutral and protective conductors form a single conductor called PEN

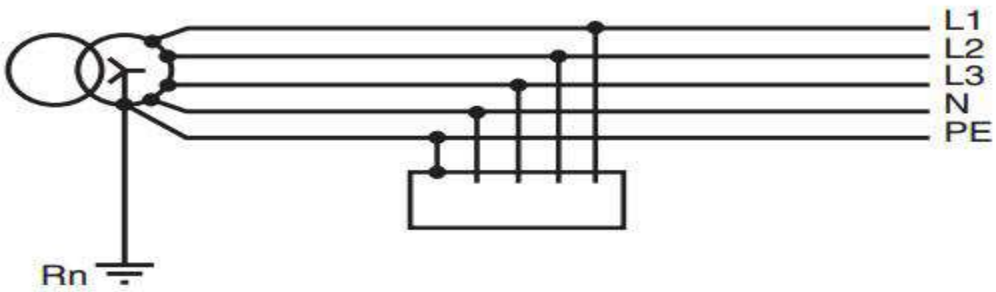
It is advised to connect PEN to ground



TN – sEarthing system

The Neutral and protective conductors are separate

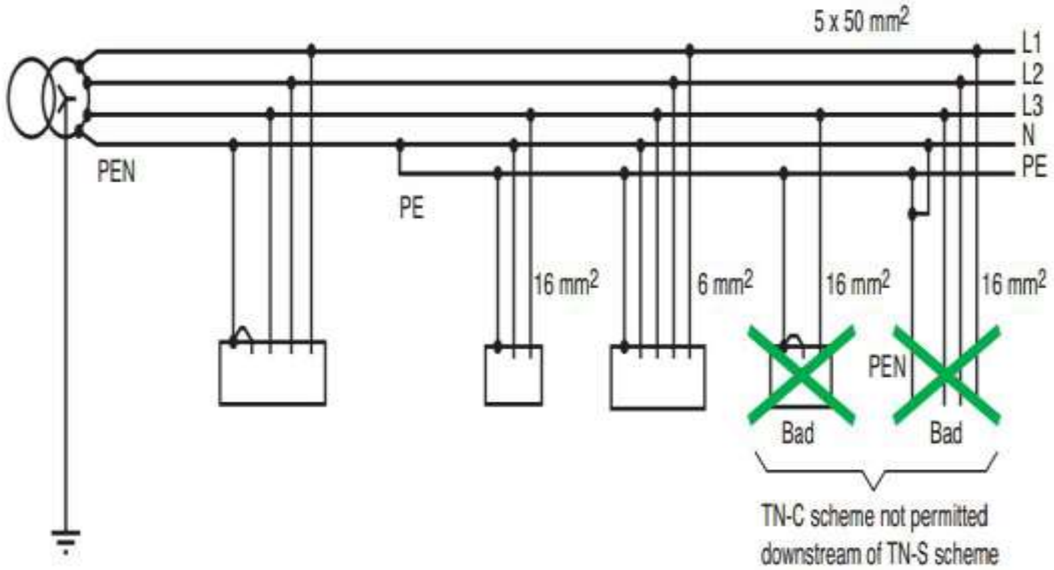
It is advised to regularly to connect the protective conductor to earth



TN – C –S Earthing system

With this arrangement the main distributor neutral is also used to return earth fault current arising in consumer installation safety to the source. To achieve this the distribution will provide consumer-earthingterminal, which is linked, to the coming neutral conductor

In the TN-C-S system, the TN-C (4 wires) system must never be used downstream of the TN-S (5 wires) system, since any accidental interruption in the neutral on the upstream part would lead to an interruption in the protective conductor in the downstream part and therefore a danger.



2.5 Electrical installation design of a consumer

2.5.1 Control of supply at the consumer premises

The scope of electrical installation in this course is limited to the domain of the consumer premises. The kWh/kVAR meter, usually owned by a power utility, establishes the boundary between the utility and the consumer. The overhead/underground cable conductor feeding power from the last pole of the utility company to the consumer building where the conductors are supported by insulated strains is called service drop. The service conductor is cable from the building strain insulator to service-entranceequipment.

2.5.2 Clearance from Building opening

i. Service conductor installed as open conductor or multi-conductor cable without any overall other jacket shall have a clearance of not less than 925 mm from windows, doors, porches, fire escape, or similar locations.

ii. Service conductors shall not be installed beneath openings through which materials may be moved, such as openings in farm and commercial buildings.

iii. Overhead wire shall not be run such that they obstruct entrance to these buildings openings.

The service-entrance equipment is a system including at least three elements. This is because it is essential that the consumer supply should be effectively controlled and also that all switch gear should be accessible. The main switch gear installation should consist of:

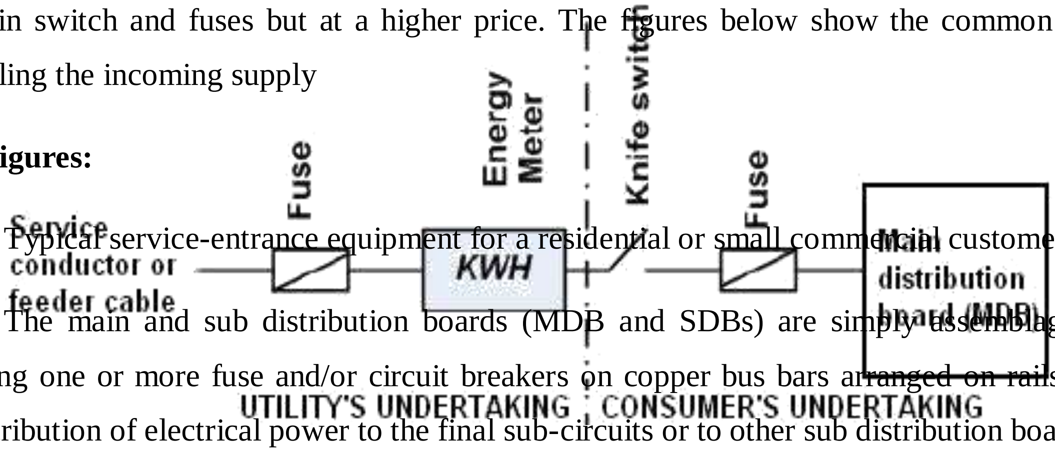
a) means of isolation the supply

b) means of protection against excess current due to overload or short circuit (plus earth-leakage protection if required),

c) Means of measuring the energy.

A main switch containing a fuse for single phase (3 fuses for 3 phase) fulfills these conditions as the switch isolates the supply while the fuse/s protect/s the circuit against excess current due to over load, short circuit or a serious earth fault. An automatic circuit breaker (ACB) does the job of both the main switch and fuses but at a higher price. The figures below show the common method of controlling the incoming supply

2.5.3 Figures:



Typical service-entrance equipment for a residential or small commercial customer

The main and sub distribution boards (MDB and SDBs) are simply assemblages of parts, including one or more fuse and/or circuit breakers on copper bus bars arranged on rails/bridges for the distribution of electrical power to the final sub-circuits or to other sub distribution boards.

A medium or high voltage supplied consumer usually uses three phase supply without/with step down transformer as well as a meter for measuring both true and reactive electric energies. They may accordingly be equipped with power correction apparatuses to optimize their energy utilization cost.

2.5.4Service-entrance equipment and feeder cable

The selection or knowledge of voltage level of service-entrance from utility company is the first step for the design of the service-entrance equipment.

Cable from the utilities operating company line to the energy meter at the consumer's intake point is called the service cable or line. The service line voltage level is determined by the power requirement of the consumer premises. If the power requirement is high, it is economical to have a high voltage service so that the cable cross sectional area is acceptable. In this case, a transformer is required in the consumer premises. In Ethiopia power is supplied to industrial premises at 15 kV which is the distribution voltage while it is at 380/220 Volts for low power consuming commercial and residential consumers.In industrial and commercial power systems, substations including transformers, reactors, pf correctors, switchgear and standby generators can be part of the electrical system to be designed, installed and inspected.

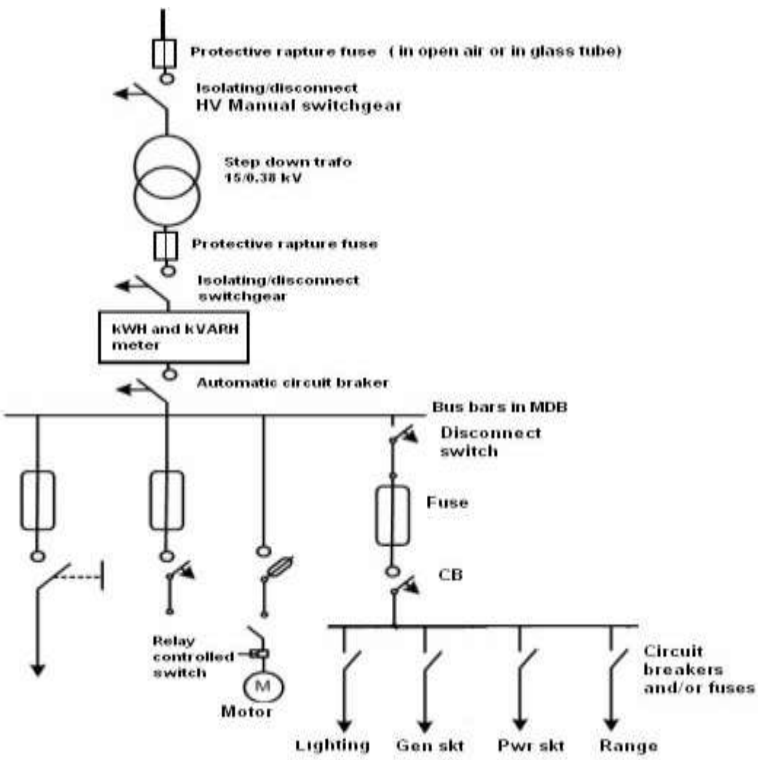


Fig. Typical sub-station for medium or high voltage supplied consumer

2.6. Arrangement of installation components

Inside the consumer's premises there are basically two ways of distributing power i.e. MDB-to-SDB interconnection. These are illustrated below.

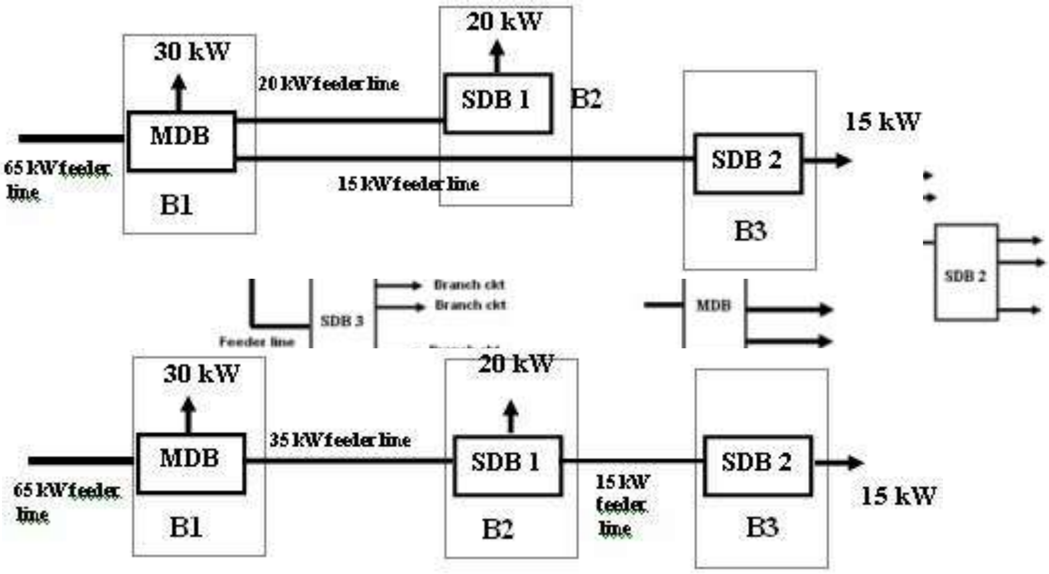


Figure a) Only from MDB to SDB b) from MDB to SDB and from SDB to SDB

Because of cable and protective device cost, the MDB as well as the SDBs are installed in a position chosen such that minimum cable cost is required but at the same time convenience of power delivery, maintenance etc should be satisfied. MDBs are usually situated in an area where maximum power is consumed which may be determined using **moment method** of the SDBs to optimize the costly large sized feeder cable, protective devices and switchgears.

Electrical installation design in general is the engineering process of selection and decision on the required materials, accessories and protective devices. Depending on the particular need for residential,public, commercial and industrial customers two or more of the following are involved in the installation design:

- Lighting installation & fitting
- General purpose socket outlet
- Power (and special purpose) socket outlet
- Trunking/feeder installations,

- Main switchgear feeders
- Sub-mains and distribution gears
- Earthing system,
- Lightening protection system
- Substation cables
- Substation transformer
- Substation switchgear,
- Power factor correction apparatuses

In electrical installation terminology, a **branch circuit or a final circuit** is the last portion of the installation in which **one** or **more** parallel connected loads are supplied with electric power as well as use one common isolating and protective devices. However, each load in a branch circuit is controlled separately with its own control such as a switch or a starter/contactor.

Thus, the following constitute a branch circuit:

- a high power socket outlet (such as for cooking range, stove or boiler), oa motor supply circuit,
- a group of light points,
- a group of general purpose socket outlets,
- a small group of light points plus small number of low power socket outlets etc

A branch circuit is fed power from an SDB or directly from an MDB and for this purpose it will be provided with a common/one sized **branch circuit feeder** cable or set of conductors along its length.

The cable or set of conductors used to connect MDB with each SDB or SDBs with SDB is called a **feeder cable** or line

Wire and cable size selection for known constant loads

Once a wire or a cable type is selected based on the mechanical, chemical and thermal strength it will be subjected to for the particular application, the cable size is to be selected next. Refer to section 4 of EBCS-10 for definitions and regulations related to cable.

All conductors have resistance that prevents an unlimited flow of current and of course voltage drop. For any given load, we must select a size of conductor that limits voltage drop to a reasonable value.

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Furthermore, current through a wire causes heat due to the inherent resistance and proportional to the square of the current. There is a limit to the degree of heat that the various types of insulation can safely withstand. Even a bare wire must not be allowed to reach a temperature that might cause fire. Codes specifiy the ampacity (the max. current- carrying capacity in amperes) that is safe for a conductor of different sizes with different kinds of insulation and under different operating circumstances.

Cable size selection accounting voltage drop calculation

- **Using pure analytical method (without table reference)**
- **Cable/conductor size selection for dc and single phase wires**

The size should neither be so small so as to have a large internal voltage drop and large heat nor be too large so as to cost too much. When selecting the size of a conductor or cable to be used in an installation there are two main factors to be considered:

i) The voltage drop caused by the resistance of the cable of the required length must not exceed a limit given as a standard. Usually drops of up to 2.5% of the supplied voltage is tolerable. For feeder cables 1%, for branch circuits (sub circuits) 2%, and equipment taking power directly 2.5% of the supply voltage drop is tolerable.

ii) The wire or cable must be able to carry the maximum current liable to flow in the circuit without undue heating. The **current rating** of a conductor is defined as the maximum current it can carry continuously without undue heating.

iii) Cable size selection may also be affected by the operating temperature of the cable and this should be compensated with what is known as **derating factor.**

iv. Cable size selection is also affected by grouping, their spacing distance, whether they are underground or in open air as well as insulation factors

Note: Individual conductor wires and each conductor of a cable are manufactured in the following International standard sizes in which the wires are circular and may be solid or stranded.

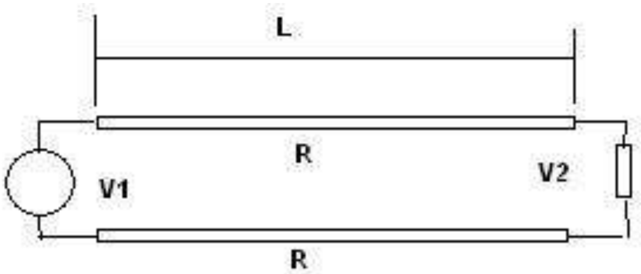
Standard nominal cross section of bare wire (mm^2)	**0.5**	**0.75**	**1**	**1.5**	**2.5**	**4**	**6**	**10**	**25**	**35**	**50**	**70**	**95**	**120**	**150**	**185**	**240**	**300**	**400**	**500**	**630**
Purpose	**Data cable**		**Electric power cables**																		

	et c	

DC circuits

a) Using line constants

Consider the two wire circuit (single phase) shown next



The voltage drop on the pair of cable must be **□V = V_1– V_2 2IR**

where**R = L/□A** ; R in □, L in meters, A in mm^2 and □ in m/□-mm^2

For copper □ = 57 m/□-mm^2 (i.e in unit of meter per ohm mm^2) and for aluminum □ = 33 m/□-mm^2

Thus cross sectional area of the wire can be related to the loading must satisfy

□V 2IR = 2IL/□A

or

A (mm^2) 2IL(m)/□ □V …….. .1

If □V is in percentage of the rated value [i.e (□V/V)100% = C or **□V = C V/100]**, then

A (mm^2) 200 x **I [**A**]** x **L[**m**]/ □CV**

If power is given instead of current

A (mm^2) 200 x**P[**W**]** x **L[**m**]/ □CV^2** …….. 2

Note in lighting designs voltage drop of up to 5% of rated value are allowed [EEPCO regulation 2.5%max]. In power applications voltage drop of up to 7% of rated values may be allowed.

Example:

2.1. A 1 kW electric appliance is to be supplied from a 220V from a single phase source 200m away.

Assuming an allowed 2.5% voltage drop, what cross sectional area of copper wire must be used.

Solution:

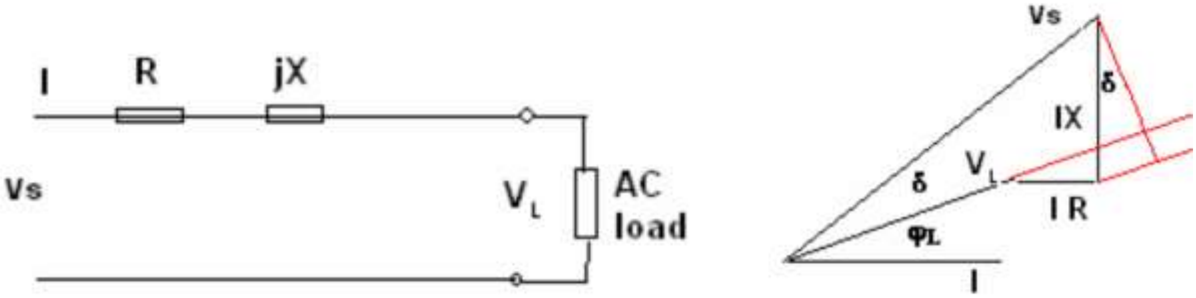
A (mm^2) 200 x 1000W x 200m/(57 x 2.5 x 220^2) = 5.8 mm^2

Since 2 x 5.8mm^2 cable is not available in the standard, the next higher size, i.e. 2 x 6 mm^2 cable will be used.

Single phase AC circuits (includes cable inductance considerations)

We note that equation 3.2 does not account the effect of cable inductance and load power factors.

Consider the following single phase circuit with an ac load and a pair power line of length L, resistance R and inductive reactance X creating a phase difference of □ between the source and load voltages:



From the phasor diagram (considering the real axis is along the load voltage V_L and the imaginary axis is perpendicular to V_L) we see and may write for the source voltage

$$V_s = V_s (\cos □ + j \sin □)$$

$$V_s \cos □ = V_L + IR \cos □_L + IX \sin □_L$$

$V_s \sin □ = IX \cos □_L - IR \sin □_L$

$=> V_s = [(V_L + IR \cos □_L + IX \sin □_L)^2 + (IX \cos □_L - IR \sin □_L)^2]^{0.5}$

To a first degree approximation, since □□□ 0 (**due to the fact that X << R for the line**) we may neglect the component $V_s \sin □$ so that

$V_s = V_L + IR \cos □_L + IX \sin □_L$

$|□V| = |V_s - V_L| = [(□V_R)^2 + (□Vx)^2]^{0.5} = [(IR \cos □_L)^2 + (IX \sin □_L)^2]^{0.5}$

If further the reactance X is negligible (as usually so), then

$V_s = V_L + IR \cos □_L$

$|□V| = |V_s - V_L| = IR \cos □_L$

The resistance R considered above is the total resistance of the pair of wires. If we consider R is only for one of the wire pair then the total resistance becomes 2R and thus

$|□V| = |Vs - VL| = 2IR \cos □L$

Cable size selection accounting increased ambient temperature

If a cable is installed in an ambient temperature of 25°C and loaded with the maximum rated current, the final temperature will be 70°C. Then, if the cable is installed at a temperature above 25°C, the starting temperature of the cable will be higher, and the running temperature will also be higher. Therefore, to prevent the cable from overheating, we must make adjustments to the current carrying capacity of the cable, if it is installed in an ambient temperature above 25°C.

For rubber insulated conductor the maximum admissible heating up is assumed to be reached with a temperature **rise** of 35^{O}C so that the limit temperature is fixed at 25^{O}C + 35^{O}C = 60^{O}C. Thermoplastics insulating materials permit an excess temperature of 45^{O}C giving a limit of 70^{O}C.

For instance, for a general purpose PVC at 35°C the correction factor is 0.94. This means that the cable may only be loaded to 94 per cent of its 30°C capacity.

Table values of current capacities are provided for a room temperature of 25^{O}C and less.

Typical table below relates to temperature correction factor (Ca) for ambient temperature.

Room temp ^{O}C	30	35	40	45	50	55	60
Temperature correction factor for value in table, Ca	0.92	0.85	0.75	0.65	0.53	0.38	0.30

Cable size selection accounting number of conductors

If circuits were grouped with other circuits or if multicore cables were bunched with other multicores in an enclosure, the heat dissipation properties of the circuits or cables would be reduced. The more cables there are in the group the dissipation properties of the cable are reduced. Then if the cables were loaded to their ungrouped level, when they are grouped they would overheat. The number of grouped circuits must therefore be taken into account. Tables should be referred for correction factors Cg to account for grouping.

For instance, for two enclosed multicore cables bunched and clipped direct to a non-metallic surface, Cg

= 0.80. This means that for two circuits, only 80 per cent of the single circuit current is allowed. For three circuits, Cg = 0.70. This means that for three circuits, only 70 per cent of the single circuit or multicore current is allowed. If a cable is grouped with three other circuits (4 in total), Cg = 0.65.

No. of multicore groups, or multiple circuit group	1	2	3	4
Grouping correction factor, Cg	1	0.8	0.7	0.65

capacity when grouped with other cables will reduce to $I'_z = Cg \times Iz$

If, in addition ambient temperature change is encountered for the bunched cables, the combined correction factor of grouping and temperature will be C = Cg x Ca. This means that the current capacities of each of the cables is reduced by a factor of C, i.e. $I'_z = C \times Iz$..

If the cable is run in heat-insulating material, its ability to dissipate heat will be impaired. To consider this, a heat insulation correction factor Ci applied to the length of the cable enclosed in thermal insulation.

Thus, the combined effects of ambient temperature change, grouping and heat insulation utilization will result a combined correction factor C = Cg x Ca x Ci and $I'_z = C \times Iz$.

3.3.4 Cable size selection accounting protective device & correction factors

The protective device current rating I_n should be greater than the design current I_b. of the circuit/ appliance. That is, I_nI_b and its value is selected from standard tables. For the protective device to

protect the cable against overload, the minimum cable rating, Iz = In or Iz In. Under normal condition (25^{O}C, un-grouped, and with no heat insulation), the tabulated rated value of the cable Iz= ItWhen one or all correction factors are to be accounted, we use them as divisor/s to determine the corrected rating of the cable as

I'_z = Min. It = In/Cg×Ca×Ci or I'_z = It In/Cg×Ca×Ci

When a rewireable fuse is to be used, a factor of 0.725 is used in addition. The formula is now amended to I'_z = Min. It = In/Cg×Ca×Ci x 0.725 or I'_z = It In/Cg×Ca×Ci x 0.725

If any of the factors are not applicable, ignore them or replace with a 1.

Example

Figure below represents one single-phase thermoplastic 70°C circuit enclosed in conduit. The design current Ib = 45A. The corresponding minimum fuse size chosen from BS88 range of fuses is 50A. For the fuse to protect the cable against overload, the minimum cable rating, Iz, is 50A. Also, the minimum tabulated rating, It, for the cable is also 50A. If the cable is grouped with three other circuits (4 in total), Cg = 0.65.

Therefore the minimum rating Iz, or the minimum tabulated rating It of the cable will be Iz = It In/Cg=50/0.65=76.92A

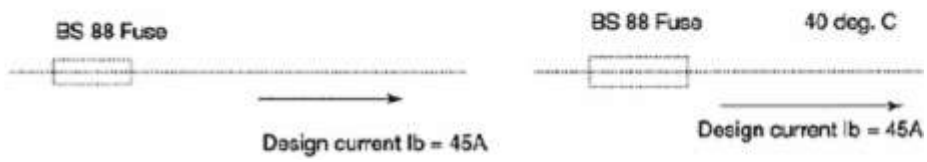


Figure: Device rating related to design current and grouping cables

In other words a cable which will carry 76.92A is acceptable, but the cable must be derated to a factor of 0.65: 76.92×0.65=50

Therefore, in these conditions, the cable is rated at 50A. We are selecting a larger size of cable because of the reduction in current carrying capacity due to grouping. However, the fuse rating remains 50A.

If the above circuit is run further at a temp of 35^{O}C, there are two correction factors to apply, one for grouping and one for ambient temperature above 30°C. The minimum rating of the cable will be Iz= It In/Cg×Ca=50/(0.94×0.65)=81.83A

Example 3

Single-phase 240V, 36A loads are to be supplied by means of 70°C thermoplastic PVC twin and earth cables having copper conductors, 25m in length, in an area having an ambient temperature of 35°C (Ca= 0.94). The cables are touching and single-layer clipped to a non-metallic surface (for 3 circuits Cg=0.79). The overcurrent device at the origin of the installation is a type-B MCB to BS EN 60898. Calculate the minimum permissible cable size.

Solution:

Method 1

Design current I_b =36A. Nominal rating of the device (from table) In=40A (I_b), Cg=0.79, Ca=0.94. Thus, tabulated rating of cable Iz = It In/Cg x Ca = 40/0.79 x 0.94 =53.86A

Consulting manufacturer's appropriate table, It = 64A. Therefore, the minimum size with respect to current carrying capacity is $10mm^2$.

If the volt drop does not exceed 4% of the nominal voltage of the mains, □V = 240 x 0.04 = 9.6V

We now need to check that the voltage drop in the 10mm^2 cable is within these limits. Table for the cable gives voltage drop in millivolts per ampere per meter of 4.4. To calculate the voltage drop, multiply mV/Amp/m x Ib x Meters/1000. Thus □V = 4.4 x 36 x 25/1000 = 3.96V < 9.6V.

We see therefore, the minimum permissible size is 10mm^2.

Method 2

Design current Ib=36A. Nominal rating of the device In=45A (a rewireable fuse to BS 3036); Cg=0.79, Ca=0.97.

Thus Iz = It   In/Cg x Ca x 0.725 = 45/0.555=81A

Consulting manufacturer's appropriate table, It = 85A. Therefore, the minimum size with respect to current carrying capacity is 16mm^2.

The voltage drop □V = mV/Amp/m x Ib x Meters/1000 = 2.8 x 36 x 25/1000 = 2.252V < 9.6V. Therefore, the minimum permissible size is 16mm^2. Note that semi-enclosed fuses should be rigorously avoided these days. BS 7671 expresses a preference for cartridge-type fuses.

Summarized Cable Size Selection Procedure for Constant Load or Final circuits

i. Determine **design current**, I_b, based on continuous load of cable.

a. Single phase

$$I_b = \frac{P_L}{V \cos\phi}$$

for single phase continuous load $\mathbf{P_L}$, **V** is phase voltage and is power factor angle.

b. Three phase

$$I_b = \frac{P_L}{\sqrt{3} V_L \cos\phi}$$

for three phase load $\mathbf{P_L}$, $\mathbf{V_L}$ is line voltage and   is power factor angle.

ii. Select cable type for desired application (for over head, underground, indoor, outdoor, wet, dry etc) based on

a. Type of insulation like PVC, Rubber, Mineral, XLPE etc.

b. Conductor type like copper and aluminum

c. Number of cores like single core, multiple core,

iii. Apply correction factors for ambient temperature, grouping, and heat insulation if any.

If Over current protection is to be used,

Corresponding to the design current I_b select from standard tables the rating of the protection device $\mathbf{I_n}$ (Note: **InIb**) and the minimum current carrying capacity of cable Iz = It to be selected will then be

$$I_t \geq \frac{I_n}{C_a C_g C_i}$$

For semi-enclosed fuses (i.e. rewireablefuse) divide further by 0.725.

If over current protection is not to be provided for the circuit,

select the minimum current carrying capacity of cable,$\mathbf{I_t}$, to be selected as

$$I_t \geq \frac{I_n}{C_a C_g C_i}$$

Where $\mathbf{C}_a$, $\mathbf{C_g}$, and $\mathbf{C_i}$ are ambient temperature, group, and insulation correction factors.

iv. Check for the allowable voltage drop using the continuous current in the cable that is the designcurrent.
If the voltage drop is higher than the allowed, choose the higher cross-section until the voltage drop is in the allowed range.

Protection and Control Device Selection (Study section 9 of EBCS-10)

Short Circuit calculation

In electrical installation design, short circuit calculation is required to select the protection devices; circuit breakers and fuses. The maximum current breaking capacity of the circuit breaker or fuse to be selected for the circuit has to be greater than the prospective short circuit current. Prospective short-circuit current is the short-circuit current that would arise in the short circuit were replaced by an ideal connection having negligible impedance with out alteration of the incoming supply [1].

Worked Example 1.

An industrial premises is supplied through a transformer 15/0.4kV, **75** KVA, and 4.75% per unit impedance. Refer to Fig. 1. Determine the prospective short circuit currents if three-phase to ground short-circuit occurs at points A, B, C and D as shown in the figure. The cable used is PVC insulated non-armored three core copper with the following size and lengths. From transformer to main distribution center (MDC) 120 mm^2 with 10 meters length, from BDC to **SDB1** 25 mm^2 and 50 meters, from **SDB1** to **SDB11** 16 mm^2 and 25 meters.

a) Calculate the prospective short circuit currents at points A, B, C, and D.

b) Select appropriate circuit breakers CB1, CB2, CB3 and CB4.

c) Select appropriate fuse if fuses are to be used in place of CB1, CB2, CB3 and CB4.
Solution:

The prospective short circuit current is the balanced three-phase to ground short circuit current. Two

phase-to-phase to ground and single phase to ground short-circuit currents are normally smaller than the three-phase to ground short-circuit current.

To determine the three-phase to ground short-circuit current let us first determine the transformer impedance.

Per unit base values per phase:

$$\text{Voltage } V_{ph} = \frac{400}{\sqrt{3}} = 231;$$

Volt-ampere per phase =75/3=25kVA

Current= 25,000/231 =108A

Impedance Z= 231/108 = 2.14

Per unit impedance 4.75% means the transformer impedance is (2.14   4.75)/100 =0.10165

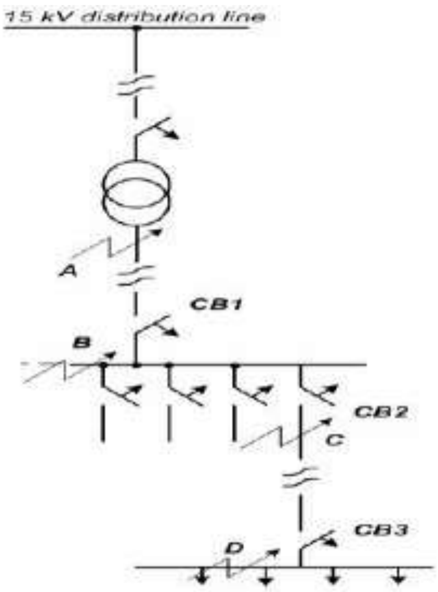


Fig. 1 Power supply to an industrial premises

The three-phase-to-ground short circuit current at point **A** can then be calculated as 231/0.10165 = 2.272kA

For short circuit at point B, the impedance is the transformer impedance plus the cable impedance. The cable of 120 mm^2 has resistivity of 0.43 mili-Ohm per meter (EBCS-10). That means for the 10 meter length it is 4.3 mili-Ohm

The prospective short circuit current at point B is approximately equal to that of A. Only bus-bar whose cross sectional area is high is between the A and B.

The short-circuit current at point C can be calculated as follows:

$$I_{SCC} = \frac{231}{0.10165 + 0.0043} = 2.180 \text{ kA.}$$

For short circuit at point C, the impedance is transformer impedance plus the total cable impedance. The 10 meter cable of 120 mm^2 and 50 meters of 25 mm^2. The cable of 25 mm^2 has resistivity of 1.85 mili-Ohm per meter (EBCS-10). That means for the 50 meter length it is 92.5 mili-Ohm. The prospective short circuit current at point C is then

$$I_{SCC} = \frac{231}{0.10165 + 0.0043 + 0.0925} = 1.164 \text{ kA.}$$

3.5. Fuse/CB selection scheme

Fuse manufacturers furnish information on **time-current characteristics** and **peak let-through charts** for each fuse.

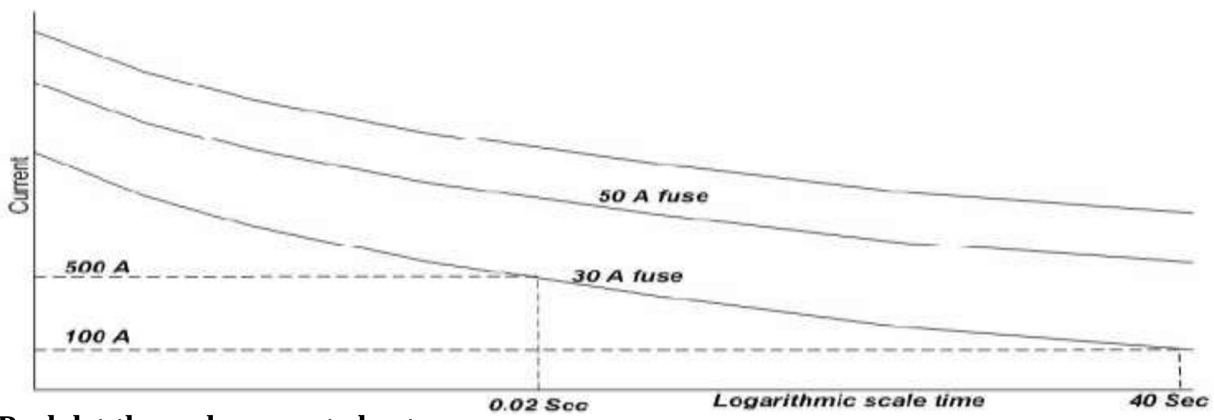
Use of the Time-current characteristics

Example of Time-Current Characteristic curves is given in Fig. 1, below.

Example: An electric motor has 24A rating current. Its inrush current is 100A. For over currentprotection of 125% check if the 30A fuse can hold the inrush current.

Solution:

At 100A draw horizontal line to intersect the 30A fuse curve. Then draw vertical line down to the base line. It can be seen that the fuse fuses at 40sec for current of 100A. Since the motor takes normally well below 40 sec to start the fuse can be used to protect the OC. If a fault of 500A occurs the fuse can clear the fault in about 0.02 sec.



Peak let through current charts

Peak let-through currents or energy are given for cables, equipments, devices, etc. That is each equipment has ability to withstand a certain amount of electric energy for a given time before the equipment is damaged.

Example: Consider a molded case circuit breakers (MCCB)

Given: - Interrupting rating of circuit breakers 10,000 A rms.

Available short-circuit current at the panel 40,000 A rms.

Fuse protecting the panel has 100 A.

Check if the fuse can protect the panel from damage incase of the short circuit current.

Solution:

Find the 40000 A on the horizontal axis and draw a vertical line until it intersects the 100A fuse line. Draw horizontal line from the intersection point until intersection with line A-B and move vertically down to the horizontal axis. Read the 4600A which means that the fuse permits an apparent let-through current of 4600A rms when subjected to 40000A.

Hence, the fuse can protect a 10000A interrupting capacity against 40000 Arms fault current.

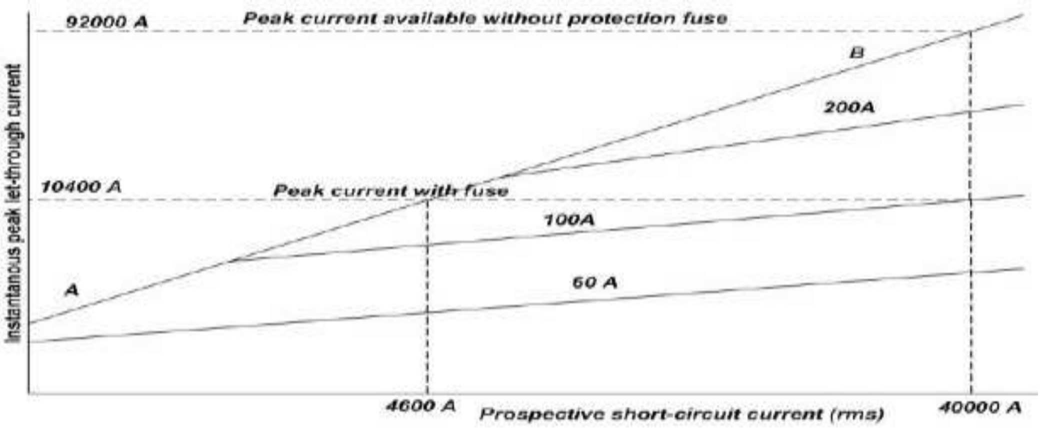


Fig. Typical Peak let-through chart for fuse

The Short circuit current

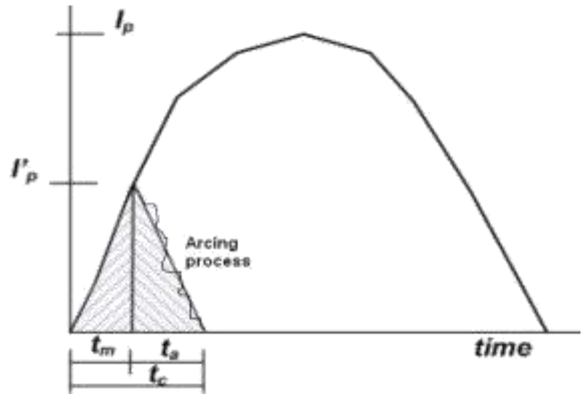


Fig. Short circuit current

Consider Fig. 3, short-circuit current at time = 0 and **Ip** is the available short circuit current peak if there is no protection. If there is protection, the fuse melts at time **tm**, and during arcing **ta**, the fault is cleared. The area shaded squared represents the (melting and arcing areas the total energy to which the circuit is subjected. If the circuit is not protected by current limiting fuse the circuit will be subjected to the area under the **Ip** curve squared.

The current limiting fuse is required to limit the let-through current and $\mathbf{I^2t}$ to the withstand rating of the equipment it is to protect. Note that the energy during the short circuit is of not only heat energy but magnetic force proportional to $\mathbf{I_p^2}$.

If the over current protection device at the origin of the circuit is for short-circuit protection only, as would be the case for a motor circuit, then the following formula stated in BS 7671 section 434–03 is employed:

$$t = \frac{k^2 \times S^2}{I^2}$$

Where t=time taken to reach the limit temperature

K=is a factor taken from table 43A BS 7671

S=cross sectional area in mm2

I=fault current.

SDB Schedule
Panal: SrvcQrt 40 Mounting: Flush Enclosure: Sheet steel
IP Rating: IP + E BUS Type: TPN Voltage: 220, 50Hz, Wires + E

No	Sub Ckt	No app	Est. Uni. Pow(W)	Est. Ttl Pow(W)	D.F	Demand Pow(W)	Wire Size(mm2)	CktBrkr Size(A)	CB Type
1	Lighting	28	60	1680	0.8	1344	2 x 2.5	10	Siemens
2	Gen Socket 1	21	200	4200	0.75	3150	3 x 2.5	16	--
3	Gen Socket 2	4	500	2000	0.8	1600	3 x 4.0	16	--
4	Bath Boiler	2	2000	2000	1.00	2000	3 x 4.0	25	--
5	Stove Range	1	3000	3000	1.00	3000	3 x 4.0	25	
6	Motor	1	3000	3000	1.00	3000	3 x 4.0	25	--
	Sub Total			15,880		14,094			
	Reserved(@10%)					1,409.4			
	Total					15,503	3 x 10	50	
	KW Connected	15.88			Location				
	D.R	0.8			Power Source		MDB		
	KW Demand	12.704			Main Switch		50A, 1-p		
	Line Current	58			Feeder		3 x 10 mm2		

Table1: SDB schedule

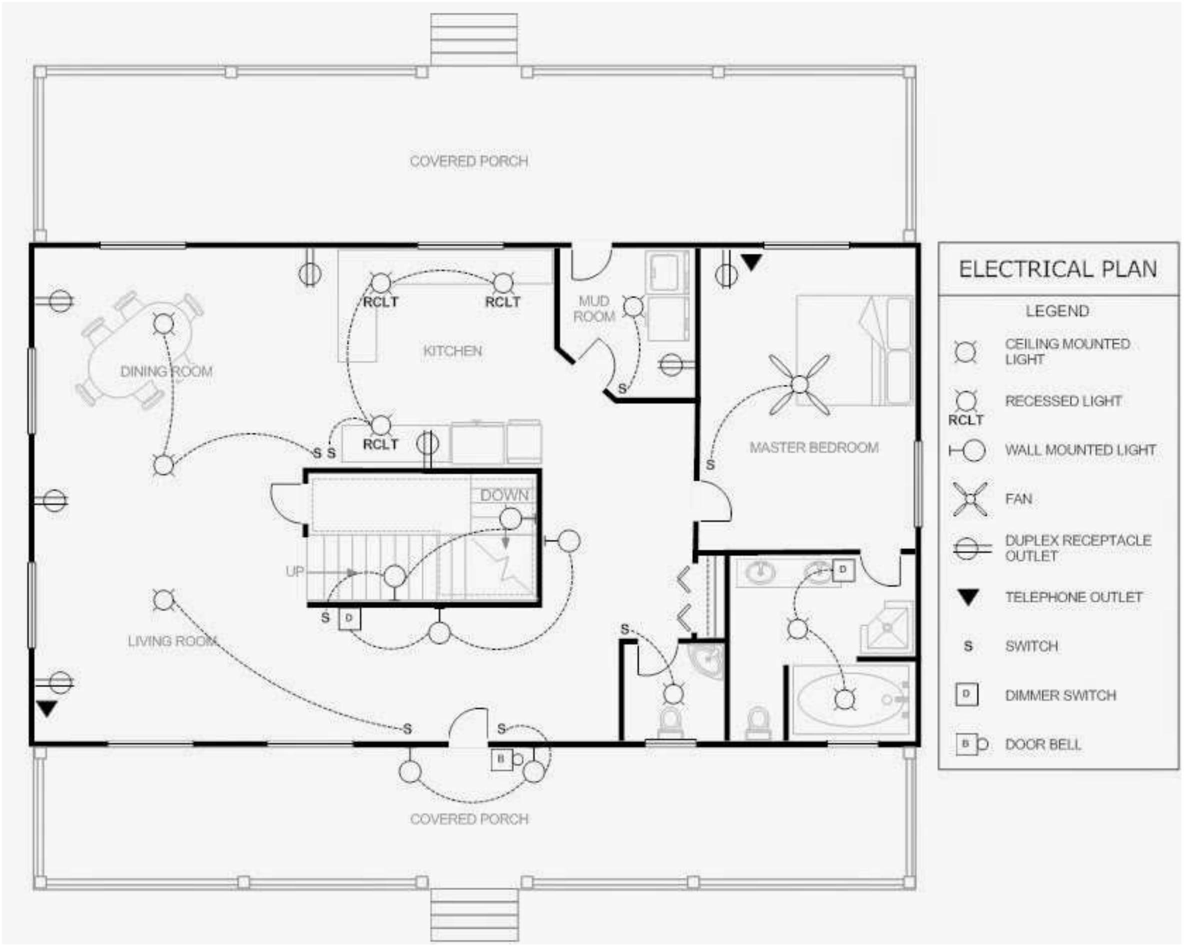


Fig house floor plan

UNIT-3

Electric Heating and Welding

Introduction

Heat plays a major role in everyday life. All heating requirements in domestic purposes such as cooking, room heater, immersion water heaters, and electric toasters and also in industrial purposes such as welding, melting of metals, tempering, hardening, and drying can be met easily by electric heating, over the other forms of conventional heating. Heat and electricity are interchangeable. Heat also can be produced by passing the current through material to be heated. This is called electric heating; there are various methods of heating a material but electric heating is considered far superior compared to the heat produced by coal, oil, and natural gas.

ADVANTAGES OF ELECTRIC HEATING

The various advantages of electric heating over other the types of heating are:

(i) **Economical**

Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.

(ii) **Cleanliness**

Since dust and ash are completely eliminated in the electric heating, it keeps surroundings cleanly.

(iii) **Pollution free**

As there are no flue gases in the electric heating, atmosphere around is pollution free; no need of providing space for their exit.

(iv) **Ease of control**

In this heating, temperature can be controlled and regulated accurately either manually or automatically.

(v) **Uniform heating**

With electric heating, the substance can be heated uniformly, throughout whether it may be conducting or non-conducting material.

(vi) **High efficiency**

In non-electric heating, only 40–60% of heat is utilized but in electric heating 75–100% of heat can be successfully utilized. So, overall efficiency of electric heating is very high.

(vii) **Automatic protection**

Protection against over current and overheating can be provided by using fast control devices.

(viii) **Heating of non-conducting materials**

The heat developed in the non-conducting materials such as wood and porcelain is possible only through the electric heating.

(ix) **Better working conditions**

No irritating noise is produced with electric heating and also radiating losses are low.

(x) **Less floor area**

Due to the compactness of electric furnace, floor area required is less.

(xi) **High temperature**

High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

(xii) **Safety**

The electric heating is quite safe.

METHODS OF ELECTRIC HEATING

Heat can be generated by passing the current through a resistance or induced currents. The initiation of an arc between two electrodes also develops heat. The bombardment by some heat energy particles such as α, γ, β, and x-rays or accelerating ion can produce heat on a surface. Electric heating can be broadly classified as follows.

(i) **Direct resistance heating**

In this method, the electric current is made to pass through the charge (or) substance to be heated. This principle of heating is employed in electrode boiler.

(ii) **Indirect resistance heating**

In this method, the electric current is made to pass through a wire or high-resistance heating element, the heat so developed is transferred to charge from the heating element by convection or radiation. This method of heating is employed in immersion water heaters.

Classification of electrical heating

Infrared (or) radiant heating

In this method of heating, the heat energy is transferred from source (incandescent lamp) and focused upon the body to be heated up in the form of electromagnetic radiations. Normally, this method is used for drying clothes in the textile industry and to dry the wet paints on an object.

Direct arc heating

In this method, by striking the arc between the charge and the electrode or electrodes, the heat so developed is directly conducted and taken by the charge. The furnace operating on this principle is known as direct arc furnaces. The main application of this type of heating is production of steel.

Indirect arc heating

In this method, arc is established between the two electrodes, the heat so developed is transferred to the charge (or) substance by radiation. The furnaces operating on this principle are known as indirect arc furnaces. This method is generally used in the melting of non-ferrous metals.

Direct induction heating

In this method of heating, the currents are induced by electromagnetic action in the charge to be heated. These induced currents are used to melt the charge in induction furnace.

Indirect induction heating

In this method, eddy currents are induced in the heating element by electromagnetic action. Thus, the developed heat in the heating element is transferred to the body (or) charge to be heated by radiation (or) convection. This principle of heating is employed in induction furnaces used for the heat treatment of metals.

Dielectric heating

In this method of electric heating, the heat developed in a non-metallic material due to inter atomic friction, known as dielectric loss. This principle of heating usually employed for preheating of plastic performs, baking foundry cores, etc.

RESISTANCE HEATING

When the electric current is made to pass through a high-resistive body (or) substance, a power loss takes place in it, which results in the form of heat energy, i.e., resistance heating is passed upon the *I*2*R* effect. This method of heating has wide applications such as drying, baking of potteries, commercial and domestic cooking, and the heat treatment of metals such as annealing and hardening. In oven where wire resistances are employed for heating, temperature up to about
1,000°C can be obtained.

The resistance heating is further classified as:

1. direct resistance heating,
2. indirect resistance heating, and
3. infrared (or) radiant heating.

Direct resistance heating

In this method, electrodes are immersed in a material or charge to be heated. The charge may be in the form of powder, pieces, or liquid. The electrodes are connected to AC or DC supply as shown in Fig. 3.1(a). In case of DC or 1-φ AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3-φsupply. When metal pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit. The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency. As the current in this case is not variable, so that automatic temperature control is not possible. This method of heating is employed in salt bath furnace and electrode boiler for heating water.

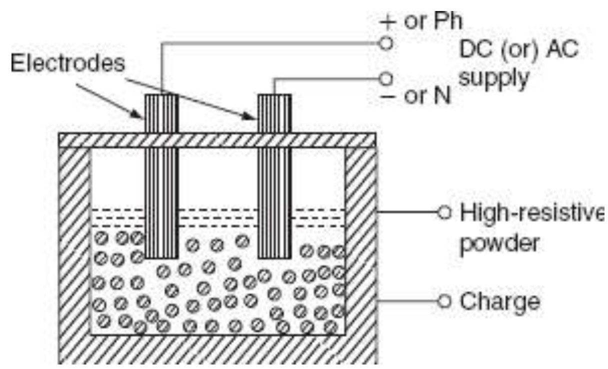


Fig. 3.1(a) Direct resistance heating

***(i)* Salt bath furnace**

This type of furnace consists of a bath and containing some salt such as molten sodium chloride and two electrodes immersed in it. Such salt have a fusing point of about 1,000–1,500°C depending upon the type of salt used. When the current is passed between the electrodes immersed in the salt, heat is developed and the temperature of the salt bath may be increased. Such an arrangement is known as a salt bath furnace. In this bath, the material or job to be heated is dipped. The electrodes should be carefully immersed in the bath in such a way that the current flows through the salt and not through the job being heated. As DC will cause electrolysis so, low-voltage AC up to 20 V and current up to 3,000 A is adopted depending upon the type of furnaces. The resistance of the salt decreases with increase in the temperature of the salt, therefore, in order to maintain the constant power input, the voltage can be controlled by providing a tap changing transformer. The control of power input is also affected by varying the depth of immersion and the distance between the electrodes.

***(ii)* Electrode boiler**

It is used to heat the water by immersing three electrodes in a tank as shown in Fig. 3.2. This is based on the principle that when the electric current passed through the water produces heat due to the resistance offered by it. For DC supply, it results in a lot of evolution of H2 at negative electrode and O2 at positive electrode. Whereas AC supply hardly results in any evolution of gas,

but heats the water. Electrode boiler tank is earthed solidly and connected to the ground. A circuit breaker is usually incorporated to make and break all poles simultaneously and an over current protective device is provided in each conductor feeding an electrode.

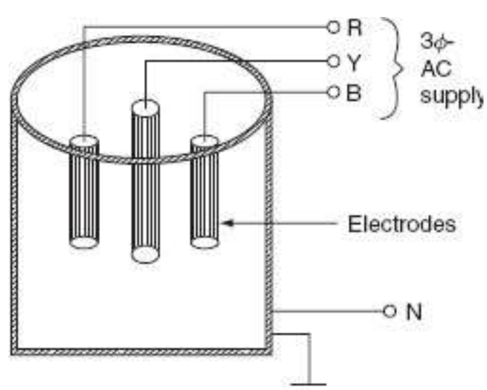


Fig. 3.2 Electrode boiler

Indirect resistance heating

In the indirect resistance heating method, high current is passed through the heating element. In case of industrial heating, some times the heating element is placed in a cylinder which is surrounded by the charge placed in a jacket is known as heating chamber is shown in Fig. 3.3. The heat is proportional to power loss produced in the heating element is delivered to the charge by one or more of the modes of the transfer of heat viz. conduction, convection, and radiation. This arrangement provides uniform temperature and automatic temperature control. Generally, this method of heating is used in immersion water heaters, room heaters, and the resistance ovens used in domestic and commercial cooling and salt bath furnace.

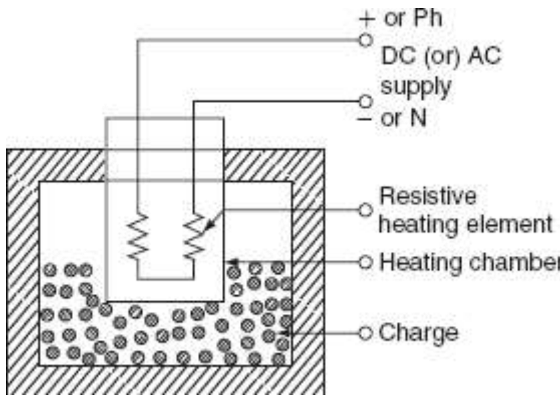


Fig. 3.3 Indirect resistance heating

Resistance ovens

According to the operating temperatures, the resistance furnaces may be classified into various types. Low-temperature heating chamber with the provision for ventilation is called as oven. For drying varnish coating, the hardening of synthetic materials, and commercial and domestic heating, etc., the resistance ovens are employed. The operating temperature of medium temperature furnaces is between 300°C and 1,050°C. These are employed for the melting of nonferrous metals, stove (annealing), etc. Furnaces operating at temperature between 1,050°C and 1,350°C are known as high-temperature furnaces. These furnaces are employed for hardening applications. A simple resistance oven is shown in Fig. 3.4.

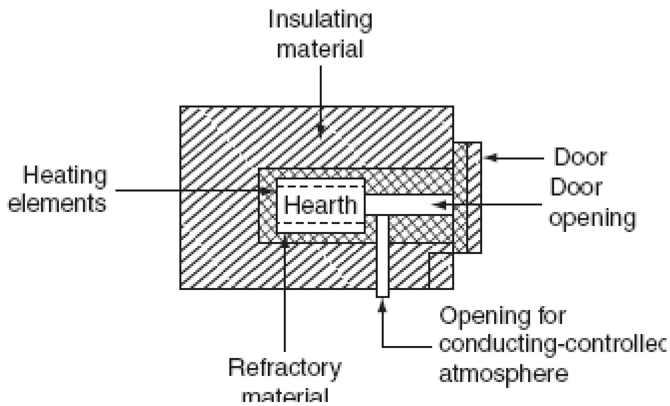


Fig. 3.4 Resistance oven

Resistance oven consists of a heating chamber in which heating elements are placed as shown in the Fig. 3.4. The inner surface of the heating chamber is made to suit the character of the charge and the type of furnace or oven. The type of insulation used for heating chamber is determined by the maximum temperature of the heating chamber.

Efficiency and losses of resistance ovens

The heat produced in the heating elements, not only raises the temperature of the charge to desired value, but also used to overcome the losses occurring due to:

1. Heat used in raising the temperature of oven (or) furnace.
2. Heat used in raising the temperature of containers (or) carriers,
3. Heat conducted through the walls.
4. Heat loss due to the opening of oven door.

1. The heat required to raise the temperature of oven to desired value can be calculated by knowing the mass of refractory material (M), its specific heat (S), and raise of temperature (ΔT) and is given by:

Hoven = $MS\Delta T$J.

In case the oven is continuously used, this loss becomes negligible.

2. Heat used in rising the temperature of containers (or) carriers can be calculated exactly the same way as for oven (or) furnaces.

3. Heat loss conducted through the walls of the container can be calculated by knowing the area of the container (A) in square meters, the thickness of the walls (t) in meters, the inside and out side

temperatures of the container $T1$ and $T2$ in °C, respectively, and the thermal conductivity of the container walls 'k' in m3/°C/hr and is given by: Heat loss by conduction Actually, there is no specific formula for the determination of loss occurring due to the opening of door for the periodic inspection of the charge so that this loss may be approximately taken as 0.58–1.15 MJ/m2 of the door area, if the door is opened for a period of 20–30 sec.

The *efficiency of the oven* is defined as the ratio of the heat required to raise the temperature of he charge to the desired value to the heat required to raise the charge and losses.

$$\text{The efficiency of the oven:} = \frac{\text{the heat required to raise the temperature of the charge}}{\text{the heat required to raise the temperature of the charge} + \text{total losses}}$$

The efficiency of the resistance oven lies in between 60% and 80%.

Infrared or radiant heating

In this method of heating, the heat transfer takes place from the source to the body to be heated through radiation, for low and medium temperature applications. Whereas in resistance ovens, the heat transfers to the charge partly by convection and partly by radiation.

In the radiant heating, the heating element consists of tungsten filament lamps together with reflector and to direct all the heat on the charge. Tungsten filament lamps are operating at 2,300°C instead of 3,000°C to give greater portion of infrared radiation and a longer life. The radiant heating is mainly used for drying enamel or painted surfaces. The high concentration of the radiant energy enables the heat to penetrate the coating of paint or enamel to a depth sufficient to dry it out without wasting energy in the body of the work piece. The main advantage of the radiant heating is that the heat absorption remains approximately constant whatever the charge temperature, whereas with the ordinary oven the heat absorption falls off very considerably as the temperature of the charge raises. The lamp ratings used are usually between 250 and 1,000 W and are operating at voltage of 115 V in order to ensure a robust filament.

TEMPERATURE CONTROL OF RESISTANCE HEATING

To control the temperature of a resistance heating at certain selected points in a furnace or oven, as per certain limits, such control may be required in order to hold the temperature constant or to vary it in accordance with a pre-determined cycle and it can be carried out by hand or automatically. In resistance furnaces, the heat developed depends upon $I^2 R t$ (or) t. Therefore, the temperature of the furnaces can be controlled either by:

1. Changing the resistance of elements.
2. Changing the applied voltage to the elements (or) current passing through the elements.
3. Changing the ratio of the on-and-off times of the supply.

Voltage across the furnace can be controlled by changing the transformer tapings. Auto transformer or induction regulator can also be used for variable voltage supply. In addition to the above, voltage can be controlled by using a series resistance so that some voltage dropped across this series resistor. But this method is not economical as the power is continuously wasted in controlling the resistance. Hence, this method is limited to small furnaces. An on-off switch can be employed to control the temperature. The time for which the oven is connected to the supply and the time for which it is disconnected from supply will determine the temperature. Temperature can be controlled by providing various combinations of groups of resistances used in the furnace and is given as follows:

(i) **Variable number of elements**

If 'R' be the resistance of one element and 'n' be the number of elements are connected in parallel, so that the equivalent resistance is R/n. Heat developed in the furnace is: i.e., if the number of elements connected in parallel increases, the heat developed in the furnace also increased. This method does not provide uniform heating unless elements not in use are well distributed.

(ii) **Series parallel (or) star delta arrangement of elements**

If the available supply is single phase, the heating elements can be connected in series for the low temperatures and connected in parallel for the high temperature by means of a series— parallel switch. In case, if the available supply is three phase, the heating elements can be connected in star for the low temperature and in delta for the high temperatures by using star— delta switch.

INDUCTION HEATING

The induction heating process makes use of the currents induced by the electromagnetic action in the material to be heated. To develop sufficient amount of heat, the resistance of the material

$$\left(\because \text{power drawn} = \frac{V^2}{R}\right)$$

must be low , which is possible only with the metals, and the voltage must be higher, which can be obtained by employing higher flux and higher frequency. Therefore, the magnetic materials can be heated than non-magnetic materials due to their high permeability. In order to analyze the factors affecting induction heating, let us consider a circular disc to be heated carrying a current of '*I*' amps at a frequency '*f*' Hz. As shown in Fig. 3.9.

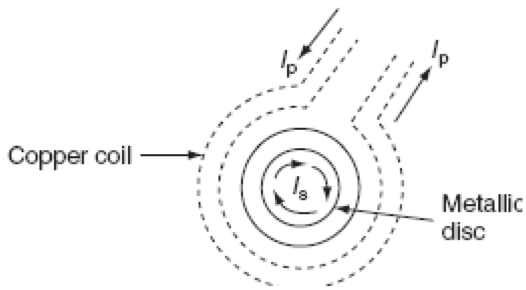


Fig. 3.9 Induction heating

Heat developed in the disc is depending upon the following factors.

- Primary coil current.
- The number of the turns of the coil.
- Supply frequency.
- The magnetic coupling between the coil and the disc.
- The high electrical resistivity of the disc.

If the charge to be heated is non-magnetic, then the heat developed is due to eddy current loss, whereas if it is magnetic material, there will be hysteresis loss in addition to eddy current loss. Both hysteresis and eddy current loss are depended upon frequency, but at high-frequency hysteresis, loss is very small as compared to eddy currents. The depth of penetration of induced currents into the disc is given by:

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu f}} \text{ cm}$$

i.e., $d \; \mu \frac{1}{\sqrt{f}}$,

where ρ is the specific resistance in Ω-cm, f is the frequency in Hz, and μ is the permeability of the charge. There are basically two types of induction furnaces and they are:

1. Core type or low-frequency induction furnace.
2. Coreless type or high-frequency induction furnace.

Core type furnace

The operating principle of the core type furnace is the electromagnetic induction. This furnace is operating just like a transformer. It is further classified as:

1. Direct core type.
2. Vertical core type.
3. Indirect core type.

(i) Direct core type induction furnace

The core type furnace is essentially a transformer in which the charge to be heated forms singleturn secondary circuit and is magnetically coupled to the primary by an iron core as shown in Fig. 3.10.

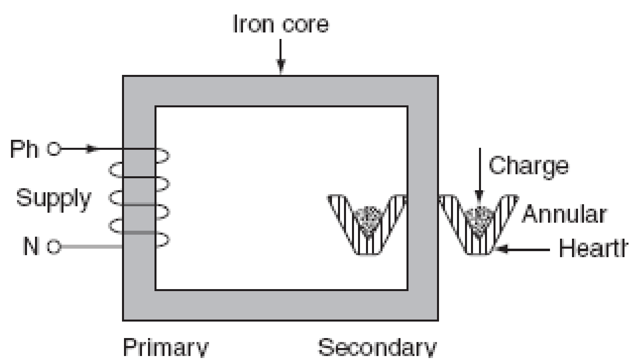


Fig. 3.10 Direct core type furnace

The furnace consists of a circular hearth in the form of a trough, which contains the charge to be melted in the form of an annular ring. This type of furnace has the following characteristics: o This metal ring is quite large in diameter and is magnetically interlinked with primary winding, which is energized from an AC source. The magnetic coupling between primary and secondary is very weak; it results in high leakage reactance and low pf. To overcome the increase in leakage reactance, the furnace should be operated at low frequency of the order of 10 Hz.

- When there is no molten metal in the hearth, the secondary becomes open circuited thereby cutting of secondary current. Hence, to start the furnace, the molten metal has to be taken in the hearth to keep the secondary as short circuit.
- Furnace is operating at normal frequency, which causes turbulence and severe stirring action in the molten metal to avoid this difficulty, it is also necessary to operate the furnace at low frequency.
- In order to obtain low-frequency supply, separate motor-generator set (or) frequency changer is to be provided, which involves the extra cost.
- The crucible used for the charge is of odd shape and inconvenient from the metallurgical viewpoint.
- If current density exceeds about 500 A/cm2, it will produce high-electromagnetic forces in the molten metal and hence adjacent molecules repel each other, as they are in the same direction. The repulsion may cause the interruption of secondary circuit (formation of bubbles and voids); this effect is known as *pinch effect.*

The pinch effect is also dependent on frequency; at low frequency, this effect is negligible, and so it is necessary to operate the furnace at low frequency.

(ii) Vertical core type induction furnace

It is an improvement over the direct core type furnace, to overcome some of the disadvantages mentioned above. This type of furnace consists of a vertical core instead of horizontal core as shown in Fig. 3.11. It is also known as *Ajax–Wyatt induction furnace.*

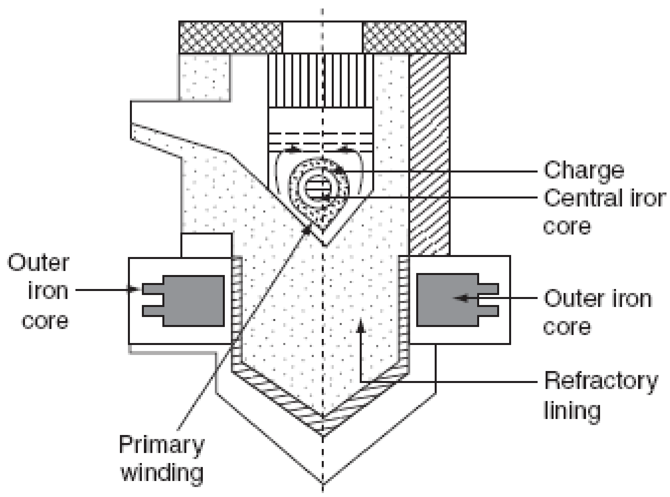


Fig. 3.11 Vertical core type furnace (Ajax–Wyatt induction furnace)

Vertical core avoids the pinch effect due to the weight of the charge in the main body of the crucible. The leakage reactance is comparatively low and the power factor is high as the magnetic coupling is high compared to direct core type. There is a tendency of molten metal to accumulate at the bottom that keeps the secondary completed for a vertical core type furnace as it consists of narrow V-shaped channel. The inside layer of furnace is lined depending upon the type charge used. Clay lining is used for yellow brass and an alloy of magnesia and alumina is used for red brass. The top surface of the furnace is covered with insulating material, which can be removed for admitting the charge. Necessary hydraulic arrangements are usually made for tilting the furnace to take out the molten metal. Even though it is having complicated construction, it is operating at power factor of the order of 0.8–0.83. This furnace is normally used for the melting and refining of brass and non-ferrous metals.

Advantages

- Accurate temperature control and reduced metal losses.
- Absence of crucibles.
- Consistent performance and simple control.
- It is operating at high power factor.
- Pinch effect can be avoided.

(iii) Indirect core type furnace

This type of furnace is used for providing heat treatment to metal. A simple induction furnace with the absence of core is shown in Fig. 3.12.

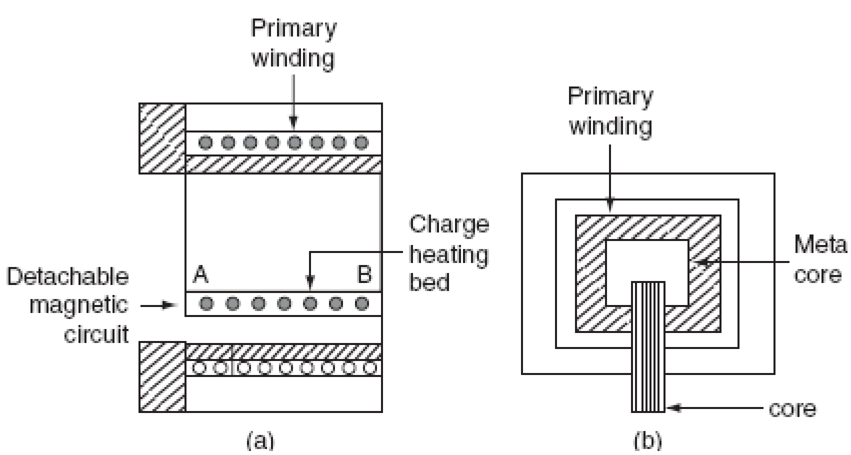


Fig. 3.12 Indirect core type furnace

The secondary winding itself forms the walls of the container or furnace and an iron core links both primary and secondary windings. The heat produced in the secondary winding is transmitted to the charge by radiation. An oven of this type is in direct competition with ordinary resistance oven. It consists of a magnetic circuit AB is made up of a special alloy and is kept inside the chamber of the furnace. This magnetic circuit loses its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature. When the oven reaches to critical temperature, the reluctance of the magnetic circuit increases many times and the inductive effect decreases thereby cutting off the supply heat. Thus, the temperature of the furnace can be effectively controlled. The magnetic circuit 'AB' is detachable type that can be replaced by the other magnetic circuits having critical temperatures ranging between 400°C and 1,000°C. The furnace operates at a pf of around 0.8. The main advantage of such furnace is wide variation of temperature control is possible.

Coreless type induction furnace It is a simple furnace with the absence core is shown in Fig.

3.13. In this furnace, heat developed in the charge due to eddy currents flowing through .

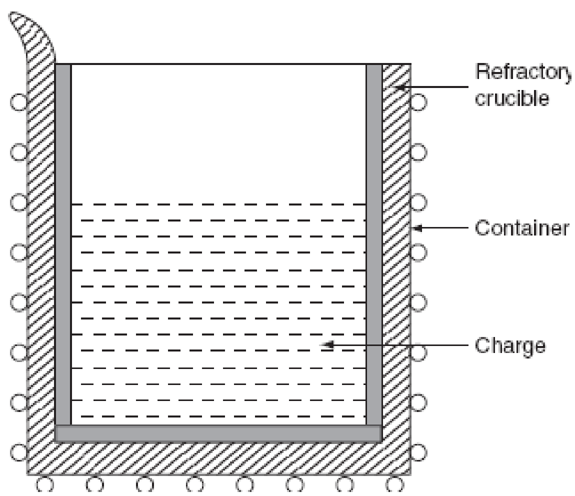


Fig. 3.13 Coreless induction furnace

The furnace consists of a refractory or ceramic crucible cylindrical in shape enclosed within a coil that forms primary of the transformer. The furnace also contains a conducting or nonconducting container that acts as secondary. If the container is made up of conducting material, charge can be conducting or nonconducting; whereas, if the container is made up of non-conducting material, charge taken should have conducting properties. When primary coils are excited by an alternating source, the flux set up by these coils induce the eddy currents in the charge. The direction of the resultant eddy current is in a direction opposite to the current in the primary coil. These currents heat the charge to melting point and they also set up electromagnetic forces that produce a stirring action to the charge. ∴ The eddy currents developed in any magnetic circuit are given as:

*W*e ∝ *B*m

2*f*2, where *B*m is the maximum flux density (tesla), *f* is the frequency in (Hz), and *W*e is the eddy current loss (watts). In coreless furnace, the flux density will be low as there is no core. Hence, the primary supply should have high frequency for compensating the low flux density. If it is operating at high frequency, due to the skin effect, it results copper loss, thereby increasing the temperature of the primary winding.

This necessitates in artificial cooling.

The coil, therefore, is made of hollow copper tube through which cold water is circulated. Minimum stray magnetic field is maintained when designing coreless furnace, otherwise there will be considerable eddy current loss. The selection of a suitable frequency of the primary current can be given by penetration formula. According to this:

$$t = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu f}},$$

where '*t*' is the thickness up to which current in the metal has penetrated, '*ρ*' is the resistivity in Ω-cm,'*μ*' is the permeability of the material, and '*f*' is the frequency in Hz. For the efficient operation, the ratio of the diameter of the charge (*d*) to the depth of the penetration of currents (*t*) should be more than '6', therefore let us take: Substitute above in Equation (Following are the advantages of coreless furnace over the other furnaces:

- Ease of control.
- Oxidation is reduced, as the time taken to reach the melting temperature is less.
- The eddy currents in the charge itself results in automatic stirring.
- The cost is less for the erection and operation.
- It can be used for heating and melting.
- Any shape of crucible can be used.
- It is suitable for intermittent operation.

DIELECTRIC HEATING

When non-metallic materials i.e., insulators such as wood, plastics, and china glass are subjected to high-voltage alternating electric field, the atoms get stresses, and due to interatomic friction caused by the repeated deformation and the rotation of atomic structure (polarization), heat is produced. This is known as dielectric loss. This dielectric loss in insulators corresponds to hysteresis loss in ferro-magnetic materials. This loss is due to the reversal of magnetism or magneto molecular friction. These losses developed in a material that has to be heated. An atom of any material is neutral, since the central positive charge is equals to the negative charge. So that, the centers of positive and negative charges coincide as long as there is no external field is applied, as shown in Fig.3.14 (a). When this atom is subjected to the influence of the electric field, the positive charge of the nucleus is acted upon by some force in the direction of negative charges in the opposite direction. Therefore, the effective centers of both positive and negative charges no longer coincident as shown in Fig. 3.14 (b). The electric charge of an atom equivalent to Fig.3.14(b) is shown in Fig. 3.14(c).

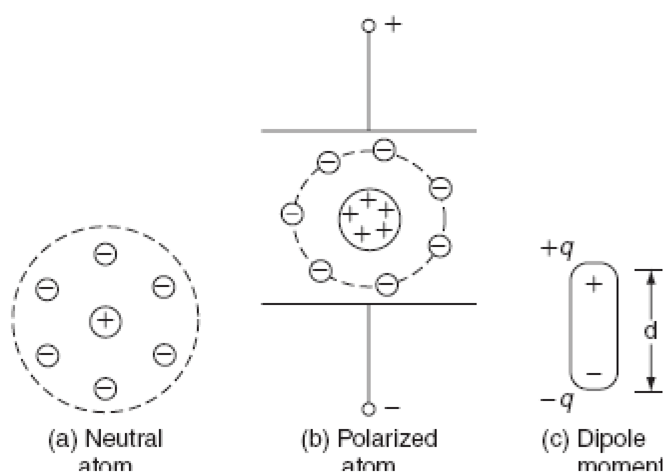


Fig.3.14 Polarization

This gives raise to an electric dipole moment equal to $P = q\,d$, where d is the distance between the two centers and q is the charge on the nucleus. Now, the atom is said to be polarized atom. If we apply alternating voltage across the capacitor plate, we will get alternating electric field. Electric dipoles will also try to change their orientation according to the direction of the impressed electric field. In doing so, some energy will be wasted as inter-atomic friction, which is called dielectric loss. As there is no perfect conductor, so there is no perfect insulator. All the dielectric materials can be represented by a parallel combination of a leakage resistor '*R*' and a capacitor '*C*' as shown in Fig. 3.15 (a) and (b).

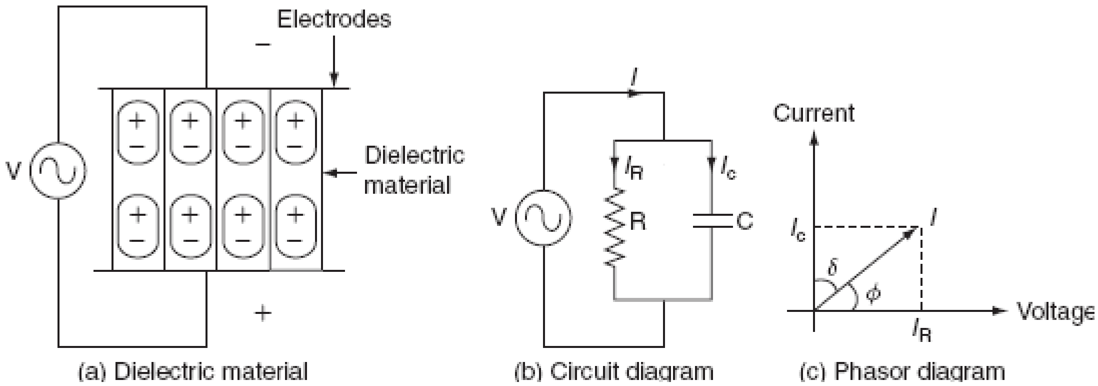


Fig.3.15 Dielectric heating

If an AC voltage is applied across a piece of insulator, an electric current flows; total current '*I*' supposed to be made up of two components *I*C and *IR,* where *I*C is the capacitive current leading the applied voltage by 90° and *I*R is in phase with applied voltage as shown in Fig. 3.15(c). where '*V*' is the applied voltage in volts, '*f*' is the supply frequency in Hz, *ε*0 is the absolute permittivity of the medium = 8.854 × 10-12 F/m,

*ε*r is the relative permittivity of the medium = 1

for free space, *A* is the area of the plate or electrode (m2), *d* is the thickness of the dielectric medium, and *δ* is the loss angle in radian. From Equation (3.14): Normally frequency used for dielectric heating is in the range of 1–40 MHz. The use of high voltage is also limited due to the breakdown voltage of thin dielectric that is to be heated, under normal conditions; the voltage gradient used is limited to 18 kV/cm.

The advantages of the dielectric heating

- The heating of the non-conducting materials is very rapid.
- The uniform heating of material is possible.
- Heat is produced in the whole mass of the material.

The applications of the dielectric heating

- The drying of paper, wood, etc.

- The gluing of wood.
- The heat-sealing of plastic sheets.
- The heating for the general processing such as coffee roasting and chocolate industry.
- The heating for the dehydration such as milk, cream, and vegetables.
- The preparation of thermoplastic resins.
- The heating of bones and tissues.
- Diathermy, i.e., the heat treatment for certain body pains and diseases, etc.
- The sterilization of absorbent cotton, bandages, etc.
- The processing of rubber, synthetic materials, chemicals, etc

Electric Welding

INTRODUCTION

Welding is the process of joining two pieces of metal or non-metal together by heating them to their melting point. Filler metal may or may not be used to join two pieces. The physical and mechanical properties of a material to be welded such as melting temperature, density, thermal conductivity, and tensile strength take an important role in welding. Depending upon how the heat applied is created; we get different types of welding such as thermal welding, gas welding, and electric welding. Here in this chapter, we will discuss only about the electric welding and some introduction to other modern welding techniques. Welding is nowadays extensively used in
automobile industry, pipe-line fabrication in thermal power plants, machine repair work, machine frames, etc.

ADVANTAGES AND DISADVANTAGES OF WELDING

Some of the advantages of welding are:

- Welding is the most economical method to permanently join two metal parts.
- It provides design flexibility.
- Welding equipment is not so costly.
- It joins all the commercial metals.
- Both similar and dissimilar metals can be joined by welding.
- Portable welding equipment are available.
- Some of the disadvantages of welding are:
- Welding gives out harmful radiations and fumes.
- Welding needs internal inspection.
- If welding is not done carefully, it may result in the distortion of workpiece.
- Skilled welding is necessary to produce good welding.

ELECTRIC WELDING

It is defined as the process of joining two metal pieces, in which the electrical energy is used to generate heat at the point of welding in order to melt the joint.

The classification

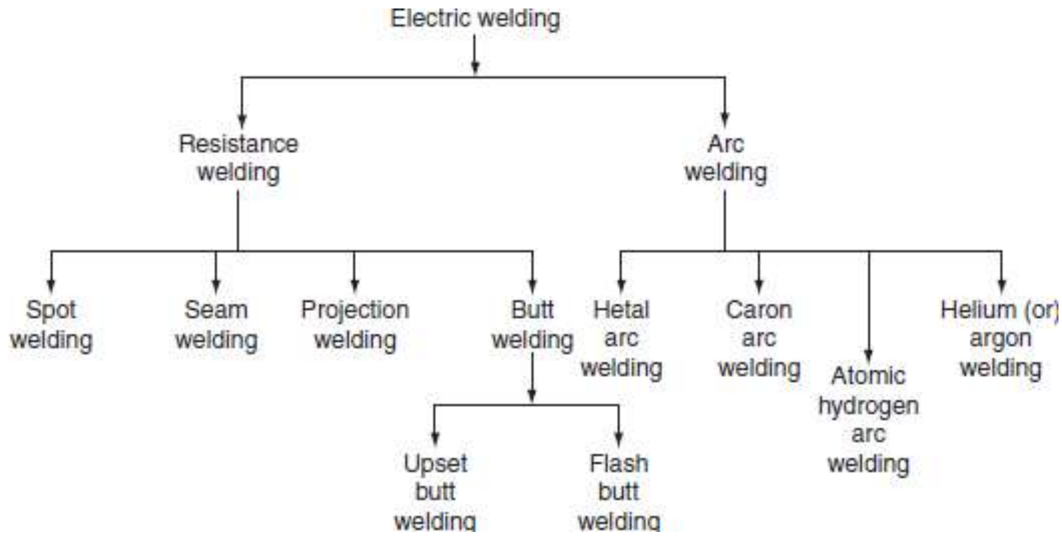


Fig. 3.16. Classification of electric welding

The selection of proper welding process depends on the following factors. o The type of metal to be joined.

- The techniques of welding adopted.
- The cost of equipment used.
- The nature of products to be fabricated.

RESISTANCE WELDING

Resistance welding is the process of joining two metals together by the heat produced due to the resistance offered to the flow of electric current at the junctions of two metals. The heat produced by the resistance to the flow of current is given by:

$$H = I^2Rt,$$

where *I* is the current through the electrodes, *R* is the contact resistance of the interface, and *t* is the time for which current flows. Here, the total resistance offered to the flow of current is made up of:

1. The resistance of current path in the work.
2. The resistance between the contact surfaces of the parts being welded.
3. The resistance between electrodes and the surface of parts being welded.

In this process of welding, the heat developed at the contact area between the pieces to be welded reduces the metal to plastic state or liquid state, then the pieces are pressed under high mechanical pressure to complete the weld. The electrical voltage input to the welding varies in between 4 and 12 V depending upon area, thickness, composition, etc. and usually power ranges from about 60 to 180 W for each sq. mm of area. Any desired combination of voltage and current can be obtained by means of a suitable transformer in AC; hence, AC is found to be most suitable for the resistance welding. The magnitude of current is controlled by changing the primary voltage of the welding transformer, which can be done by using an auto-transformer or a tap-changing transformer. Automatic arrangements are provided to switch off the supply after a pre-determined time from applying the pressure, why because the duration of the current flow through the work is very important in the resistance welding. The electrical circuit diagram for the resistance welding is shown in Fig. 5.2. This method of welding consists of a tap-changing transformer, a clamping device for holding the metal pieces, and some sort of mechanical arrangement for forcing the pieces to form a complete weld.

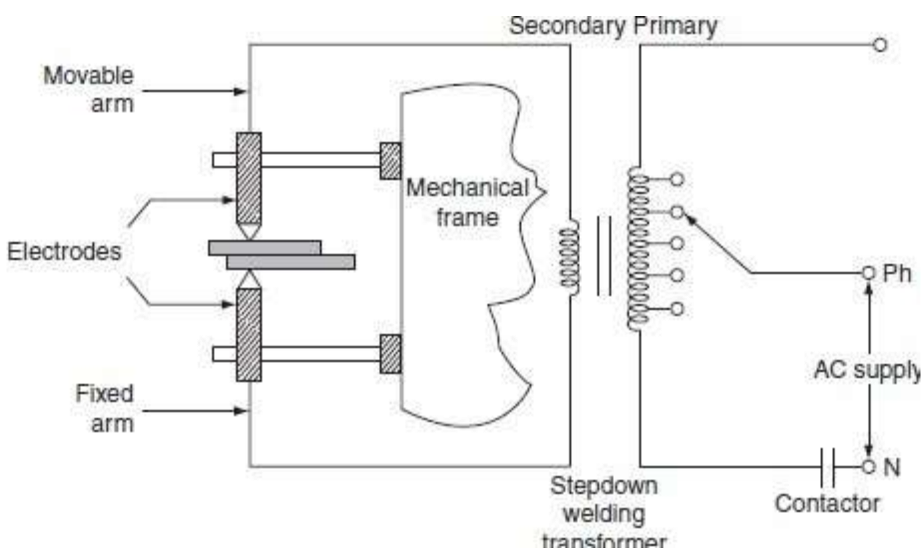


Fig. 3.17. Electric circuit for resistance welding

Advantages

- Welding process is rapid and simple.
- Localized heating is possible, if required.
- No need of using filler metal.

- Both similar and dissimilar metals can be welded.
- Comparatively lesser skill is required.
- Maintenance cost is less.
- It can be employed for mass production.
- *However, the resistance welding has got some drawbacks and they are:*
- Initial cost is very high.
- High maintenance cost.
- The workpiece with heavier thickness cannot be welded, since it requires high input current.

Applications

- It is used by many industries manufacturing products made up of thinner gauge metals.
- It is used for the manufacturing of tubes and smaller structural sections.

Types of resistance welding

Depending upon the method of weld obtained and the type of electrodes used, the resistance welding is classified as:

1. Spot welding.
2. Seam welding.
3. Projection welding.
4. Butt welding.

(i) Spot welding

Spot welding means the joining of two metal sheets and fusing them together between copper electrode tips at suitably spaced intervals by means of heavy electric current passed through the electrodes as shown in Fig. 3.18

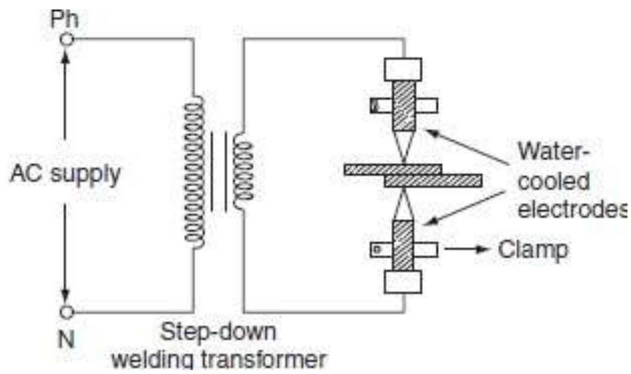


Fig. 3.18. Spot welding

This type of joint formed by the spot welding provides mechanical strength and not air or water tight, for such welding it is necessary to localize the welding current and to apply sufficient pressure on the sheet to be welded. The electrodes are made up of copper or copper alloy and are water cooled. The welding current varies widely depending upon the thickness and composition of the plates. It varies from 1,000 to 10,000 A, and voltage between the electrodes is usually less than 2 V. The period of the flow of current varies widely depending upon the thickness of sheets to be joined. A step-down transformer is used to reduce a high-voltage and low-current supply to low-voltage and high-current supply required. Since the heat developed being proportional to the product of welding time and square of the current. Good weld can be obtained by low currents for longer duration and high currents for shorter duration; longer welding time usually produces stronger weld but it involves high energy expenditure, electrode maintenance, and lot of distortion of workpiece. When voltage applied across the electrode, the flow of current will generate heat at the three junctions, i.e., heat developed, between the two electrode tips and workpiece, between the two workpieces to be joined as shown in Fig. 3.18.

The generation of heat at junctions 1 and 3 will effect electrode sticking and melt through holes, the prevention of electrode striking is achieved by:

1. Using water-cooled electrodes shown in Fig. 3.19. By avoiding the heating of junctions 1 and 3 electrodes in which cold water circulated continuously as shown in Fig. 3.19.

2. The material used for electrode should have high electrical and thermal conductivity. Spot welding is widely used for automatic welding process, for joining automobile parts, joining and fabricating sheet metal structure, etc.

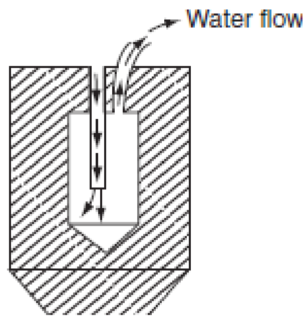


Fig.3.19 Water cooled electrode

(ii) Seam welding

Seam welding is nothing but the series of continuous spot welding. If number spots obtained by spot welding are placed very closely that they can overlap, it gives rise to seam welding. In this welding, continuous spot welds can be formed by using wheel type or roller electrodes instead of tipped electrodes as shown in Fig. 3.20.

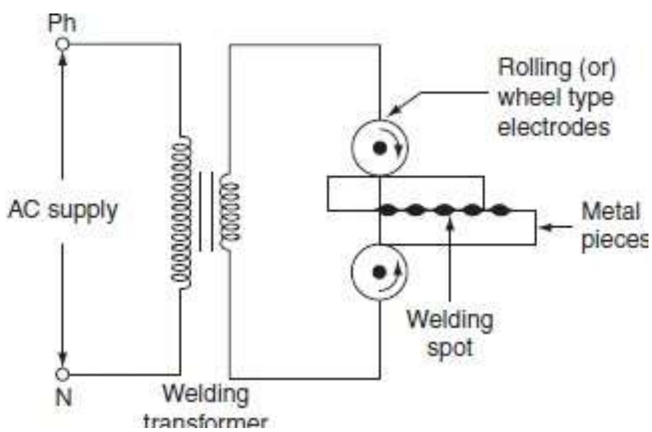


Fig. 3.20 Seam welding

Seam welding is obtained by keeping the job under electrodes. When these wheel type electrodes travel over the metal pieces which are under pressure, the current passing between them heats the two metal pieces to the plastic state and results into continuous spot welds. In this welding, the contact area of electrodes should be small, which will localize the current pressure to the welding point. After forming weld at one point, the weld so obtained can be cooled by splashing water over the job by using cooling jets. In general, it is not satisfactory to make a continuous weld, for which the flow of continuous current build up high heat that causes burning and wrapping of the metal piece. To avoid this difficulty, an interrupter is provided on the circuit which turns on supply for a period sufficient to heat the welding point. The series of weld spots depends upon the number of welding current pulses. The two forms of welding currents are shown in Fig. 3.21(a) and (b).

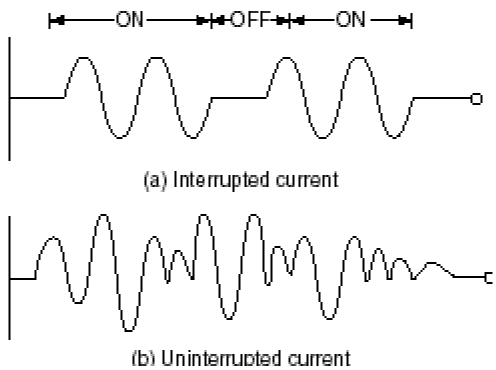


Fig. 3.21 Welding current

Welding cannot be made satisfactorily by using uninterrupted or un-modulated current, which builds up high heat as the welding progress; this will over heat the workpiece and cause distortion. Seam welding is very important, as it provides leak proof joints. It is usually employed in welding of pressure tanks, transformers, condensers, evaporators, air craft tanks, refrigerators, varnish containers, etc.

(iii) Projection welding

It is a modified form of the spot welding. In the projection welding, both current and pressure are localized to the welding points as in the spot welding. But the only difference in the projection welding is the high mechanical pressure applied on the metal pieces to be welded, after the formation of weld. The electrodes used for such welding are flat metal plates known as *platens*. The two pieces of base metal to be weld are held together in between the two platens, one is movable and the other is fixed, as shown in Fig. 3.22

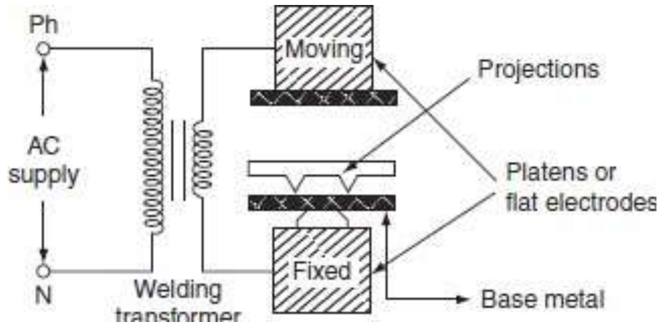


Fig. 3.22. Projection welding

One of the two pieces of metal is run through a machine that makes the bumps or projections of required shape and size in the metal. As current flows through the two metal parts to be welded, which heat up and melt. These weld points soon reach the plastic state, and the projection touches the metal then force applied by the two flat electrodes forms the complete weld. The projection welding needs no protective atmosphere as in the spot welding to produce successful results. This welding process reduces the amount of current and pressure in order to join two metal surfaces, so that there is less chance of distortion of the surrounding areas of the weld zone. Due to this reason, it has been incorporated into many manufacturing process. The projection welding has the following advantages over the spot welding.

- Simplicity in welding process.
- It is easy to weld some of the parts where the spot welding is not possible.
- It is possible to join several welding points.
- Welds are located automatically by the position of projection.

As the electrodes used in the projection welding are flat type, the cZontact area over the projection is sufficient. This type of welding is usually employed on punched, formed, or stamped parts where the projection automatically exists. The projection welding is particularly employed for mass production work, i.e., welding of refrigerators, condensers, crossed wire welding, refrigerator racks, grills, etc.

(iv) **Butt welding**

Butt welding is similar to the spot welding; however, the only difference is, in butt welding, instead of electrodes the metal parts that are to be joined or butted together are connected to the supply. The three basic types of the butt welding process are:

1. Upset butt welding.
2. Flash butt welding.
3. Percussion butt welding.

(a) Upset butt welding

In upset welding, the two metal parts to be welded are joined end to end and are connected across the secondary of a welding transformer as shown in Fig. 3.23

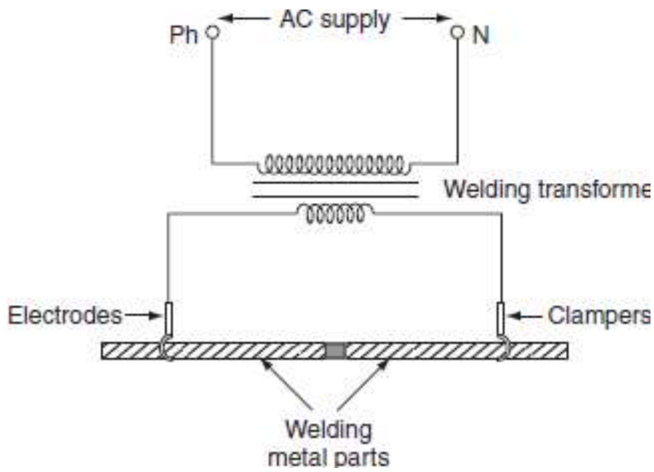


Fig. 3.23 Upset butt welding

Due to the contact resistance of the metals to be welded, heating effect is generated in this welding. When current is made to flow through the two electrodes, heat will develop due to the contact resistance of the two pieces and then melts. By applying high mechanical pressure either manually or by toggle mechanism, the two metal pieces are pressed. When jaw-type electrodes are used that introduce the high currents without treating any hot spot on the job. This type of welding is usually employed for welding of rods, pipes, and wires and for joining metal parts end to end.

(b) Flash butt welding

Flash butt welding is a combination of resistance, arc, and pressure welding. This method of welding is mainly used in the production welding. A simple flash butt welding arrangement is shown in Fig. 3.24

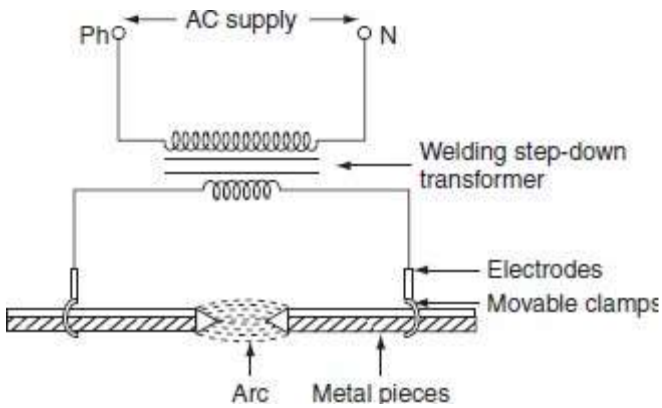


Fig. 3.24 Flash butt welding

In this method of welding, the two pieces to be welded are brought very nearer to each other under light mechanical pressure. These two pieces are placed in a conducting movable clamps. When high current is passed through the two metal pieces and they are separated by some distance, then arc established between them. This arc or flashing is allowed till the ends of the workpieces reach melting temperature, the supply will be switched off and the pieces are rapidly brought together under light pressure. As the pieces are moved together, the fused metal and slag
come out of the joint making a good solid joint. Following are the advantages of the flash butt welding over the upset welding.

- Less requirement of power.
- When the surfaces being joined, it requires only less attention.
- Weld obtained is so clean and pure; due to the foreign metals appearing on the surfaces will burn due to flash or arc.

(c) Percussion welding

It is a form of the flash butt welding, where high current of short duration is employed using stored energy principle. This is a self-timing spot welding method. Percussion welding arrangement consists of one fixed holder and the other one is movable. The pieces to be welded are held apart, with the help of two holders, when the movable clamp is released, it moves rapidly carrying the piece to be welded. There is a sudden discharge of electrical energy, which establishes an arc between the two surfaces and heating them to their melting temperature, when the two pieces are separated by a distance of 1.5 mm apart. As the pieces come in contact with each other under heavy pressure, the arc is extinguished due to the percussion blow of the two parts and the force between them affects the weld. The percussion welding can be obtained in two methods; one is capacitor energy storage system and the other is magnetic energy storage system. The capacitor discharge circuit for percussion welding is shown in Fig 3.25.

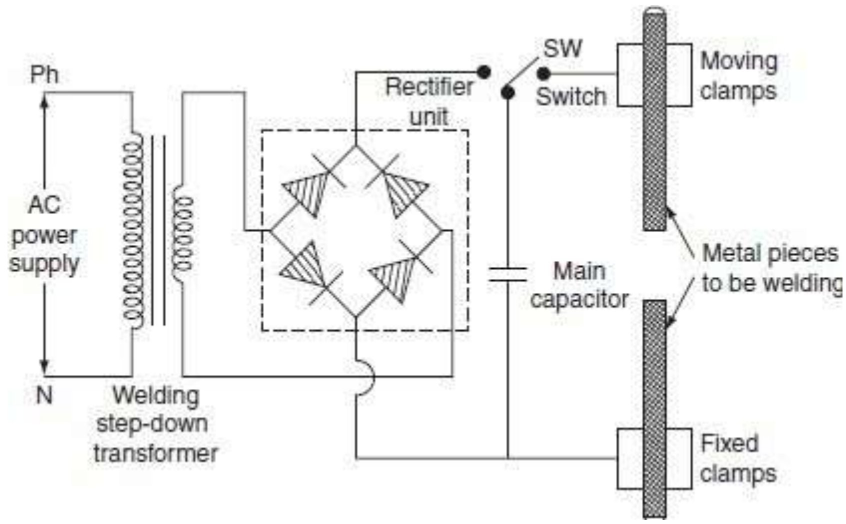


Fig. 3.25 Capacitor discharge circuit for percussion welding

The capacitor 'C' is charged to about 3,000 V from a controlled rectifier. The capacitor is connected to the primary of welding transformer through the switch and will discharge. This discharge will produce high transient current in the secondary to join the two metal pieces. Percussion welding is difficult to obtain uniform flashing of the metal part areas of the cross section grater than 3 sq. cm. Advantage of this welding is so fast, extremely shallow of heating is obtained with a span of about 0.1 sec. It can be used for welding a large number of dissimilar metals.

Applications

- It is useful for welding satellite tips to tools, sliver contact tips to copper, cast iron to steel, etc.
- Commonly used for electrical contacts.
- The metals such as copper alloys, aluminum alloys, and nickel alloys are percussion welded.

ELECTRIC ARC WELDING

Electric arc welding is the process of joining two metallic pieces or melting of metal is obtained due to the heat developed by an arc struck between an electrode and the metal to be welded or between the two electrodes as shown in Fig. 3.26(a).

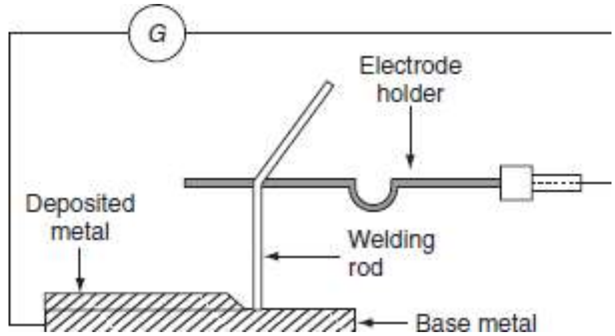


Fig.3.26 Arrangement of electric welding equipment

In this process, an electric arc is produced by bringing two conductors (electrode and metal piece) connected to a suitable source of electric current, momentarily in contact and then separated by a small gap, arc blows due to the ionization and give intense heat. The heat so developed is utilized to melt the part of workpiece and filler metal and thus forms the weld. In this method of welding, no mechanical pressure is employed; therefore, this type of welding is also known as *'non-pressure welding'*.

The length of the arc required for welding depends upon the following factors:

- The surface coating and the type of electrodes used.
- The position of welding.
- The amount of current used.

When the supply is given across the conductors separated by some distance apart, the air gap present between the two conductors gets ionized, as the arc welding is in progress, the ionization of the arc path and its surrounding area increases. This increase in ionization decreases the resistance of the path. Thus, current increases with the decrease in voltage of arc. This *VI* characteristic of an arc is shown in Fig. (b), it also known as *negative resistance characteristics of an arc*. Thus, it will be seen that this decrease in resistance with increase in current does not remain the arc steadily. This difficulty cab be avoided, with the supply, it should fall rapidly with the increase in the current so that any further increase in the current is restricted. For the arc welding, the temperature of the arc should be 3,500°C. At this temperature, mechanical pressure for melting is not required. Both AC and DC can be used in the arc welding. Usually 70–100 V on AC supply and 50–60 V on DC supply system is sufficient to struck the arc in the air gap between the electrodes. Once the arc is struck, 20–30 V is only required to maintain it. However, in certain cases, there is any danger of electric shock to the operator, low voltage should be used for the welding purpose. Thus, DC arc welding of low voltage is generally preferred. Electric arc welding is extensively used for the joining of metal parts, the repair of fractured casting, and the fillings by the deposition of new metal on base metal, etc.

Various types of electric arc welding are:

1. Carbon arc welding.
2. Metal arc welding.
3. Atomic hydrogen arc welding.
4. Inert gas metal arc welding.
5. Submerged arc welding.

Carbon arc welding

It is one of the processes of arc welding in which arc is struck between two carbon electrodes or the carbon electrode and the base metal. The simple arrangement of the carbon arc welding is shown in Fig. 3.27.

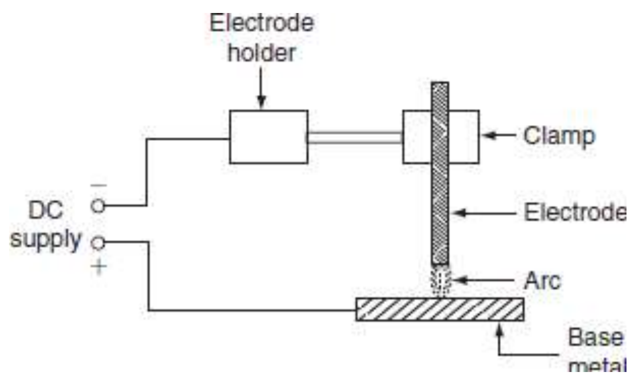


Fig. 3.27 Carbon arc welding

In this process of welding, the electrodes are placed in an electrode holder used as negative electrode and the base metal being welded as positive. Unless, the electrode is negative relative to the work, due to high temperature, there is a tendency of the particles of carbon will fuse and mix up with the base metal, which causes brittleness; DC is preferred for carbon arc welding since there is no fixed polarity maintained in case of AC. In the carbon arc welding, carbon or graphite rods are used as electrode. Due to longer life and low resistance, graphite electrodes are used, and thus capable of conducting more current. The arc produced between electrode and base metal; heat the metal to the melting temperature, on the negative electrode is 3,200°C and on the positive electrode is 3,900°C. This process of welding is normally employed where addition of filler metal is not required. The carbon arc is easy to maintain, and also the length of the arc can be easily varied. One major problem with carbon arc is its instability which can be overcome by using an inductor in the electrode of 2.5-cm diameter and with the current of about of 500–800 A employed to deposit large amount of filler metal on the base metal. Filler metal and flux may not be used depending upon the type of joint and material to be welded.

Advantages

- The heat developed during the welding can be easily controlled by adjusting the length of the arc.
- It is quite clean, simple, and less expensive when compared to other welding process.
- Easily adoptable for automation.
- Both the ferrous and the non-ferrous metals can be welded.

Disadvantages

- Input current required in this welding, for the work piece to rise its temperature to melting/welding temperature, is approximately double the metal arc welding.
- In case of the ferrous metal, there is a chance of disintegrating the carbon at high temperature and transfer to the weld, which causes harder weld deposit and brittlement.
- A separate filler rod has to be used if any filler metal is required.

Applications

- It can be employed for the welding of stainless steel with thinner gauges.
- Useful for the welding of thin high-grade nickel alloys and for galvanized sheets using copper silicon manganese alloy filler metal.

Metal arc welding In metal arc welding, the electrodes used must be of the same metal as that of the work-piece to be welded. The electrode itself forms the filler metal. An electric arc is stuck by bringing the electrode connected to a suitable source of electric current, momentarily in contract with the work pieces to be welded and withdrawn apart. The circuit diagram for the metal arc welding is shown in fig.3.28.

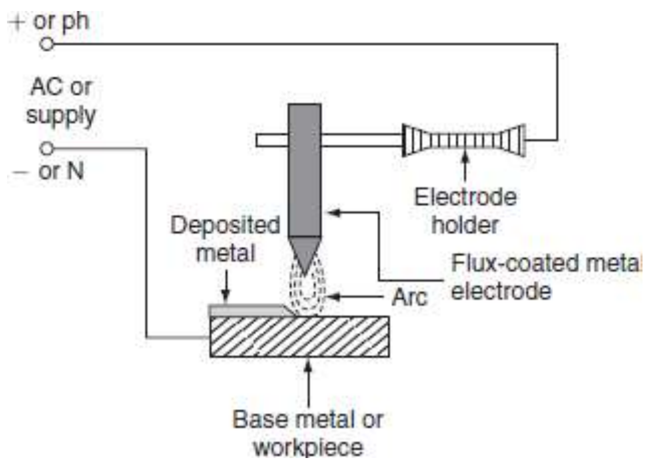


Fig. 3.28 Metal arc welding

The arc produced between the work piece and the electrode results high temperature of the order of about 2,400°C at negative metal electrode and 2,600°C at positive base metal or work piece. This high temperature of the arc melts the metal as well as the tip of the electrode, then the electrode melts and deposited over the surface of the workpiece, forms complete weld. Both AC and DC can be used for the metal arc welding. The voltage required for the DC metal arc welding is about 50–60 V and for the AC metal arc welding is about 80–90 V In order to maintain the voltage drop across the arc less than 13 V, the arc length should be kept as small as possible, otherwise the weld will be brittle. The current required for the welding varies from 10 to 500 A depending upon the type of work to be welded. The main disadvantage in the DC metal arc welding is the presence of arc blow, i.e., distortion of arc stream from the intended path due to the magnetic forces of the non-uniform magnetic field with AC arc blow is considerably reduced. For obtaining good weld, the flux-coated electrodes must be used, so the metal which is melted is covered with slag produces a non oxidizing gas or a molten slag to cover the weld, and also stabilizes the arc.

COMPARISON BETWEEN AC AND DC WELDING

1 Motor generator set or rectifier is required in case of the availability of AC supply.

Only transformer is required.

2 The cost of the equipment is high. The cost of the equipment is cheap.

3 Arc stability is more. Arc stability is less.

4 The heat produced is uniform. The heat produced is not uniform.

5 Both bare and coated electrodes can be used. Only coated electrodes should be used.

6 The operating power factor is high. The power factor is low. So, the capacitors are necessary to improve the power factor.

7 It is safer since no load voltage is low. It is dangerous since no load voltage is high.

8 The electric energy consumption is 5–10 kWh/kg of deposited metal. The electrical energy consumption is 3–4 kWh/kg of deposited metal

9 Arc blow occurs due to the presence of non-uniform magnetic field. Arc blow will not occur due to the uniform magnetic field.

10 The efficiency is low due to the rotating parts. The efficiency is high due to the absence of rotating parts.

UNIT-3

Electric Heating and Welding

Introduction

Heat plays a major role in everyday life. All heating requirements in domestic purposes such as cooking, room heater, immersion water heaters, and electric toasters and also in industrial purposes such as welding, melting of metals, tempering, hardening, and drying can be met easily by electric heating, over the other forms of conventional heating. Heat and electricity are interchangeable. Heat also can be produced by passing the current through material to be heated. This is called electric heating; there are various methods of heating a material but electric heating is considered far superior compared to the heat produced by coal, oil, and natural gas.

ADVANTAGES OF ELECTRIC HEATING

The various advantages of electric heating over other the types of heating are:

(xiii) **Economical**

Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.

(xiv) **Cleanliness**

Since dust and ash are completely eliminated in the electric heating, it keeps surroundings cleanly.

(xv) **Pollution free**

As there are no flue gases in the electric heating, atmosphere around is pollution free; no need of providing space for their exit.

(xvi) **Ease of control**

In this heating, temperature can be controlled and regulated accurately either manually or automatically.

(xvii) **Uniform heating**

With electric heating, the substance can be heated uniformly, throughout whether it may be conducting or non-conducting material.

(xviii) **High efficiency**

In non-electric heating, only 40–60% of heat is utilized but in electric heating 75–100% of heat can be successfully utilized. So, overall efficiency of electric heating is very high.

(xix) **Automatic protection**

Protection against over current and overheating can be provided by using fast control devices.

(xx) **Heating of non-conducting materials**

The heat developed in the non-conducting materials such as wood and porcelain is possible only through the electric heating.

(xxi) **Better working conditions**

No irritating noise is produced with electric heating and also radiating losses are low.

(xxii) **Less floor area**

Due to the compactness of electric furnace, floor area required is less.

(xxiii) **High temperature**

High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

(xxiv) **Safety**

The electric heating is quite safe.

METHODS OF ELECTRIC HEATING

Heat can be generated by passing the current through a resistance or induced currents. The initiation of an arc between two electrodes also develops heat. The bombardment by some heat energy particles such as α, γ, β, and x-rays or accelerating ion can produce heat on a surface. Electric heating can be broadly classified as follows.

(iii) **Direct resistance heating**

In this method, the electric current is made to pass through the charge (or) substance to be heated.

This principle of heating is employed in electrode boiler.

***(iv)* Indirect resistance heating**

In this method, the electric current is made to pass through a wire or high-resistance heating element, the heat so developed is transferred to charge from the heating element by convection or radiation. This method of heating is employed in immersion water heaters.

Classification of electrical heating

Infrared (or) radiant heating

In this method of heating, the heat energy is transferred from source (incandescent lamp) and focused upon the body to be heated up in the form of electromagnetic radiations. Normally, this method is used for drying clothes in the textile industry and to dry the wet paints on an object.

Direct arc heating

In this method, by striking the arc between the charge and the electrode or electrodes, the heat so developed is directly conducted and taken by the charge. The furnace operating on this principle is known as direct arc furnaces. The main application of this type of heating is production of steel.

Indirect arc heating

In this method, arc is established between the two electrodes, the heat so developed is transferred to the charge (or) substance by radiation. The furnaces operating on this principle are known as indirect arc furnaces. This method is generally used in the melting of non-ferrous metals.

Direct induction heating

In this method of heating, the currents are induced by electromagnetic action in the charge to be heated. These induced currents are used to melt the charge in induction furnace.

Indirect induction heating

In this method, eddy currents are induced in the heating element by electromagnetic action. Thus, the developed heat in the heating element is transferred to the body (or) charge to be heated by radiation (or) convection. This principle of heating is employed in induction furnaces used for the heat treatment of metals.

Dielectric heating

In this method of electric heating, the heat developed in a non-metallic material due to inter atomic friction, known as dielectric loss. This principle of heating usually employed for preheating of plastic performs, baking foundry cores, etc.

RESISTANCE HEATING

When the electric current is made to pass through a high-resistive body (or) substance, a power loss takes place in it, which results in the form of heat energy, i.e., resistance heating is passed upon the $I2R$ effect. This method of heating has wide applications such as drying, baking of potteries, commercial and domestic cooking, and the heat treatment of metals such as annealing and hardening. In oven where wire resistances are employed for heating, temperature up to about 1,000°C can be obtained.

The resistance heating is further classified as:

4. direct resistance heating,
5. indirect resistance heating, and
6. infrared (or) radiant heating.

Direct resistance heating

In this method, electrodes are immersed in a material or charge to be heated. The charge may be in the form of powder, pieces, or liquid. The electrodes are connected to AC or DC supply as shown in Fig. 3.1(a). In case of DC or 1-φ AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3-φsupply. When metal pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit. The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency. As the current in this case is not variable, so that automatic temperature control is not possible. This method of heating is employed in salt bath furnace and electrode boiler for heating water.

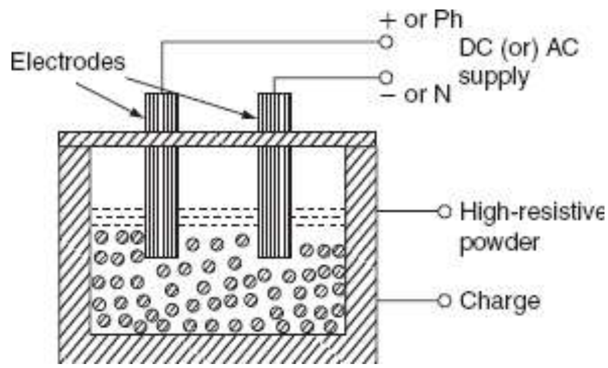


Fig. 3.1(a) Direct resistance heating

(iii) **Salt bath furnace**

This type of furnace consists of a bath and containing some salt such as molten sodium chloride and two electrodes immersed in it. Such salt have a fusing point of about 1,000–1,500°C depending upon the type of salt used. When the current is passed between the electrodes immersed in the salt, heat is developed and the temperature of the salt bath may be increased. Such an arrangement is known as a salt bath furnace. In this bath, the material or job to be heated is dipped. The electrodes should be carefully immersed in the bath in such a way that the current flows through the salt and not through the job being heated. As DC will cause electrolysis so, low-voltage AC up to 20 V and current up to 3,000 A is adopted depending upon the type of furnaces. The resistance of the salt decreases with increase in the temperature of the salt, therefore, in order to maintain the constant power input, the voltage can be controlled by providing a tap changing transformer. The control of power input is also affected by varying the depth of immersion and the distance between the electrodes.

(iv) **Electrode boiler**

It is used to heat the water by immersing three electrodes in a tank as shown in Fig. 3.2. This is based on the principle that when the electric current passed through the water produces heat due to the resistance offered by it. For DC supply, it results in a lot of evolution of H2 at negative electrode and O2 at positive electrode. Whereas AC supply hardly results in any evolution of gas,

but heats the water. Electrode boiler tank is earthed solidly and connected to the ground. A circuit breaker is usually incorporated to make and break all poles simultaneously and an over current protective device is provided in each conductor feeding an electrode.

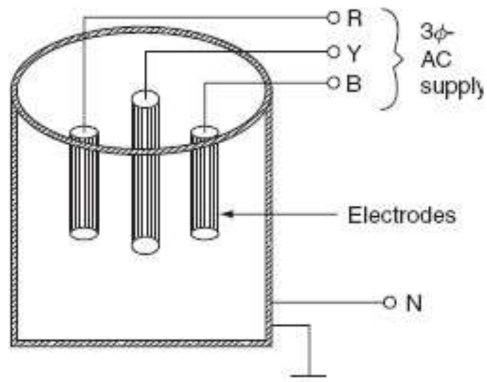


Fig. 3.2 Electrode boiler

Indirect resistance heating

In the indirect resistance heating method, high current is passed through the heating element. In case of industrial heating, some times the heating element is placed in a cylinder which is surrounded by the charge placed in a jacket is known as heating chamber is shown in Fig. 3.3. The heat is proportional to power loss produced in the heating element is delivered to the charge by one or more of the modes of the transfer of heat viz. conduction, convection, and radiation. This arrangement provides uniform temperature and automatic temperature control. Generally, this method of heating is used in immersion water heaters, room heaters, and the resistance ovens used in domestic and commercial cooling and salt bath furnace.

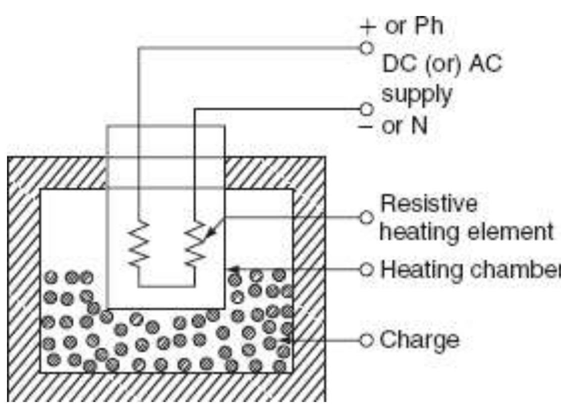


Fig. 3.3 Indirect resistance heating

Resistance ovens

According to the operating temperatures, the resistance furnaces may be classified into various types. Low-temperature heating chamber with the provision for ventilation is called as oven. For drying varnish coating, the hardening of synthetic materials, and commercial and domestic heating, etc., the resistance ovens are employed. The operating temperature of medium temperature furnaces is between 300°C and 1,050°C. These are employed for the melting of nonferrous metals, stove (annealing), etc. Furnaces operating at temperature between 1,050°C and 1,350°C are known as high-temperature furnaces. These furnaces are employed for hardening applications. A simple resistance oven is shown in Fig. 3.4.

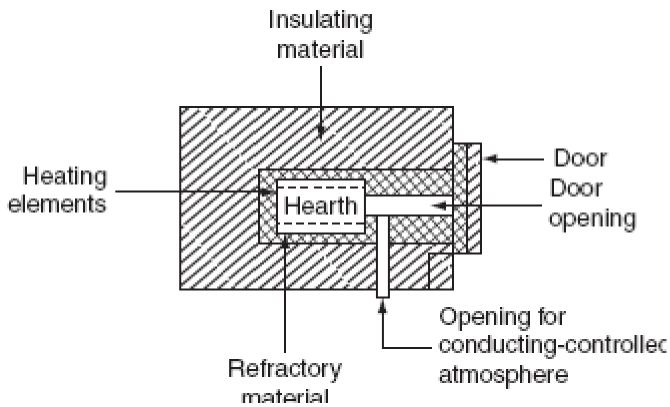


Fig. 3.4 Resistance oven

Resistance oven consists of a heating chamber in which heating elements are placed as shown in the Fig. 3.4. The inner surface of the heating chamber is made to suit the character of the charge and the type of furnace or oven. The type of insulation used for heating chamber is determined by the maximum temperature of the heating chamber.

Efficiency and losses of resistance ovens

The heat produced in the heating elements, not only raises the temperature of the charge to desired value, but also used to overcome the losses occurring due to:

5. Heat used in raising the temperature of oven (or) furnace.
6. Heat used in raising the temperature of containers (or) carriers,
7. Heat conducted through the walls.
8. Heat loss due to the opening of oven door.

4. The heat required to raise the temperature of oven to desired value can be calculated by knowing the mass of refractory material (M), its specific heat (S), and raise of temperature (ΔT) and is given by:

Hoven = $MS\Delta T$J.

In case the oven is continuously used, this loss becomes negligible.

5. Heat used in rising the temperature of containers (or) carriers can be calculated exactly the same way as for oven (or) furnaces.

6. Heat loss conducted through the walls of the container can be calculated by knowing the area of the container (A) in square meters, the thickness of the walls (t) in meters, the inside and out side temperatures of the container $T1$ and $T2$ in °C, respectively, and the thermal conductivity of the container walls 'k' in m3/°C/hr and is given by: Heat loss by conduction Actually, there is no specific formula for the determination of loss occurring due to the opening of door for the periodic inspection of the charge so that this loss may be approximately taken as 0.58–1.15 MJ/m2 of the door area, if the door is opened for a period of 20–30 sec.

The *efficiency of the oven* is defined as the ratio of the heat required to raise the temperature of he charge to the desired value to the heat required to raise the charge and losses.

$$\text{The efficiency of the oven: } = \frac{\text{the heat required to raise the temperature of the charge}}{\text{the heat required to raise the temperature of the charge} + \text{total losses}}$$

The efficiency of the resistance oven lies in between 60% and 80%.

Infrared or radiant heating

In this method of heating, the heat transfer takes place from the source to the body to be heated through radiation, for low and medium temperature applications. Whereas in resistance ovens, the heat transfers to the charge partly by convection and partly by radiation.

In the radiant heating, the heating element consists of tungsten filament lamps together with reflector and to direct all the heat on the charge. Tungsten filament lamps are operating at 2,300°C instead of 3,000°C to give greater portion of infrared radiation and a longer life. The radiant heating is mainly used for drying enamel or painted surfaces. The high concentration of the radiant energy enables the heat to penetrate the coating of paint or enamel to a depth sufficient to dry it out without wasting energy in the body of the work piece. The main advantage of the radiant heating is that the heat absorption remains approximately constant whatever the charge temperature, whereas with the ordinary oven the heat absorption falls off very considerably as the temperature of the charge raises. The lamp ratings used are usually between 250 and 1,000 W and are operating at voltage of

115 V in order to ensure a robust filament.

TEMPERATURE CONTROL OF RESISTANCE HEATING

To control the temperature of a resistance heating at certain selected points in a furnace or oven, as per certain limits, such control may be required in order to hold the temperature constant or to vary it in accordance with a pre-determined cycle and it can be carried out by hand or automatically. In resistance furnaces, the heat developed depends upon $I^2 R t$ (or) t. Therefore, the temperature of the furnaces can be controlled either by:

4. Changing the resistance of elements.
5. Changing the applied voltage to the elements (or) current passing through the elements.
6. Changing the ratio of the on-and-off times of the supply.

Voltage across the furnace can be controlled by changing the transformer tapings. Auto transformer or induction regulator can also be used for variable voltage supply. In addition to the above, voltage can be controlled by using a series resistance so that some voltage dropped across this series resistor. But this method is not economical as the power is continuously wasted in controlling the resistance. Hence, this method is limited to small furnaces. An on-off switch can be employed to control the temperature. The time for which the oven is connected to the supply and the time for which it is disconnected from supply will determine the temperature. Temperature can be controlled by providing various combinations of groups of resistances used in the furnace and is given as follows:

(iii) **Variable number of elements**

If 'R' be the resistance of one element and 'n' be the number of elements are connected in parallel, so that the equivalent resistance is R/n. Heat developed in the furnace is: i.e., if the number of elements connected in parallel increases, the heat developed in the furnace also increased. This method does not provide uniform heating unless elements not in use are well distributed.

(iv) **Series parallel (or) star delta arrangement of elements**

If the available supply is single phase, the heating elements can be connected in series for the low temperatures and connected in parallel for the high temperature by means of a series— parallel switch. In case, if the available supply is three phase, the heating elements can be connected in star for the low temperature and in delta for the high temperatures by using star— delta switch.

INDUCTION HEATING

The induction heating process makes use of the currents induced by the electromagnetic action in the material to be heated. To develop sufficient amount of heat, the resistance of the material

$$\left(\because \text{power drawn} = \frac{V^2}{R}\right)$$

must be low , which is possible only with the metals, and the voltage must be higher, which can be obtained by employing higher flux and higher frequency. Therefore, the magnetic materials can be heated than non-magnetic materials due to their high permeability. In order to analyze the factors affecting induction heating, let us consider a circular disc to be heated carrying a current of '*I*' amps at a frequency '*f*' Hz. As shown in Fig. 3.9.

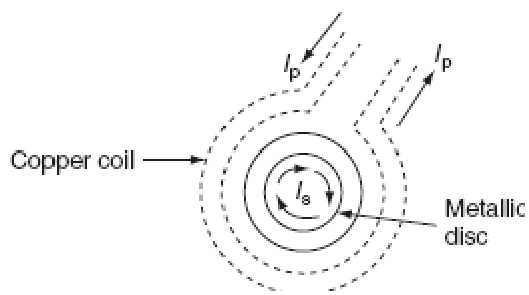


Fig. 3.9 Induction heating

Heat developed in the disc is depending upon the following factors.

- Primary coil current.
- The number of the turns of the coil.
- Supply frequency.
- The magnetic coupling between the coil and the disc.
- The high electrical resistivity of the disc.

If the charge to be heated is non-magnetic, then the heat developed is due to eddy current loss, whereas if it is magnetic material, there will be hysteresis loss in addition to eddy current loss. Both hysteresis and eddy current loss are depended upon frequency, but at high-frequency hysteresis, loss is very small as compared to eddy currents. The depth of penetration of induced currents into the disc is given by:

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu f}} \text{ cm}$$

$$\text{i.e., } d \; \mu \frac{1}{\sqrt{f}},$$

where ρ is the specific resistance in Ω-cm, f is the frequency in Hz, and μ is the permeability of the charge. There are basically two types of induction furnaces and they are:

3. Core type or low-frequency induction furnace.

4. Coreless type or high-frequency induction furnace.

Core type furnace

The operating principle of the core type furnace is the electromagnetic induction. This furnace is operating just like a transformer. It is further classified as:

4. Direct core type.

5. Vertical core type.

6. Indirect core type.

(iv) Direct core type induction furnace

The core type furnace is essentially a transformer in which the charge to be heated forms singleturn secondary circuit and is magnetically coupled to the primary by an iron core as shown in Fig. 3.10.

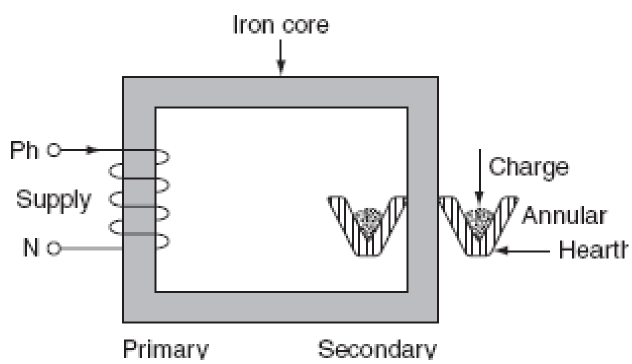


Fig. 3.10 Direct core type furnace

The furnace consists of a circular hearth in the form of a trough, which contains the charge to be melted in the form of an annular ring. This type of furnace has the following characteristics: o This metal ring is quite large in diameter and is magnetically interlinked with primary winding, which is energized from an AC source. The magnetic coupling between primary and secondary is very weak; it results in high leakage reactance and low pf. To overcome the increase in leakage reactance, the furnace should be operated at low frequency of the order of 10 Hz.

- When there is no molten metal in the hearth, the secondary becomes open circuited thereby cutting of secondary current. Hence, to start the furnace, the molten metal has to be taken in the hearth to keep the secondary as short circuit.
- Furnace is operating at normal frequency, which causes turbulence and severe stirring action in the molten metal to avoid this difficulty, it is also necessary to operate the furnace at low frequency.
- In order to obtain low-frequency supply, separate motor-generator set (or) frequency changer is to be provided, which involves the extra cost.
- The crucible used for the charge is of odd shape and inconvenient from the metallurgical viewpoint.
- If current density exceeds about 500 A/cm2, it will produce high-electromagnetic forces in the molten metal and hence adjacent molecules repel each other, as they are in the same direction. The repulsion may cause the interruption of secondary circuit (formation of bubbles and voids); this effect is known as *pinch effect.*

The pinch effect is also dependent on frequency; at low frequency, this effect is negligible, and so it is necessary to operate the furnace at low frequency.

(v) Vertical core type induction furnace

It is an improvement over the direct core type furnace, to overcome some of the disadvantages mentioned above. This type of furnace consists of a vertical core instead of horizontal core as shown in Fig. 3.11. It is also known as *Ajax–Wyatt induction furnace.*

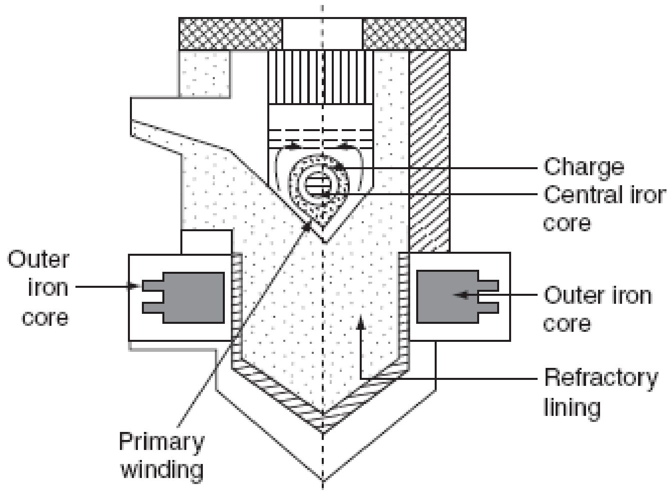


Fig. 3.11 Vertical core type furnace (Ajax–Wyatt induction furnace)

Vertical core avoids the pinch effect due to the weight of the charge in the main body of the crucible. The leakage reactance is comparatively low and the power factor is high as the magnetic coupling is high compared to direct core type. There is a tendency of molten metal to accumulate at the bottom that keeps the secondary completed for a vertical core type furnace as it consists of narrow V-shaped channel. The inside layer of furnace is lined depending upon the type charge used. Clay lining is used for yellow brass and an alloy of magnesia and alumina is used for red brass. The top surface of the furnace is covered with insulating material, which can be removed for admitting the charge. Necessary hydraulic arrangements are usually made for tilting the furnace to take out the molten metal. Even though it is having complicated construction, it is operating at power factor of the order of 0.8–0.83. This furnace is normally used for the melting and refining of brass and non-ferrous metals.

Advantages

- Accurate temperature control and reduced metal losses.
- Absence of crucibles.
- Consistent performance and simple control.
- It is operating at high power factor.
- Pinch effect can be avoided.

(vi) Indirect core type furnace

This type of furnace is used for providing heat treatment to metal. A simple induction furnace with the absence of core is shown in Fig. 3.12.

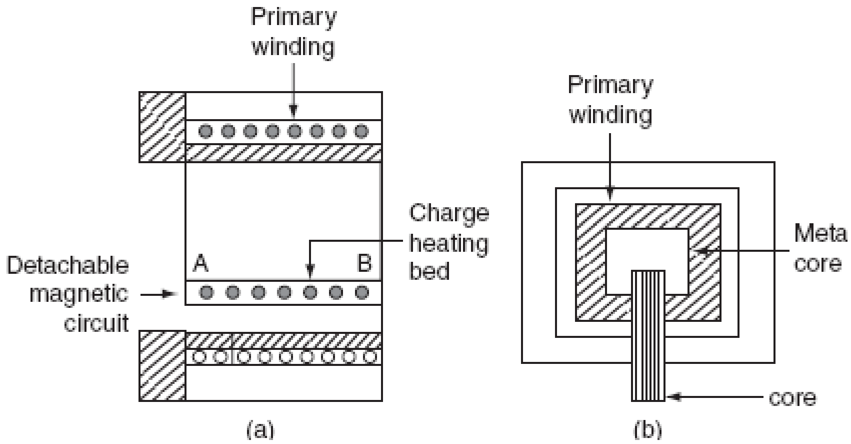


Fig. 3.12 Indirect core type furnace

The secondary winding itself forms the walls of the container or furnace and an iron core links both primary and secondary windings. The heat produced in the secondary winding is transmitted to the charge by radiation. An oven of this type is in direct competition with ordinary resistance oven. It consists of a magnetic circuit AB is made up of a special alloy and is kept inside the chamber of the furnace. This magnetic circuit loses its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature. When the oven reaches to critical temperature, the reluctance of the magnetic circuit increases many times and the inductive effect decreases thereby cutting off the supply heat. Thus, the temperature of the furnace can be effectively controlled. The magnetic circuit 'AB' is detachable type that can be replaced by the other magnetic circuits having critical temperatures ranging between 400°C and 1,000°C. The furnace operates at a pf of around 0.8. The main advantage of such furnace is wide variation of temperature control is possible.

Coreless type induction furnace It is a simple furnace with the absence core is shown in Fig.

3.13. In this furnace, heat developed in the charge due to eddy currents flowing through .

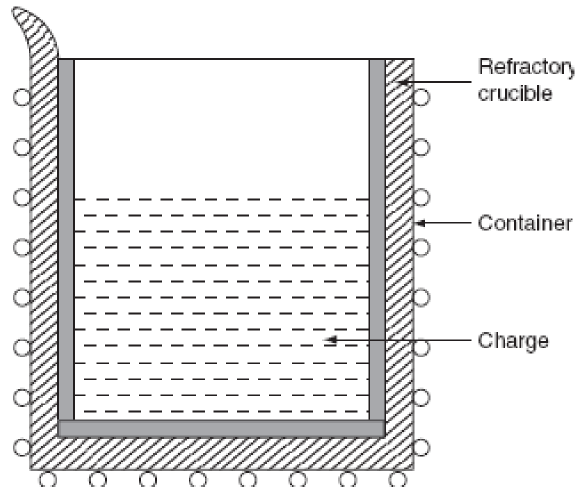


Fig. 3.13 Coreless induction furnace

The furnace consists of a refractory or ceramic crucible cylindrical in shape enclosed within a coil that forms primary of the transformer. The furnace also contains a conducting or nonconducting container that acts as secondary. If the container is made up of conducting material, charge can be conducting or nonconducting; whereas, if the container is made up of non-conducting material, charge taken should have conducting properties. When primary coils are excited by an alternating source, the flux set up by these coils induce the eddy currents in the charge. The direction of the resultant eddy current is in a direction opposite to the current in the primary coil. These currents heat the charge to melting point and they also set up electromagnetic forces that produce a stirring action to the charge. ∴ The eddy currents developed in any magnetic circuit are given as:

$W_e \propto B_m$

$2f2$, where B_m is the maximum flux density (tesla), f is the frequency in (Hz), and W_e is the eddy current loss (watts). In coreless furnace, the flux density will be low as there is no core. Hence, the primary supply should have high frequency for compensating the low flux density. If it is operating at high frequency, due to the skin effect, it results copper loss, thereby increasing the temperature of the primary winding.

This necessitates in artificial cooling.

The coil, therefore, is made of hollow copper tube through which cold water is circulated. Minimum stray magnetic field is maintained when designing coreless furnace, otherwise there will be considerable eddy current loss. The selection of a suitable frequency of the primary current can be given by penetration formula. According to this:

$$t = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu f}},$$

where 't' is the thickness up to which current in the metal has penetrated, 'ρ' is the resistivity in Ω-cm,'μ' is the permeability of the material, and 'f' is the frequency in Hz. For the efficient operation, the ratio of the diameter of the charge (d) to the depth of the penetration of currents (t) should be more than '6', therefore let us take: Substitute above in Equation (Following are the advantages of coreless furnace over the other furnaces:

- Ease of control.
- Oxidation is reduced, as the time taken to reach the melting temperature is less.
- The eddy currents in the charge itself results in automatic stirring.
- The cost is less for the erection and operation.
- It can be used for heating and melting.
- Any shape of crucible can be used.
- It is suitable for intermittent operation.

DIELECTRIC HEATING

When non-metallic materials i.e., insulators such as wood, plastics, and china glass are subjected to high-voltage alternating electric field, the atoms get stresses, and due to interatomic friction caused by the repeated deformation and the rotation of atomic structure (polarization), heat is produced. This is known as dielectric loss. This dielectric loss in insulators corresponds to hysteresis loss in ferro-magnetic materials. This loss is due to the reversal of magnetism or magneto molecular friction. These losses developed in a material that has to be heated. An atom of any material is neutral, since the central positive charge is equals to the negative charge. So that, the centers of positive and negative charges coincide as long as there is no external field is applied, as shown in Fig.3.14 (a). When this atom is subjected to the influence of the electric field, the positive charge of the nucleus is acted upon by some force in the direction of negative charges in the opposite direction. Therefore, the effective centers of both positive and negative charges no longer coincident as shown in Fig. 3.14 (b). The electric charge of an atom equivalent to Fig.3.14(b) is shown in Fig. 3.14(c).

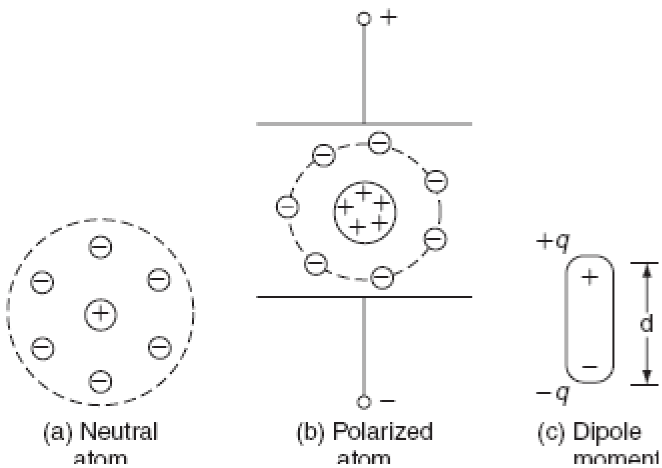


Fig.3.14 Polarization

This gives raise to an electric dipole moment equal to $P = q\ d$, where d is the distance between the two centers and q is the charge on the nucleus. Now, the atom is said to be polarized atom. If we apply alternating voltage across the capacitor plate, we will get alternating electric field. Electric dipoles will also try to change their orientation according to the direction of the impressed electric field. In doing so, some energy will be wasted as inter-atomic friction, which is called dielectric loss. As there is no perfect conductor, so there is no perfect insulator. All the dielectric materials can be represented by a parallel combination of a leakage resistor 'R' and a capacitor 'C' as shown in Fig. 3.15 (a) and (b).

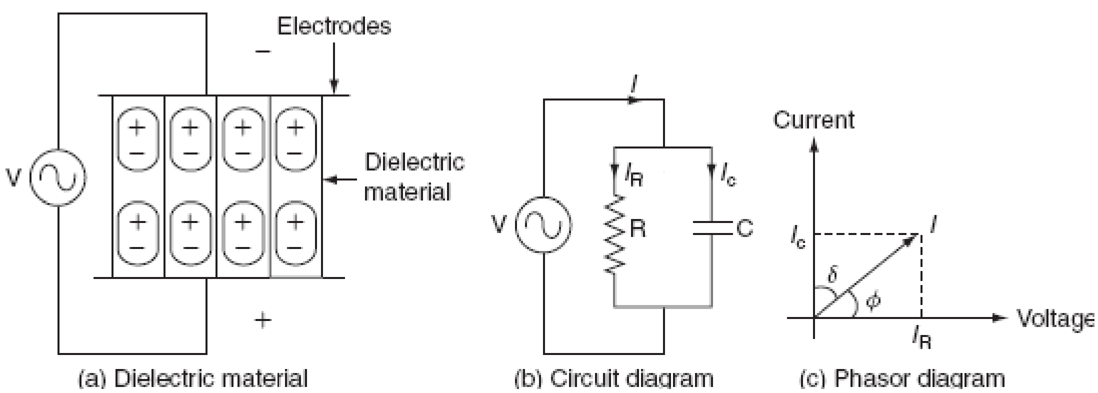


Fig.3.15 Dielectric heating

If an AC voltage is applied across a piece of insulator, an electric current flows; total current '*I*' supposed to be made up of two components I_C and I_R, where I_C is the capacitive current leading the applied voltage by 90° and I_R is in phase with applied voltage as shown in Fig. 3.15(c). where '*V*' is the applied voltage in volts, '*f*' is the supply frequency in Hz, ε_0 is the absolute permittivity of the medium = 8.854×10^{-12} F/m,

ε_r is the relative permittivity of the medium = 1

for free space, *A* is the area of the plate or electrode (m^2), *d* is the thickness of the dielectric medium, and δ is the loss angle in radian. From Equation (3.14): Normally frequency used for dielectric heating is in the range of 1–40 MHz. The use of high voltage is also limited due to the breakdown voltage of thin dielectric that is to be heated, under normal conditions; the voltage gradient used is limited to 18 kV/cm.

The advantages of the dielectric heating

- The heating of the non-conducting materials is very rapid.
- The uniform heating of material is possible.
- Heat is produced in the whole mass of the material.

The applications of the dielectric heating

- The drying of paper, wood, etc.
- The gluing of wood.
- The heat-sealing of plastic sheets.
- The heating for the general processing such as coffee roasting and chocolate industry.
- The heating for the dehydration such as milk, cream, and vegetables.
- The preparation of thermoplastic resins.
- The heating of bones and tissues.
- Diathermy, i.e., the heat treatment for certain body pains and diseases, etc.
- The sterilization of absorbent cotton, bandages, etc.
- The processing of rubber, synthetic materials, chemicals, etc

Electric Welding

INTRODUCTION

Welding is the process of joining two pieces of metal or non-metal together by heating them to their melting point. Filler metal may or may not be used to join two pieces. The physical and mechanical properties of a material to be welded such as melting temperature, density, thermal conductivity, and tensile strength take an important role in welding. Depending upon how the heat applied is created; we get different types of welding such as thermal welding, gas welding, and electric welding. Here in this chapter, we will discuss only about the electric welding and some introduction to other modern welding techniques. Welding is nowadays extensively used in
automobile industry, pipe-line fabrication in thermal power plants, machine repair work, machine frames, etc.

ADVANTAGES AND DISADVANTAGES OF WELDING

Some of the advantages of welding are:

- Welding is the most economical method to permanently join two metal parts.
- It provides design flexibility.
- Welding equipment is not so costly.
- It joins all the commercial metals.
- Both similar and dissimilar metals can be joined by welding.
- Portable welding equipment are available.
- Some of the disadvantages of welding are:
- Welding gives out harmful radiations and fumes.
- Welding needs internal inspection.
- If welding is not done carefully, it may result in the distortion of workpiece.
- Skilled welding is necessary to produce good welding.

ELECTRIC WELDING

It is defined as the process of joining two metal pieces, in which the electrical energy is used to generate heat at the point of welding in order to melt the joint.

The classification

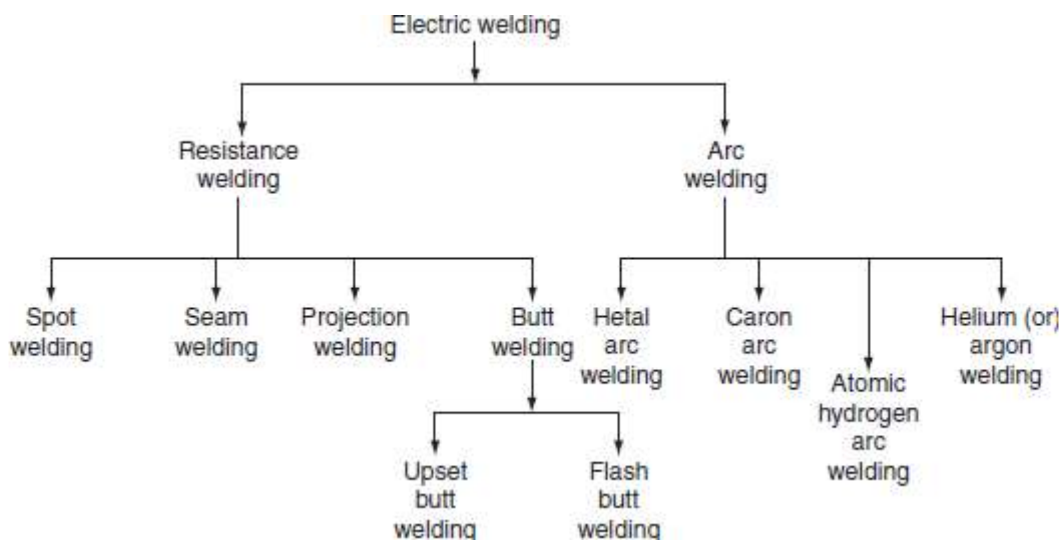


Fig. 3.16. Classification of electric welding

The selection of proper welding process depends on the following factors. o The type of metal to be joined.

- The techniques of welding adopted.
- The cost of equipment used.
- The nature of products to be fabricated.

RESISTANCE WELDING

Resistance welding is the process of joining two metals together by the heat produced due to the resistance offered to the flow of electric current at the junctions of two metals. The heat produced by the resistance to the flow of current is given by:

$$H = I^2Rt,$$

where I is the current through the electrodes, R is the contact resistance of the interface, and t is the time for which current flows. Here, the total resistance offered to the flow of current is made up of:

4. The resistance of current path in the work.
5. The resistance between the contact surfaces of the parts being welded.
6. The resistance between electrodes and the surface of parts being welded.

In this process of welding, the heat developed at the contact area between the pieces to be welded reduces the metal to plastic state or liquid state, then the pieces are pressed under high mechanical pressure to complete the weld. The electrical voltage input to the welding varies in between 4 and 12 V depending upon area, thickness, composition, etc. and usually power ranges from about 60 to 180 W for each sq. mm of area. Any desired combination of voltage and current can be obtained by means of a suitable transformer in AC; hence, AC is found to be most suitable for the resistance welding. The magnitude of current is controlled by changing the primary voltage of the welding transformer, which can be done by using an auto-transformer or a tap-changing transformer. Automatic arrangements are provided to switch off the supply after a pre-determined time from applying the pressure, why because the duration of the current flow through the work is very important in the resistance welding. The electrical circuit diagram for the resistance welding is shown in Fig. 5.2. This method of welding consists of a tap-changing transformer, a clamping device for holding the metal pieces, and some sort of mechanical arrangement for forcing the pieces to form a complete weld.

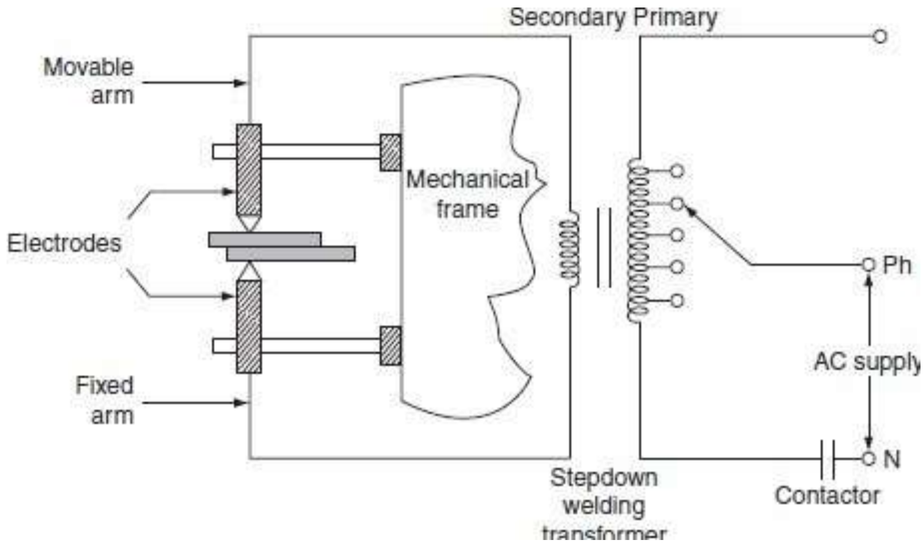


Fig. 3.17. Electric circuit for resistance welding

Advantages

- Welding process is rapid and simple.
- Localized heating is possible, if required.
- No need of using filler metal.
- Both similar and dissimilar metals can be welded.
- Comparatively lesser skill is required.
- Maintenance cost is less.
- It can be employed for mass production.
- *However, the resistance welding has got some drawbacks and they are:*
- Initial cost is very high.
- High maintenance cost.
- The workpiece with heavier thickness cannot be welded, since it requires high input current.

Applications

- It is used by many industries manufacturing products made up of thinner gauge metals.
- It is used for the manufacturing of tubes and smaller structural sections.

Types of resistance welding

Depending upon the method of weld obtained and the type of electrodes used, the resistance welding is classified as:

5. Spot welding.
6. Seam welding.
7. Projection welding.
8. Butt welding.

(v) Spot welding

Spot welding means the joining of two metal sheets and fusing them together between copper electrode tips at suitably spaced intervals by means of heavy electric current passed through the electrodes as shown in Fig. 3.18

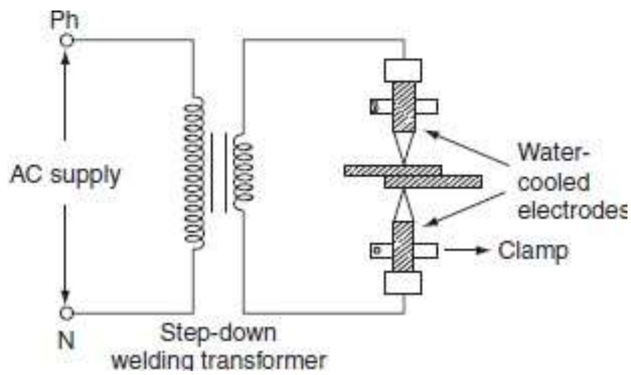


Fig. 3.18. Spot welding

This type of joint formed by the spot welding provides mechanical strength and not air or water tight, for such welding it is necessary to localize the welding current and to apply sufficient pressure on the sheet to be welded. The electrodes are made up of copper or copper alloy and are water cooled. The welding current varies widely depending upon the thickness and composition of the plates. It varies from 1,000 to 10,000 A, and voltage between the electrodes is usually less than 2 V. The period of the flow of current varies widely depending upon the thickness of sheets to be joined. A step-down transformer is used to reduce a high-voltage and low-current supply to low-voltage and high-current supply required. Since the heat developed being proportional to the product of welding time and square of the current. Good weld can be obtained by low currents for longer duration and high currents for shorter duration; longer welding time usually produces stronger weld but it involves high energy expenditure, electrode maintenance, and lot of distortion of workpiece. When voltage applied across the electrode, the flow of current will generate heat at the three junctions, i.e., heat developed, between the two electrode tips and workpiece, between the two workpieces to be joined as shown in Fig. 3.18.

The generation of heat at junctions 1 and 3 will effect electrode sticking and melt through holes, the prevention of electrode striking is achieved by:

3. Using water-cooled electrodes shown in Fig. 3.19. By avoiding the heating of junctions 1 and 3 electrodes in which cold water circulated continuously as shown in Fig. 3.19.

4. The material used for electrode should have high electrical and thermal conductivity. Spot welding is widely used for automatic welding process, for joining automobile parts, joining and fabricating sheet metal structure, etc.

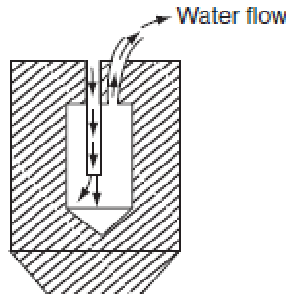


Fig.3.19 Water cooled electrode

(vi) Seam welding

Seam welding is nothing but the series of continuous spot welding. If number spots obtained by spot welding are placed very closely that they can overlap, it gives rise to seam welding. In this welding, continuous spot welds can be formed by using wheel type or roller electrodes instead of tipped electrodes as shown in Fig. 3.20.

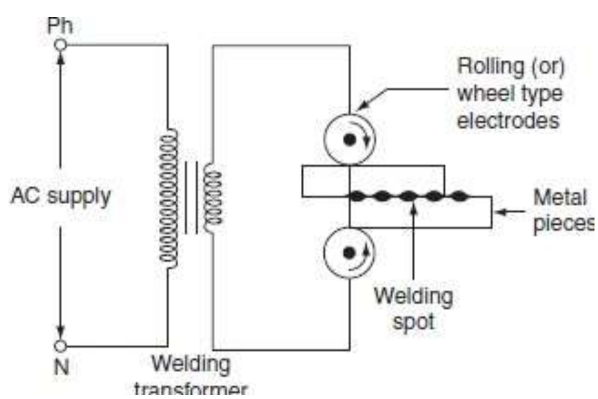


Fig. 3.20 Seam welding

Seam welding is obtained by keeping the job under electrodes. When these wheel type electrodes travel over the metal pieces which are under pressure, the current passing between them heats the two metal pieces to the plastic state and results into continuous spot welds. In this welding, the contact area of electrodes should be small, which will localize the current pressure to the welding point. After forming weld at one point, the weld so obtained can be cooled by splashing water over the job by using cooling jets. In general, it is not satisfactory to make a continuous weld, for which the flow of continuous current build up high heat that causes burning and wrapping of the metal piece. To avoid this difficulty, an interrupter is provided on the circuit which turns on supply for a period sufficient to heat the welding point. The series of weld spots depends upon the number of welding current pulses. The two forms of welding currents are shown in Fig. 3.21(a) and (b).

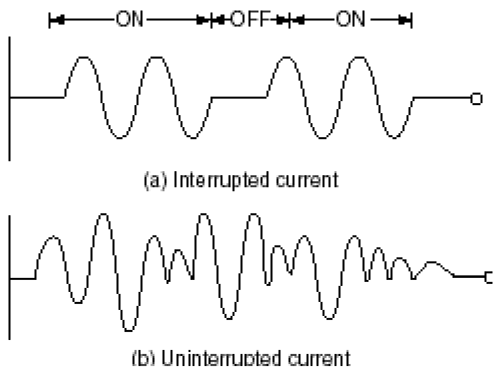


Fig. 3.21 Welding current

Welding cannot be made satisfactorily by using uninterrupted or un-modulated current, which builds up high heat as the welding progress; this will over heat the workpiece and cause distortion. Seam welding is very important, as it provides leak proof joints. It is usually employed in welding of pressure tanks, transformers, condensers, evaporators, air craft tanks, refrigerators, varnish containers, etc.

(vii) Projection welding

It is a modified form of the spot welding. In the projection welding, both current and pressure are localized to the welding points as in the spot welding. But the only difference in the projection welding is the high mechanical pressure applied on the metal pieces to be welded, after the formation of weld. The electrodes used for such welding are flat metal plates known as *platens*. The two pieces of base metal to be weld are held together in between the two platens, one is movable and the other is fixed, as shown in Fig. 3.22

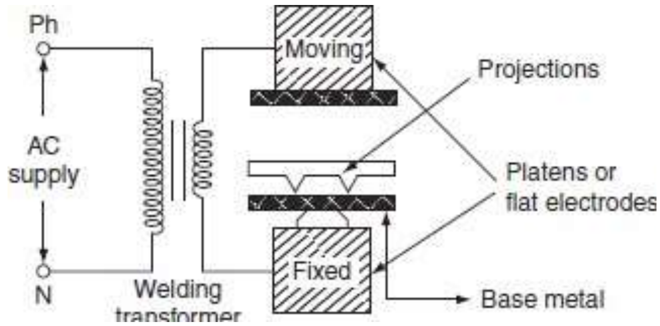


Fig. 3.22. Projection welding

One of the two pieces of metal is run through a machine that makes the bumps or projections of required shape and size in the metal. As current flows through the two metal parts to be welded, which heat up and melt. These weld points soon reach the plastic state, and the projection touches the metal then force applied by the two flat electrodes forms the complete weld. The projection welding needs no protective atmosphere as in the spot welding to produce successful results. This welding process reduces the amount of current and pressure in order to join two metal surfaces, so that there is less chance of distortion of the surrounding areas of the weld zone. Due to this reason, it has been incorporated into many manufacturing process. The projection welding has the following advantages over the spot welding.

- Simplicity in welding process.
- It is easy to weld some of the parts where the spot welding is not possible.
- It is possible to join several welding points.
- Welds are located automatically by the position of projection.

As the electrodes used in the projection welding are flat type, the cZontact area over the projection is sufficient. This type of welding is usually employed on punched, formed, or stamped parts where the projection automatically exists. The projection welding is particularly employed for mass production work, i.e., welding of refrigerators, condensers, crossed wire welding, refrigerator racks, grills, etc.

(viii) **Butt welding**

Butt welding is similar to the spot welding; however, the only difference is, in butt welding, instead of electrodes the metal parts that are to be joined or butted together are connected to the supply. The three basic types of the butt welding process are:

4. Upset butt welding.

5. Flash butt welding.

6. Percussion butt welding.

(d) Upset butt welding

In upset welding, the two metal parts to be welded are joined end to end and are connected across the secondary of a welding transformer as shown in Fig. 3.23

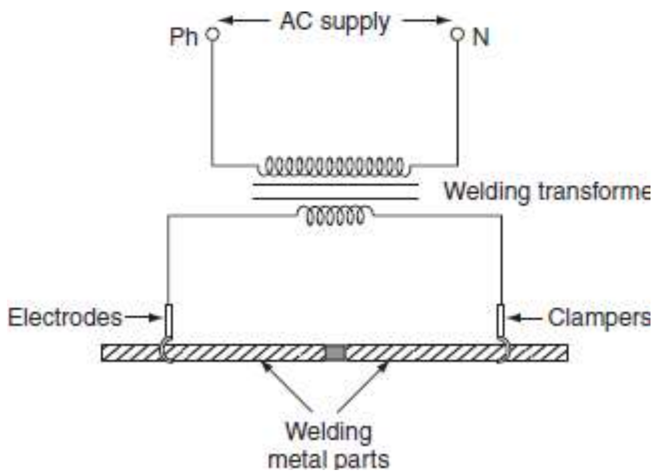


Fig. 3.23 Upset butt welding

Due to the contact resistance of the metals to be welded, heating effect is generated in this welding. When current is made to flow through the two electrodes, heat will develop due to the contact resistance of the two pieces and then melts. By applying high mechanical pressure either manually or by toggle mechanism, the two metal pieces are pressed. When jaw-type electrodes are used that introduce the high currents without treating any hot spot on the job. This type of welding is usually employed for welding of rods, pipes, and wires and for joining metal parts end to end.

(e) Flash butt welding

Flash butt welding is a combination of resistance, arc, and pressure welding. This method of welding is mainly used in the production welding. A simple flash butt welding arrangement is shown in Fig. 3.24

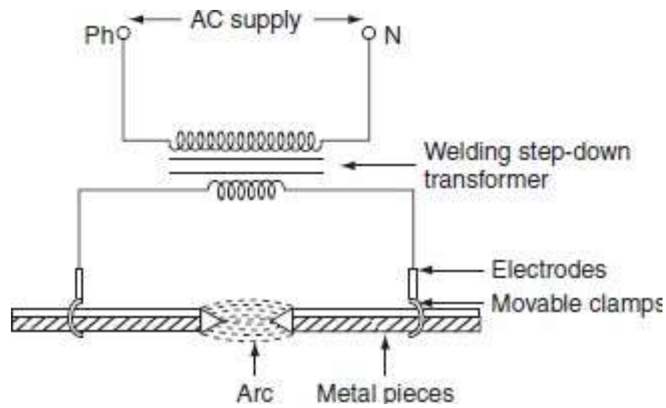


Fig. 3.24 Flash butt welding

In this method of welding, the two pieces to be welded are brought very nearer to each other under light mechanical pressure. These two pieces are placed in a conducting movable clamps. When high current is passed through the two metal pieces and they are separated by some distance, then arc established between them. This arc or flashing is allowed till the ends of the workpieces reach melting temperature, the supply will be switched off and the pieces are rapidly brought together under light pressure. As the pieces are moved together, the fused metal and slag

come out of the joint making a good solid joint. Following are the advantages of the flash butt welding over the upset welding.

- Less requirement of power.
- When the surfaces being joined, it requires only less attention.
- Weld obtained is so clean and pure; due to the foreign metals appearing on the surfaces will burn due to flash or arc.

(f) Percussion welding

It is a form of the flash butt welding, where high current of short duration is employed using stored energy principle. This is a self-timing spot welding method. Percussion welding arrangement consists of one fixed holder and the other one is movable. The pieces to be welded are held apart, with the help of two holders, when the movable clamp is released, it moves rapidly carrying the piece to be welded. There is a sudden discharge of electrical energy, which establishes an arc between the two surfaces and heating them to their melting temperature, when the two pieces are separated by a distance of 1.5 mm apart. As the pieces come in contact with each other under heavy pressure, the arc is extinguished due to the percussion blow of the two parts and the force between them affects the weld. The percussion welding can be obtained in two methods; one is capacitor energy storage system and the other is magnetic energy storage system. The capacitor discharge circuit for percussion welding is shown in Fig 3.25.

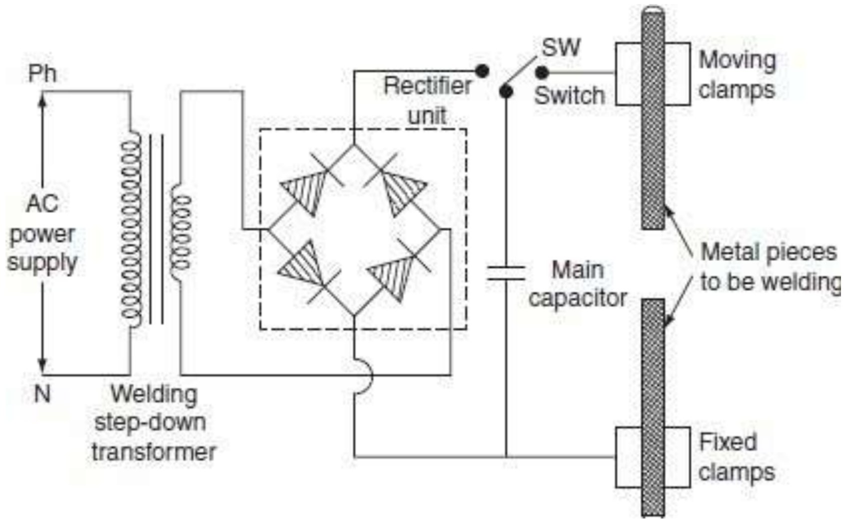


Fig. 3.25 Capacitor discharge circuit for percussion welding

The capacitor 'C' is charged to about 3,000 V from a controlled rectifier. The capacitor is connected to the primary of welding transformer through the switch and will discharge. This discharge will produce high transient current in the secondary to join the two metal pieces. Percussion welding is difficult to obtain uniform flashing of the metal part areas of the cross section grater than 3 sq. cm. Advantage of this welding is so fast, extremely shallow of heating is

obtained with a span of about 0.1 sec. It can be used for welding a large number of dissimilar metals.

Applications

- It is useful for welding satellite tips to tools, sliver contact tips to copper, cast iron to steel, etc.
- Commonly used for electrical contacts.
- The metals such as copper alloys, aluminum alloys, and nickel alloys are percussion welded.

ELECTRIC ARC WELDING

Electric arc welding is the process of joining two metallic pieces or melting of metal is obtained due to the heat developed by an arc struck between an electrode and the metal to be welded or between the two electrodes as shown in Fig. 3.26(a).

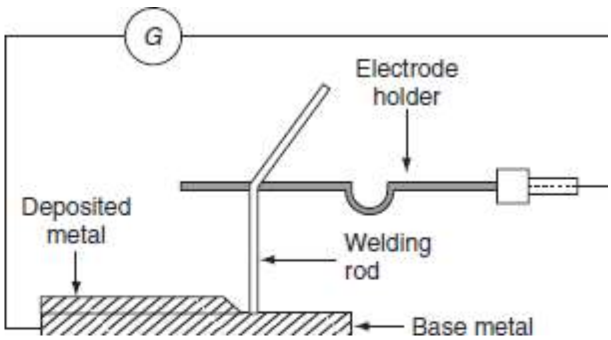


Fig.3.26 Arrangement of electric welding equipment

In this process, an electric arc is produced by bringing two conductors (electrode and metal piece) connected to a suitable source of electric current, momentarily in contact and then separated by a small gap, arc blows due to the ionization and give intense heat. The heat so developed is utilized to melt the part of workpiece and filler metal and thus forms the weld. In this method of welding, no mechanical pressure is employed; therefore, this type of welding is also known as *'non-pressure welding'*.

The length of the arc required for welding depends upon the following factors:

- The surface coating and the type of electrodes used.
- The position of welding.
- The amount of current used.

When the supply is given across the conductors separated by some distance apart, the air gap present between the two conductors gets ionized, as the arc welding is in progress, the ionization of the arc path and its surrounding area increases. This increase in ionization decreases the resistance of the path. Thus, current increases with the decrease in voltage of arc. This *VI* characteristic of an arc is shown in Fig. (b), it also known as *negative resistance characteristics of an arc*. Thus, it will be seen that this decrease in resistance with increase in current does not remain the arc steadily. This difficulty cab be avoided, with the supply, it should fall rapidly with the increase in the current so that any further increase in the current is restricted. For the arc welding, the temperature of the arc should be 3,500°C. At this temperature, mechanical pressure for melting is not required. Both AC and DC can be used in the arc welding. Usually 70–100 V on AC supply and 50–60 V on DC supply system is sufficient to struck the arc in the air gap between the electrodes. Once the arc is struck, 20–30 V is only required to maintain it. However, in certain cases, there is any danger of electric shock to the operator, low voltage should be used for the welding purpose. Thus, DC arc welding of low voltage is generally preferred. Electric arc welding is extensively used for the joining of metal parts, the repair of fractured casting, and the fillings by the deposition of new metal on base metal, etc.

Various types of electric arc welding are:

6. Carbon arc welding.

7. Metal arc welding.

8. Atomic hydrogen arc welding.

9. Inert gas metal arc welding.

10. Submerged arc welding.

Carbon arc welding

It is one of the processes of arc welding in which arc is struck between two carbon electrodes or the carbon electrode and the base metal. The simple arrangement of the carbon arc welding is shown in Fig. 3.27.

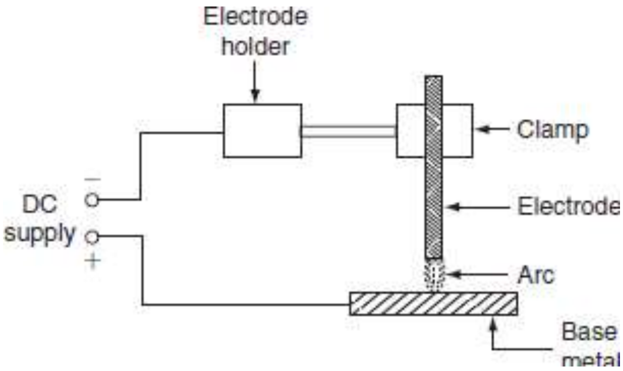


Fig. 3.27 Carbon arc welding

In this process of welding, the electrodes are placed in an electrode holder used as negative electrode and the base metal being welded as positive. Unless, the electrode is negative relative to the work, due to high temperature, there is a tendency of the particles of carbon will fuse and mix up with the base metal, which causes brittleness; DC is preferred for carbon arc welding since there is no fixed polarity maintained in case of AC. In the carbon arc welding, carbon or graphite rods are used as electrode. Due to longer life and low resistance, graphite electrodes are used, and thus capable of conducting more current. The arc produced between electrode and base metal; heat the metal to the melting temperature, on the negative electrode is 3,200°C and on the positive electrode is 3,900°C. This process of welding is normally employed where addition of filler metal is not required. The carbon arc is easy to maintain, and also the length of the arc can be easily varied. One major problem with carbon arc is its instability which can be overcome by using an inductor in the electrode of 2.5-cm diameter and with the current of about of 500–800 A employed to deposit large amount of filler metal on the base metal. Filler metal and flux may not be used depending upon the type of joint and material to be welded.

Advantages

- The heat developed during the welding can be easily controlled by adjusting the length of the arc.
- It is quite clean, simple, and less expensive when compared to other welding process.
- Easily adoptable for automation.

- Both the ferrous and the non-ferrous metals can be welded.

Disadvantages

- Input current required in this welding, for the work piece to rise its temperature to melting/welding temperature, is approximately double the metal arc welding.
- In case of the ferrous metal, there is a chance of disintegrating the carbon at high temperature and transfer to the weld, which causes harder weld deposit and brittlement.
- A separate filler rod has to be used if any filler metal is required.

Applications

- It can be employed for the welding of stainless steel with thinner gauges.
- Useful for the welding of thin high-grade nickel alloys and for galvanized sheets using copper silicon manganese alloy filler metal.

Metal arc welding In metal arc welding, the electrodes used must be of the same metal as that of the work-piece to be welded. The electrode itself forms the filler metal. An electric arc is stuck by bringing the electrode connected to a suitable source of electric current, momentarily in contract with the work pieces to be welded and withdrawn apart. The circuit diagram for the metal arc welding is shown in fig.3.28.

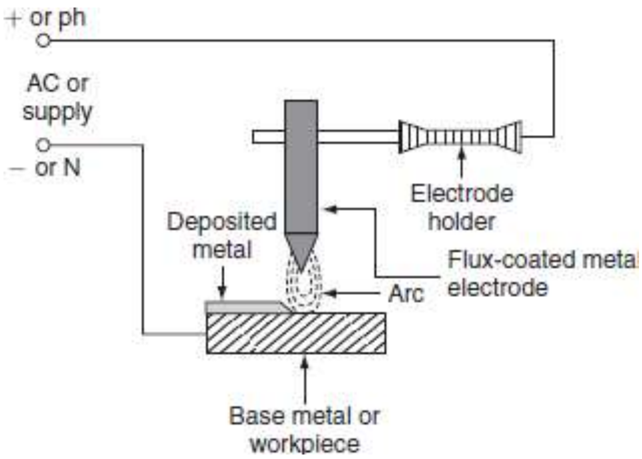


Fig. 3.28 Metal arc welding

The arc produced between the work piece and the electrode results high temperature of the order of about 2,400°C at negative metal electrode and 2,600°C at positive base metal or work piece. This high temperature of the arc melts the metal as well as the tip of the electrode, then the electrode melts and deposited over the surface of the workpiece, forms complete weld. Both AC and DC can be used for the metal arc welding. The voltage required for the DC metal arc welding is about 50–60 V and for the AC metal arc welding is about 80–90 V In order to maintain the voltage drop across the arc less than 13 V, the arc length should be kept as small as possible, otherwise the weld will be brittle. The current required for the welding varies from 10 to 500 A depending upon the type of work to be welded. The main disadvantage in the DC metal arc welding is the presence of arc blow, i.e., distortion of arc stream from the intended path due to the magnetic forces of the non-uniform magnetic field with AC arc blow is considerably reduced. For obtaining good weld, the flux-coated electrodes must be used, so the metal which is melted is covered with slag produces a non oxidizing gas or a molten slag to cover the weld, and also stabilizes the arc.

COMPARISON BETWEEN AC AND DC WELDING

3 Motor generator set or rectifier is required in case of the availability of AC supply.
Only transformer is required.

4 The cost of the equipment is high. The cost of the equipment is cheap.

3 Arc stability is more. Arc stability is less.

11 The heat produced is uniform. The heat produced is not uniform.

12 Both bare and coated electrodes can be used. Only coated electrodes should be used.

13 The operating power factor is high. The power factor is low. So, the capacitors are necessary to improve the power factor.

14 It is safer since no load voltage is low. It is dangerous since no load voltage is high.

15 The electric energy consumption is 5–10 kWh/kg of deposited metal. The electrical energy consumption is 3–4 kWh/kg of deposited metal

16 Arc blow occurs due to the presence of non-uniform magnetic field. Arc blow will not occur due to the uniform magnetic field.

17 The efficiency is low due to the rotating parts. The efficiency is high due to the absence of rotating parts.

UNIT 5
Electric Traction

The system that causes the propulsion of a vehicle in which that driving force or tractive force is obtained from various devices such as electric motors, steam engine drives, diesel engine dives, etc. is known as traction system. Traction system may be broadly classified into two types. They are electric traction systems, which use electrical energy, and non-electric traction system, which does not use electrical energy for the propulsion of vehicle. Requirements of ideal traction system Normally, no single traction system fulfills the requirements of ideal traction system, why because each traction system has its merits and suffers from its own demerits, in the fields of applications.

The requirements of ideal traction systems are:

- Ideal traction system should have the capability of developing high tractive effort in order to have rapid acceleration.
- The speed control of the traction motors should be easy.
- Vehicles should be able to run on any route, without interruption.
- Equipment required for traction system should be minimum with high efficiency.
- It must be free from smoke, ash, durt, etc.
- Regenerative braking should be possible and braking should be in such a way to cause minimum wear on the break shoe.
- Locomotive should be self-contained and it must be capable of withstanding overloads.
- Interference to the communication lines should be eliminated while the locomotive running along the track.

Advantages and Disadvantages of Electric Traction

Electric traction system has many advantages compared to non-electric traction systems. The following are the advantages of electric traction:

- ➢ Electric traction system is more clean and easy to handle.
- ➢ No need of storage of coal and water that in turn reduces the maintenance cost as well as the saving of high-grade coal.
- ➢ Electric energy drawn from the supply distribution system is sufficient to maintain the common necessities of locomotives such as fans and lights; therefore, there is no need of providing additional generators.
- ➢ The maintenance and running costs are comparatively low.
- ➢ The speed control of the electric motor is easy.

- Regenerative braking is possible so that the energy can be fed back to the supply system during the braking period.
- In electric traction system, in addition to the mechanical braking, electrical braking can also be used that reduces the wear on the brake shoes, wheels, etc.
- Electrically operated vehicles can withstand for overloads, as the system is capable of drawing more energy from the system.
- In addition to the above advantages, the electric traction system suffers from the following drawbacks:
- Electric traction system involves high erection cost of power system.
- Interference causes to the communication lines due to the overhead distribution networks.
- The failure of power supply brings whole traction system to stand still.
- In an electric traction system, the electrically operated vehicles have to move only on the electrified routes.
- Additional equipment should be needed for the provision of regenerative braking, it will increase the overall cost of installation.

REVIEW OF EXISTING ELECTRIC TRACTION SYSTEM IN INDIA

In olden days, first traction system was introduced by Britain in 1890 (600-V DC track). Electrification system was employed for the first traction vehicle. This traction system was introduced in India in the year 1925 and the first traction system employed in India was from Bombay VT to Igatpuri and Pune, with 1,500-V DC supply. This DC supply can be obtained for traction from substations equipped with rotary converters. Development in the rectifiers leads to the replacement of rotary converters by mercury arc rectifiers. But nowadays further development in the technology of semiconductors, these mercury arc valves are replaced by solid-state semiconductors devices due to fast traction system was introduced on 3,000-V DC. Further development in research on traction system by French international railways was suggested that, based on relative merits and demerits, it is advantageous to prefer to AC rather than DC both financially and operationally.

Thus, Indian railways was introduced on 52-kV, 50-Hz single-phase AC system in 1957; this system of track electrification leads to the reduction of the cost of overhead, locomotive equipment, etc. Various systems employed for track electrification are shown in Table 5.1.

Table 5.1 Track electrification systems

S. no	System	Voltage	Frequency
1	DC system	600 V, 1,500 V, or 3,000 V	—
2	Single-phase AC system	15–25 kV is stepped down to 300–400 V	$\frac{162}{3}$ Hz and 25 Hz
3	Three-phase AC system	15–25 kV is stepped down to 3,300–3,600 V	$\frac{162}{3}$ Hz and 50 Hz

System of Traction

Traction system is normally classified into two types based on the type of energy given as input to drive the system and they are:

(i) Non-electric traction system

Traction system develops the necessary propelling torque, which do not involve the use of electrical energy at any stage to drive the traction vehicle known as electric traction system.

Ex: Direct stea..m engine drive and direct internal combustion engine drive.

(ii) Electric traction system

Traction system develops the necessary propelling torque, which involves the use of electrical energy at any stage to drive the traction vehicle, known as electric traction system.

Based upon the type of sources used to feed electric supply for traction system, electric traction

electric traction may be classified into two groups:

1. Self-contained locomotives.
2. Electric vehicle fed from the distribution networks.

Self-contained locomotives

In this type, the locomotives or vehicles themselves have a capability of generating electrical energy for traction purpose. Examples for such type of locomotives are:

1. Steam electric drive

In steam electric locomotives, the steam turbine is employed for driving a generator used to feed the electric motors. Such types of locomotives are not generally used for traction because of some mechanical difficulties and maintenance problems.

2. Diesel electric trains

A few locomotives employing diesel engine coupled to DC generator used to feed the electric motors producing necessary propelling torque. Diesel engine is a variable high-speed type that feeds the self- or separately excited DC generator. The excitation for generator can be supplied from any auxiliary devices and battery. Generally, this type of traction system is suggested in the areas where coal and steam tractions are not available. The advantages and disadvantages of the diesel engine drive are given below:

Advantages

o As these are no overhead distribution system, initial cost is low.

o Easy speed control is possible.

o Power loss in speed control is very low o Time taken to bring the locomotive into service is less.

o In this system, high acceleration and braking retardation can be obtained compared to steam locomotives.

o The overall efficiency is high compared to steam locomotives.

Disadvantages

o The overloading capability of the diesel engine is less.

o The running and maintenance costs are high.

o The regenerative braking cannot be employed for the diesel engine drives.

Petrol electric traction

This system of traction is used in road vehicles such as heavy lorries and buses These vehicles are capable of handling overloads. At the same time, this system provides fine and smooth control so that they can run along roads without any jerking. Battery drives In this drive, the locomotive consists of batteries used to supply power to DC motors employed for driving the vehicle. This type of drives can be preferred for frequently operated services such as local delivery goods traction in industrial works and mines, etc. This is due to the unreliability of supply source to feed the electric motors. Electric vehicles fed from distribution network Vehicles in electrical traction system that receives power from over head distribution network fed or substations with suitable spacing. Based on the available supply, these groups of vehicles are further subdivided into:

1. System operating with DC supply. Ex: tramways, trolley buses, and railways.
2. System operating with AC supply. Ex: railways.

Systems operating with DC supply

In case if the available supply is DC, then the necessary propelling power can be obtained for the vehicles from DC system such as tram ways, trolley buses, and railways.

Tramways: Tramways are similar to the ordinary buses and cars but only the difference is they are able to run only along the track. Operating power supply for the tramways is 500-V DC tramways are fed from single overhead conductor acts as positive polarity that is fed at suitable points from either power station or substations and the track rail acts as return conductor. The equipment used in tramways is similar to that used in railways but with small output not more than 40–50 kW. Usually, the tramways are provided with two driving axels to control the speed of the vehicles from either ends. The main drawback of tramways is they have to run along the guided routes only. Rehostatic and mechanical brakings can be applied to tramways. Mechanical brakes can be applied at low speeds for providing better saturation where electric braking is ineffective, during the normal service. The erection and maintenance costs of tramways are high since the cost of overhead distribution structure is costlier and sometimes, it may cause a source of danger to other road users.

Trolley buses: The main drawback of tramways is, running along the track is avoided in case of trolley buses. These are electrically operated vehicles, and are fed usually 600-V DC from two overhead conductors, by means of two collectors. Even though overhead distribution structure is costlier, the trolley buses are advantageous because, they eliminate the necessity of track in the roadways. In case of trolley buses, rehostatic braking is employed, due to high adhesion between roads and rubber types. A DC compound motor is employed in trolley buses.

SYSTEM OF TRACK ELECTRIFICATION

Now a day, based on the available supply, the track electrification system are categorized into.

1. DC system.
2. Single-phase AC system.
3. Three-phase AC system.
4. Composite system.

1. DC system

In this system of traction, the electric motors employed for getting necessary propelling torque should be selected in such a way that they should be able to operate on DC supply. Examples for such vehicles operating based on DC system are tramways and trolley buses. Usually, DC series motors are preferred for tramways and trolley buses even though DC compound motors are available where regenerative braking is desired. The operating voltages of vehicles for DC track

electrification system are 600, 750, 1,500, and 3,000 V. Direct current at 600–750 V is universally employed for tramways in the urban areas and for many suburban and main line railways, 1,500–3,000 V is used. In some cases, DC supply for traction motor can be obtained from substations equipped with rotary converters to convert AC power to DC. These substations receive AC power from 3-φ high voltage line or single-phase overhead distribution network. The operating voltage for traction purpose can be justified by the spacing between stations and the type of traction motors available. Theses substations are usually automatic and remote controlled and they are so costlier since they involve rotary converting equipment. The DC system is preferred for suburban services and road transport where stops are frequent and distance between the stops is small.

2 . Single-phase AC system

In this system of track electrification, usually AC series motors are used for getting the necessary propelling power. The distribution network employed for such traction systems is normally 15–25 kV at reduced frequency of 163∴ Hz or 25 Hz. The main reason of operating at reduced frequencies is AC series motors that are more efficient and show better performance at low frequency. These high voltages are stepped down to suitable low voltage of 300–400 V by means of step-down transformer. Low frequency can be obtained from normal supply frequency with the help of frequency converter. Low-frequency operation of overhead transmission line reduces the line reactance and hence the voltage drops directly and single- phase AC system is mainly preferred for main line services where the cost of overhead structure is not much importance moreover rapid acceleration and retardation is not required for suburban services.

3 Three-phase AC system

In this system of track electrification, 3-φ induction motors are employed for getting the necessary propelling power. The operating voltage of induction motors is normally 3,000– 3,600-V AC at either normal supply frequency or 16∴-Hz frequency. Usually 3-φ induction motors are preferable because they have simple and robust construction, high operating efficiency, provision of regenerative braking without placing any additional equipment, and better performance at both normal and seduced frequencies. In addition to the above advantages, the induction motors

suffer from some drawbacks; they are low-starting torque, high-starting current, and the absence of speed control. The main disadvantage of such track electrification system is high cost of overhead distribution structure. This distribution system consists of two overhead wires and track rail for the third phase and receives power either directly from the generating station or through transformer substation. Three-phase AC system is mainly adopted for the services where the output power required is high and regeneration of electrical energy is possible.

4 Composite system

As the above track electrification system have their own merits and demerits, 1- φ AC system is preferable in the view of distribution cost and distribution voltage can be stepped up to high voltage with the use of transformers, which reduces the transmission losses. Whereas in DC system, DC series motors have most desirable features and for 3-φ system, 3-φ induction motor has the advantage of automatic regenerative braking. So, it is necessary to combine the advantages of the DC/AC and 3-φ/1-φ systems. The above cause leads to the evolution of composite system.

Composite systems are of two types.

1. Single-phase to DC system.
2. Single-phase to three-phase system or kando system.

Single-phase to DC system

In this system, the advantages of both 1-φ and DC systems are combined to get high voltage for distribution in order to reduce the losses that can be achieved with 1-φ distribution networks, and DC series motor is employed for producing the necessary propelling torque. Finally, 1-φ AC distribution network results minimum cost with high transmission efficiency and DC series motor is ideally suited for traction purpose. Normal operating voltage employed of distribution is 25 kV at normal frequency of 50 Hz. This track electrification is employed in India. *Single- phase to 3-φ system or kando system* In this system, 1-φ AC system is preferred for distribution network. Since single phase overhead distribution system is cheap and 3-φ induction motors are employed as traction motor because of their simple, robust construction, and the provision of automatic regenerative braking. The voltage used for the distribution network is about 15–25 kV at 50 Hz. This 1-φ supply is converted to 3-φ supply through the help of the phase converters and high voltage is stepped down transformers to feed the 3-φ induction motors. Frequency converters are also employed to get high-starting torque and to achieve better speed control with the variable supply frequency.

SPECIAL FEATURES OF TRACTION MOTORS

The general features of the electric motors used for traction purpose are:

1. Mechanical features.
2. Electrical features.

Mechanical features

1. A traction motor must be mechanically strong and robust and it should be capable of withstanding severe mechanical vibrations.
2. The traction motor should be completely enclosed type when placed beneath the locomotive to protect against dirt, dust, mud, etc.
3. In overall dimensions, the traction motor must have small diameter, to arrange easily beneath the motor coach.
4. A traction motor must have minimum weight so the weight of locomotive will decrease. Hence, the load carrying capability of the motor will increase.

Electrical features

High-starting torque

A traction motor must have high-starting torque, which is required to start the motor on load during the starting conditions in urban and suburban services.

Speed control

The speed control of the traction motor must be simple and easy. This is necessary for the frequent starting and stopping of the motor in traction purpose.

Dynamic and regenerative braking

Traction motors should be able to provide easy simple rehostatic and regenerative braking subjected to higher voltages so that system must have the capability of withstanding voltage fluctuations.

Temperature

The traction motor should have the capability of withstanding high temperatures during transient conditions.

Overload capacity

The traction motor should have the capability of handling excessecive overloads.

Parallel running

In traction work, more number of motors need to run in parallel to carry more load. Therefore, the traction motor should have such speed–torque and current–torque characteristics and those motors may share the total load almost equally.

Commutation

Traction motor should have the feature of better commutation, to avoid the sparking at

the brushes and commutator segments.

TRACTION MOTORS

No single motor can have all the electrical operating features required for traction.

In earlier days, DC motor is suited for traction because of the high-starting torque and having the capability of handling overloads. In addition to the above characteristics, the speed control of the DC motor is very complicated through semiconductor switches. So that, the motor must be designed for high base speed initially by reducing the number of turns in the field winding. But this will decrease the torque developed per ampere at the time of staring. And regenerative braking is also complicated in DC series motor; so that, the separately excited motors can be preferred over the series motor because their speed control is possible through semi-controlled converters. And also dynamic and regenerative braking in separately excited DC motor is simple and efficient.

DC compound motors are also preferred for traction applications since it is having advantageous features than series and separately excited motors.

But nowadays squirrel cage induction and synchronous motors are widely used for traction because of the availability of reliable variable frequency semiconductor inverters.

The squirrel cage induction motor has several advantages over the DC motors. They are:

(i) Robust construction.

(ii) Highly reliable.

(iii) Low maintenance and low cost.

(iv) High efficiency.

Synchronous motor features lie in between the squirrel cage induction motor and the DC motor. The main advantages of the synchronous motor over the squirrel cage induction motor are:

1. The synchronous motors can be operated at leading power by varying the field excitation.

2. Load commutated thyristor inverter is used in synchronous motors as compared to forced commutation thyristor inverter in squirrel cage induction motors. Even though such forced commutation reduces the weight and volume of induction motor, the synchronous motor is less expensive.

1. DC series motor

From the construction and operating characteristics of the DC series motor, it is widely suitable for traction purpose. Following features of series motor make it suitable for traction.

1. DC series motor is having high-starting torque and having the capability of handling overloads that is essential for traction drives.

2. These motors are having simple and robust construction.

3. The speed control of the series motor is easy by series parallel control.

4. Sparkless commutation is possible, because the increase in armature current increases the load torque and decreases the speed so that the emf induced in the coils undergoing commutation.

5. Series motor flux is proportional to armature current and torque. But armature current is independent of voltage fluctuations. Hence, the motor is unaffected by the variations in supply voltage.

6. We know that:

$$N \alpha \frac{1}{\phi} \alpha \frac{1}{I_a} \quad \text{and} \quad T \propto \phi I_a$$

But for series motor $\phi \propto I_a$

$$\therefore \; T \alpha I_{a^2}$$

$$\therefore \; N \alpha \frac{1}{I_a} \alpha \frac{1}{\sqrt{T}}.$$

But the power output of the motor is proportional to the product of torque and speed.

$$\alpha \, T \, N \, \alpha \sqrt{T}$$

∴ Motor output

That is motor input drawn from the source is proportional to the square root of the torque. Hence, the series motor is having self-retaining property.

7. If more than one motor are to be run in parallel, their speed–torque and current–torque characteristics must not have wide variation, which may result in the unequal wear of driving wheels.

2 DC shunt motor

From the characteristics of DC shunt motor, it is not suitable for traction purpose, due to the following reasons:

1. DC shunt motor is a constant speed motor but for traction purpose, the speed of the motor should vary with service conditions.

2. In case of DC shunt motor, the power output is independent of speed and is proportional to torque. In case of DC series motor, the power output is proportional to So that, for a given load torque, the shunt motor has to draw more power from the supply than series motor. 3. For shunt motor, the torque developed is proportional to armature current ($T \propto I$a). So for a given load torque motor has to draw more current from the supply.

4. The flux developed by shunt motor is proportional to shunt field current and hence

$$\left[\because \phi_{sh} \propto I_{sh} \propto \frac{V}{R_{sh}}\right]$$

supplyvoltage. . But the torque developed is proportional to φsh and Ia. Hence, the torque developed by the shunt motor is affected by small variations in supply voltage.

5. If two shunt motors are running in parallel, their speed–torque and speed–current characteristics must be flat and same. Otherwise, the currents drawn by the motor from the supply mains will be different and cause to unequal sharing of load.

AC series motor

Practically, AC series motor is best suited for the traction purpose due to high starting torque (Fig. 9.1). When DC series motor is fed from AC supply, it works but not satisfactorily due to some of the following reasons:

1. If DC series motor is fed from AC supply, both the field and the armature currents reverse for every half cycle. Hence, unidirectional torque is developed at double frequency.

2. Alternating flux developed by the field winding causes excessive eddy current loss, which will cause the heating of the motor. Hence, the operating efficiency of the motor will decrease.

3. Field winding inductance will result abnormal voltage drop and low power factor that leads to the poor performance of the motor.

4. Induced emf and currents flowing through the armature coils undergoing commutation will cause sparking at the brushes and commutator segments.

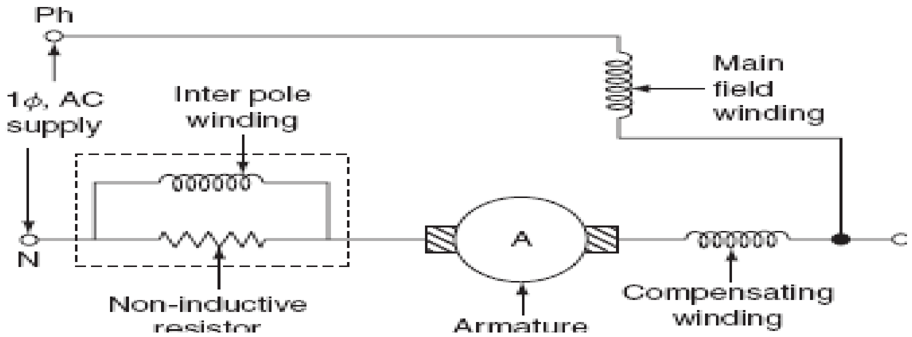


Fig. 5.1 AC series motor

Hence, some modifications are necessary for the satisfactory operation of the DC series motor on the AC supply and they are as follows:

1. In order to reduce the inductive reactance of the series field, the field winding of AC series motor must be designed for few turns.

2. The decrease in the number of turns of the field winding reduces the load torque, i.e., if field turns decrease, its mmf decrease and then flux, which will increase the speed, and hence the torque will decrease. But in order to maintain constant load torque, it is necessary to increase the armature turns proportionately.

3. If the armature turns increase, the inductive reactance of the armature would increase, which can be neutralized by providing the compensating winding.

4. Magnetic circuit of an AC series motor should be laminated to reduce eddy current losses.

5. Series motor should be operating at low voltage because high voltage low current supply would require large number of turns to produce given flux.

6. Motor should be operating at low frequency, because inductive reactance is proportional to the frequency. So, at low frequency, the inductive reactance of the field winding decreases. The operating characteristics of the AC series motor are similar to the DC series motor. Weight of an AC series motor is one and a half to two times that of a DC series motor. And operating voltage is limited to 300 V. They can be built up to the size of several hundred kW for traction work. At the time of starting operation, the power factor is low; so that, for a given current, the torque developed by the AC motor is less compared to the DC motor. Thus, the AC series motor is not suitable for suburban services with frequent stops and preferred for main line service where high acceleration is not required.

Three-phase induction motor

The three-phase induction motors are generally preferred for traction purpose due to the following advantages.

1. Simple and robust construction.

2. Trouble-free operation.

3. The absence of commutator.

4. Less maintenance.

5. Simple and automatic regeneration.

6. High efficiency.

Three-phase induction motor also suffer from the following drawbacks.

1. Low-starting torque.

2. High-starting current and complicated speed control system.

3. It is difficult to employ three-phase induction motor for a multiple-unit system used for propelling a heavy train. Three-phase induction motor draws less current when the motor is started at low frequencies. When a three-phase induction motor is used, the cost of overhead distribution system increases and it consists of two overhead conductors and track rail for the third phase to feed power to locomotive, which is a complicated overhead structure and if any person comes in contact with the third rail, it may cause danger to him or her. This drawback can be overcome by employing kando system. In this system, 1- φ supply from the overhead distribution structure is converted to 3-φ supply by using phase converters and is fed to 3-φinduction motor. The speed controller of induction motor becomes smooth and easy with the use of thyristorized inverter circuits to get variable frequency supply that can be used to control the speed of three-phase induction motor. Nowadays, by overcoming the drawbacks of three-phase induction motor, it can be used for traction purpose.

Linear induction motor It is a special type of induction motor that gives linear motion instead of rotational motion, as in the case of a conventional motor. In case of linear induction motor, both the movement of field and the movement of the conductors are linear. A linear induction motor consists of 3-φ distributed field winding placed in slots, and secondary is nothing but a conducting plate made up of either copper or aluminum as shown in Fig.5.2

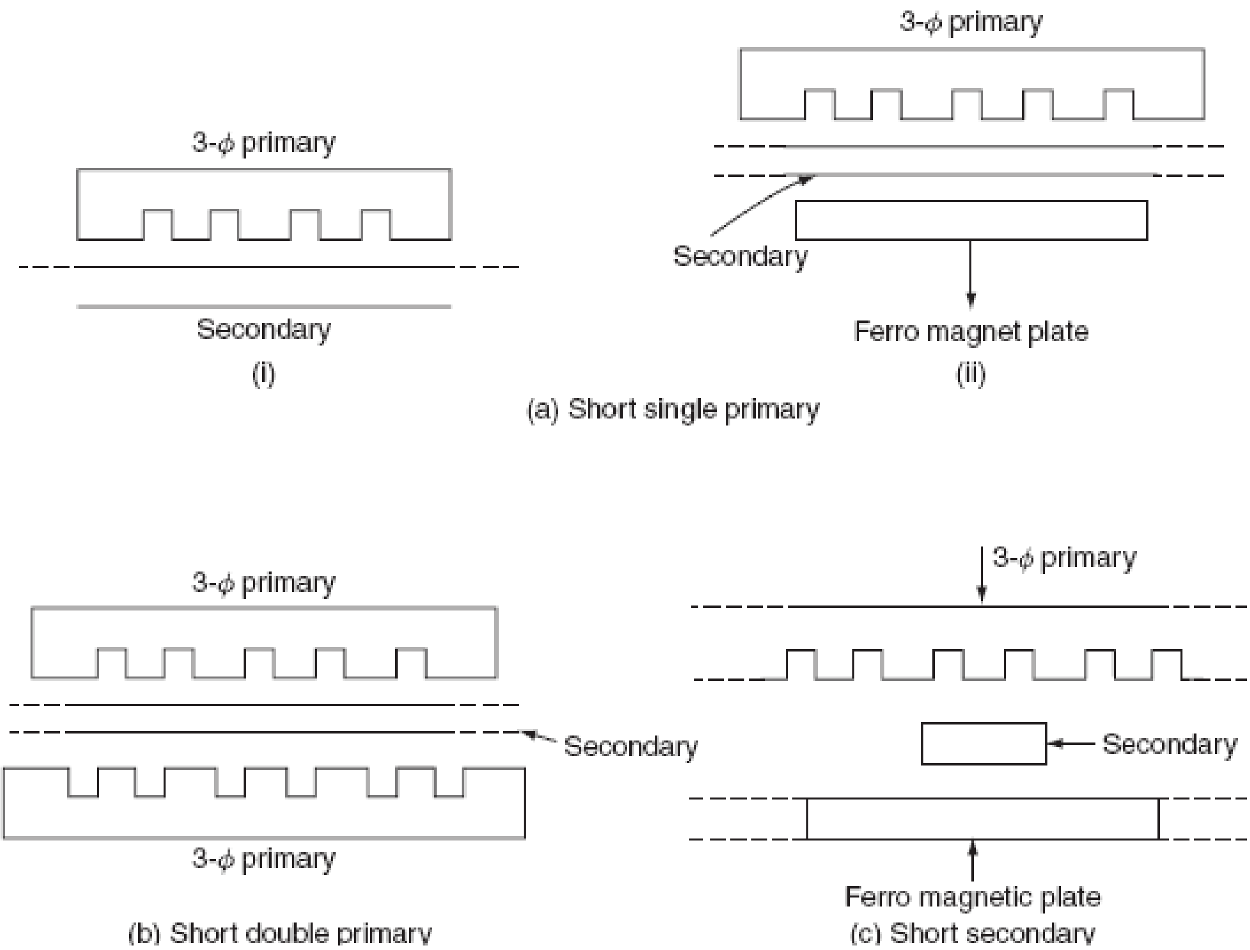


Fig 5.2 Linear induction motor

The field system may be either single primary or double primary system. In single primary system, a ferro magnetic plate is placed on the other side of the copper plate; it is necessary to provide low reluctance path for the magnetic flux. When primary is excited by 3-*φ* AC supply, according to mutual induction, the induced currents are flowing through secondary and ferro magnetic plate. Now, the ferro magnetic plate energized and attracted toward the primary causes to unequal air gap between primary and secondary as shown in Fig. 9.2(a). This drawback can be overcome by double primary system as shown in Fig. 9.2(b). In this system, two primaries are placed on both the sides of secondary, which will be shorter in length compared to the other depending upon the use of the motor. When the operating distance is large, the length of the primary is made shorter than the secondary because it is not economical to place very large 3-*φ* primary. Generally, the short secondary form of system is preferred for limited operating distance, as shown in

When 3-*φ* primary winding is excited by giving 3-*φ* AC supply, magnetic field is developed rotating at linear synchronous speed, *V*s.

The linear synchronous speed is given by:

$V_s = 2\tau f$ m/s,

where τ is the pole pitch in m and *f* is the supply frequency in hertzs. Note: here, the synchronous speed does not depend upon the number of poles but depends upon the pole pitch and the supply frequency.

1. Short single primary.
2. Short double primary.
3. Short secondary.

The flux developed by the field winding pulls the rotor same as to the direction of the magnetic field linearly, which will reduce relative speed between field and rotor plate. If the speed of the rotor plate is equal to the magnetic field, then the field would be stationary when viewed from the rotor plate. If rotor plate is rotating at a speed more than linear synchronous, the direction of a force would be reversed, which causes regenerative braking. The slip of the linear induction motor is given by:

$$s = \frac{V_s - V}{V_s}$$

where '*V* ' is the actual speed of the rotor plate.

The speed–torque (tractive effort) characteristics is shown in Fig. 5.3.

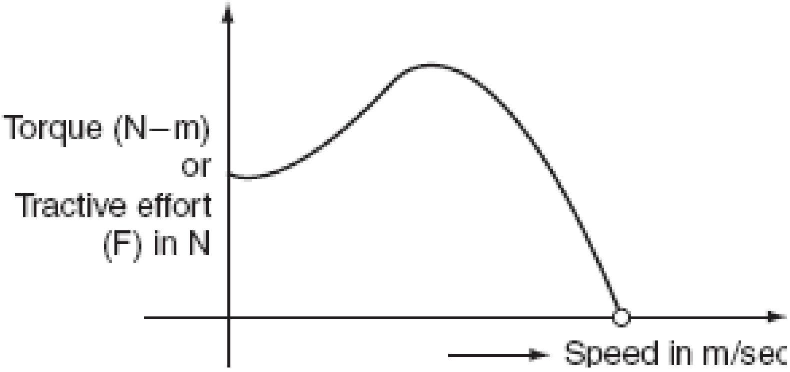


Fig. 5.3 Torque–speed characteristics

Therefore, force or tractive effort is given by: where '*P*2' is the actual power supply to the rotor.

Advantages

1. Simple in construction.
2. Low initial cost.
3. Maintenance cost is low.
4. Maximum speed is not limited due centrifugal forces.
5. Better power to weight ratio.

Disadvantages

1. High cost of providing collector system.
2. Poor efficiency and low power factor, due to high currents drawn by the motor because of large air gap.

Applications

Linear induction motor are generally used in:

o High-speed rail traction.

o Trolley cars and metallic belt conveyors.

o Electromagnetic pumps.

Synchronous motor

The synchronous motor is one type of AC motor working based upon the principle of magnetic lacking. It is a constant speed motor running from no-load to full load. The construction of the synchronous motor is similar to the AC generator; armature winding is excited by giving three-phase AC supply and field winding is excited by giving DC supply. The synchronous motor can be operated at leading and lagging power factors by varying field excitation. The synchronous motor can be widely used various applications because of constant speed from no-load to full load.

o High efficiency.

o Low-initial cost.

o Power factor improvement of three-phase AC industrial circuits.

BRAKING

If at any time, it is required to stop an electric motor, then the electric supply must be disconnected from its terminals to bring the motor to rest. In this method, even though supply is cut off, the motor continue to rotate for long time due to inertia. In some cases, there is delay in bringing the other equipment. So that, it is necessary to bring the motor to rest quickly. The process of bringing the motor to rest within the pre-determined time is known as braking.

A good braking system must have the following features:

o Braking should be fast and reliable.

o The equipment to stop the motor should be in such a way that the kinetic energy of the rotating parts of the motor should be dissipated as soon as the brakes are applied.

Braking applied to bring the motor to rest position is of two types and they are:

1. Electric braking.
2. Mechanical braking.

Electric braking

In this process of braking, the kinetic energy of the rotating parts of the motor is converted into electrical energy which in turn is dissipated as heat energy in a resistance or in sometimes, electrical energy is returned to the supply. Here, no energy is dissipated in brake shoes.

Mechanical braking

In this process of braking, the kinetic energy of the rotating parts is dissipated in the form of heat by the brake shoes of the brake lining that rubs on a wheel of vehicle or brake drum.

The advantages of the electric braking over the mechanical braking

o The electric braking is smooth, fast, and reliable.

o Higher speeds can be maintained; this is because the electric braking is quite fast. This leads to the higher capacity of the system.

o The electric braking is more economical; this is due to excessive wear on brake blocks or brake lining that results frequent and costly replacement in mechanical braking.

o Heat produced in the electric braking is less and not harmful but heat produced in the mechanical braking will cause the failure of brakes.

o In the electric braking, sometimes, it is possible to fed back electric energy during braking period to the supply system. This results in saving in the operating cost. This is not possible in case of mechanical braking.

Disadvantages

In addition to the above advantages, the electric braking suffers from the following disadvantages.

o During the braking period, the traction motor acts generator and electric brakes can almost stop the motor but it cannot hold stationary. Hence, it is necessary to employ mechanical braking in addition to electric braking.

o Traction motor has to work as a generator during braking period. So that, motor has to select in such a way that it should have suitable braking characteristics.

o The initial cost of the electric braking equipment is costlier.

The movement of trains and their energy consumption can be most conveniently studied by means of the speed–distance and the speed–time curves. The motion of any vehicle may be at constant speed or it may consist of periodic acceleration and retardation. The speed–time curves have significant importance in traction. If the frictional resistance to the motion is known value, the energy required for motion of the vehicle can be determined from it. Moreover, this curve gives the speed at various time instants after the start of run directly.

TYPES OF SERVICES

There are mainly three types of passenger services, by which the type of traction system has to be selected, namely:

1. Main line service.
2. Urban or city service.
3. Suburban service.

Main line services

In the main line service, the distance between two stops is usually more than 10 km. High balancing speeds should be required. Acceleration and retardation are not so important.

Urban service

In the urban service, the distance between two stops is very less and it is less than 1 km. It requires high average speed for frequent starting and stopping.

Suburban service

In the suburban service, the distance between two stations is between 1 and 8 km. This service requires rapid acceleration and retardation as frequent starting and stopping is required.

SPEED–TIME AND SPEED–DISTANCE CURVES FOR DIFFERENT SERVICES

The curve that shows the instantaneous speed of train in kmph along the ordinate and time in seconds along the abscissa is known as '*speed–time*' curve. The curve that shows the distance between two stations in km along the ordinate and time in seconds along the abscissa is known as '*speed–distance*' curve. The area under the speed–time curve gives the distance travelled during, given time internal and slope at any point on the curve toward abscissa gives the acceleration and retardation at the instance, out of the two speed–time curve is more important. Speed–time curve for main line service Typical speed–time curve of a train running on main line service is shown in Fig. 5.4. It mainly consists of the following time periods:

1. Constant accelerating period.
2. Acceleration on speed curve.
3. Free-running period.
4. Coasting period.
5. Braking period.

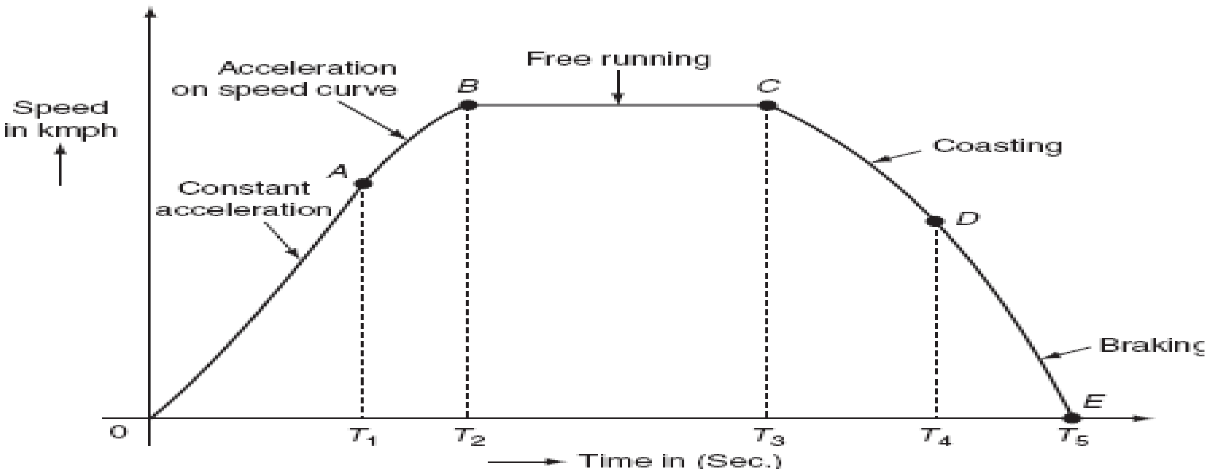


Fig. 5.4 Speed–time curve for mainline service

Constant acceleration

During this period, the traction motor accelerate from rest. The curve 'OA' represents the constant accelerating period. During the instant 0 to *T*1, the current is maintained approximately constant and the voltage across the motor is gradually increased by cutting out the starting resistance slowly moving from one notch to the other. Thus, current taken by the motor and the tractive efforts are practically constant and therefore acceleration remains constant during this period. Hence, this period is also called as notch up accelerating period or rehostatic accelerating
period. Typical value of acceleration lies between 0.5 and 1 kmph. Acceleration is denoted with the symbol 'α'.

Acceleration on speed-curve

During the running period from *T*1 to *T*2, the voltage across the motor remains constant and the current starts decreasing, this is because cut out at the instant '*T*1'. According to the characteristics of motor, its speed increases with the decrease in the current and finally the current taken by the motor remains constant. But, at the same time, even though train accelerates, the acceleration decreases with the increase in speed. Finally, the acceleration reaches to zero for certain speed, at which the tractive effort excreted by the motor is exactly equals to the train resistance. This is also known as decreasing accelerating period. This period is shown by the curve '*AB*'.

Free-running or constant-speed period

The train runs freely during the period *T*2 to *T*3 at the speed attained by the train at the instant '*T*2'. During this speed, the motor draws constant power from the supply lines. This period is shown by the curve *BC*.

Coasting period

This period is from *T*3 to *T*4, i.e., from C to D. At the instant '*T*3' power supply to the traction, the motor will be cut off and the speed falls on account of friction, windage resistance, etc. During this period, the train runs due to the momentum attained at that particular instant. The rate of the decrease of the speed during coasting period is known as coasting retardation. Usually, it is denoted with the symbol 'βc'.

Braking period

Braking period is from *T*4 to *T*5, i.e., from *D* to *E*. At the end of the coasting period, i.e., at '*T*4' brakes are applied to bring the train to rest. During this period, the speed of the train decreases rapidly and finally reduces to zero. In main line service, the free-running period will be more, the starting and braking periods are very negligible, since the distance between the stops for the main line service is more than 10 km. Speed–time curve for suburban service In suburban service, the distance between two adjacent stops for electric train is lying between 1 and 8 km. In this service, the distance between stops is more than the urban service and smaller than the main line service. The typical speed–time curve for suburban service is shown in Fig. 5.5.

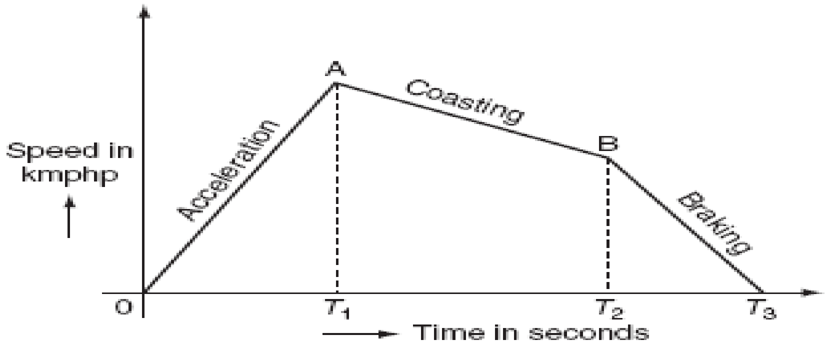


Fig. 5.5 Typical speed–time curve for suburban service

The speed–time curve for urban service consists of three distinct periods. They are:

1. Acceleration.
2. Coasting.
3. Retardation.

For this service, there is no free-running period. The coasting period is comparatively longer since the distance between two stops is more. Braking or retardation period is comparatively small. It requires relatively high values of acceleration and retardation. Typical acceleration and retardation values are lying between 1.5 and 4 kmphp and 3 and 4 kmphp, respectively. Speed–time curve for urban or city service The speed–time curve urban or city service is almost similar to suburban service and is shown in Fig.5.6.

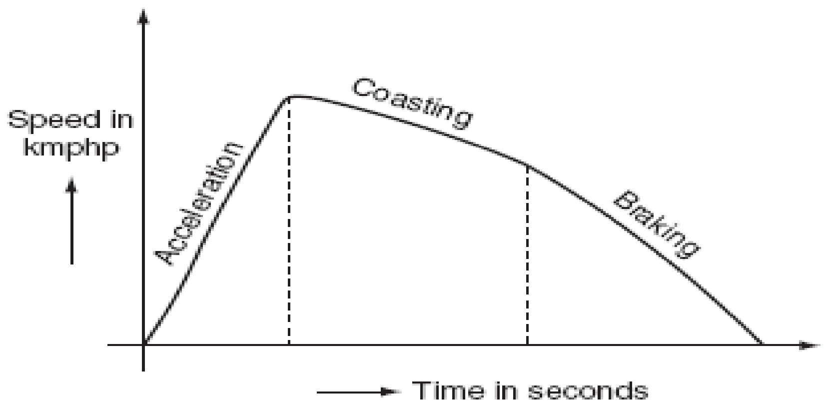


Fig. 5.6 Typical speed–time curve for urban service

In this service also, there is no free-running period. The distance between two stop is less about 1 km. Hence, relatively short coasting and longer braking period is required. The relative values of acceleration and retardation are high to achieve moderately high average between the stops. Here, the small coasting period is included to save the energy consumption. The acceleration for the urban service lies between 1.6 and 4 kmphp. The coasting retardation is about 0.15 kmphp and the braking retardation is lying between 3 and 5 kmphp. Some typical values of various services are shown in Table. 5.2

Table 5.2 Types of services

	Mainline service	*Suburban service*	*Urban service*
Distance between stops in km	More than 10	1–8	1
Maximum speed in kmph	160	120	120
Acceleration in kmphp	0.5–0.9	1.5–4	1.5–4
Retardation in kmphp	1.5	3–4	3–4
Features	Long free-run period, coasting and acceleration braking periods are small	No free-running period, coasting period is long	No free-running period, coasting period is small

SOME DEFINITIONS

Crest speed

The maximum speed attained by the train during run is known as crest speed. It is denoted with '*V*m'.

Average speed

It is the mean of the speeds attained by the train from start to stop, i.e., it is defined as the ratio of the distance covered by the train between two stops to the total time of rum. It is denoted

$$\therefore \text{Average speed} = \frac{\text{distance between stops}}{\text{actual time of run}}$$

$$V_a = \frac{D}{T},$$

with '*V*a'.

Where *V*a is the average speed of train in kmph, *D* is the distance between stops in km, and *T* is the actual time of run in hours.

Schedule speed

The ratio of the distance covered between two stops to the total time of the run including the time for stop is known as schedule speed. It is denoted with the symbol '*V*s'.

where *T*s is the schedule time in hours.

Schedule time

It is defined as the sum of time required for actual run and the time required for stop.

i.e., *T*s = *T*run + *T*stop.

FACTORS AFFECTING THE SCHEDULE SPEED OF A TRAIN

The factors that affect the schedule speed of a train are:

1. Crest speed.
2. The duration of stops.
3. The distance between the stops.
4. Acceleration.
5. Braking retardation.

1.Crest speed

It is the maximum speed of train, which affects the schedule speed as for fixed acceleration, retardation, and constant distance between the stops. If the crest speed increases, the actual running time of train decreases. For the low crest speed of train it running so, the high crest speed of train will increases its schedule speed.

2. Duration of stops

If the duration of stops is more, then the running time of train will be less; so that, this leads to the low schedule speed. Thus, for high schedule speed, its duration of stops must be low.

3.Distance between the stops

If the distance between the stops is more, then the running time of the train is less; hence, the schedule speed of train will be more.

4. Acceleration

If the acceleration of train increases, then the running time of the train decreases provided the distance between stops and crest speed is maintained as constant. Thus, the increase in acceleration will increase the schedule speed.

5. Breaking retardation

High breaking retardation leads to the reduction of running time of train. These will cause high schedule speed provided the distance between the stops is small..

SIMPLIFIED TRAPEZOIDAL AND QUADRILATERAL SPEED TIME CURVES

Simplified speed–time curves gives the relationship between acceleration, retardation average speed, and the distance between the stop, which are needed to estimate the performance of a service at different schedule speeds. So that, the actual speed–time curves for the main line, urban, and suburban services are approximated to some from of the simplified curves. These curves may be of either trapezoidal or quadrilateral shape. Analysis of trapezoidal speed–time curve Trapezoidal speed–time curve can be approximated from the actual speed–time curves of different services by assuming that:

- The acceleration and retardation periods of the simplified curve is kept same as to that of the actual curve.
- The running and coasting periods of the actual speed–time curve are replaced by the constant periods.

This known as trapezoidal approximation, a simplified trapezoidal speed–time curve is shown in fig 5.7,

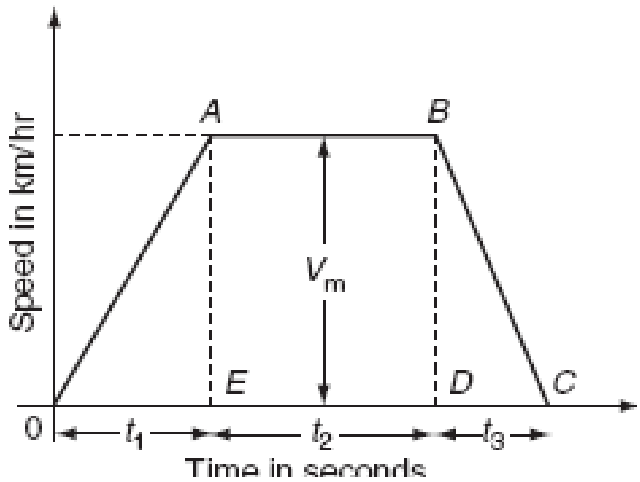


Fig. 5.7 Trapezoidal speed–time curve

Calculations from the trapezoidal speed–time curve

Let *D* be the distance between the stops in km, *T* be the actual running time of train in second, α be the acceleration in km/h/sec, β be the retardation in km/h/sec, *V*m be the maximum or the crest speed of train in km/h, and *V*a be the average speed of train in km/h. From the Fig. 5.7.

Actual running time of train, $T = t_1 + t_2 + t_3$. **(5.1)**

Time for acceleration, $t_1 = \frac{V_m - 0}{\alpha} = \frac{V_m}{\alpha}$. **(5.2)**

Time for retardation, $t_3 = \frac{V_m - 0}{\beta} = \frac{V_m}{\beta}$. **(5.3)**

$\therefore$ Time for free-running period, $t_2 = T - (t_1 + t_3)$

$$= T - \left[\frac{V_m}{\alpha} + \frac{V_m}{\beta}\right]. \quad \textbf{(5.4)}$$

Area under the trapezoidal speed–time curve gives the total distance between the two stops (*D*).

$\therefore$ The distance between the stops (*D*) = area under triangle *OAE* + area of rectangle *ABDE* + area of triangle *DBC*= The distance travelled during acceleration + distance travelled during free running period + distance travelled during retardation.

Now:

The distance travelled during acceleration = average speed during accelerating period × time for acceleration

$$= \frac{0 + V_m}{2} \times t_1 \text{ km/h} \times \text{sec}$$

$$= \frac{0 + V_m}{2} \times \frac{t_1}{3,600} \text{ km.}$$

The distance travelled during free-running period = average speed × time of free running

$$= V_m \times t_2 \text{ km/h} \times \text{sec}$$

$$= V_m \times \frac{t_2}{3,600} \text{ km.}$$

The distance travelled during retardation period = average speed × time for retardation

$$= \frac{V_m + 0}{2} \times t_3 \text{ km/h} \times \text{sec}$$

$$= \frac{0 + Vm}{2} \times \frac{t_3}{3.600} \text{km.}$$

The distance between the two stops is:

$$D = \frac{V_m}{2} \times \frac{t_1}{3.600} + V_m \times \frac{t_2}{3.600} + \frac{V_m}{2} \times \frac{t_3}{3.600}$$

$$D = \frac{V_m t_1}{7,200} + \frac{V_m}{3,600}\left[T - V_m(t_1 + t_2)\right] + \frac{V_m t_3}{7,200}$$

$$D = \frac{V_m^{\ 2}}{7,200\alpha} + \frac{V_m}{3,600}\left[T - V_m\left(\frac{1}{\alpha} + \frac{1}{\beta}\right)\right] + \frac{V_m^{\ 2}}{7,200\beta}$$

$$3,600 \times D = \frac{V_m^{\ 2}}{2\alpha} + \frac{V_m^{\ 2}}{\beta} - V_m^{\ 2}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right) + V_m T$$

$$3,600\ D = V_m^{\ 2}\left(\frac{1}{2\alpha} - \frac{1}{\alpha}\right) + V_m^{\ 2}\left(\frac{1}{2\beta} - \frac{1}{\beta}\right) + V_m T$$

$$3,600\ D = \frac{-V_m^{\ 2}}{2\alpha} - \frac{V_m^{\ 2}}{2\beta} + V_m T$$

$$\therefore V_m^{\ 2}\left[\frac{1}{2\alpha} + \frac{1}{2\beta}\right] - V_m T + 3,600 D = 0.$$

$$\text{Let } \frac{1}{2\alpha} + \frac{1}{2\beta} = X = \frac{\alpha + \beta}{2\alpha\beta}$$

$$\therefore V_m^{\ 2} X - V_m T + 3,600 D = 0. \qquad \textbf{(5.5)}$$

Solving quadratic Equation (5.5), we get:

$$V_{\mathrm{m}} = \frac{T + \sqrt{T^2 - 4\times X \times 3,600D}}{2\times X.}$$

$$= \frac{T}{2X} \pm \sqrt{\frac{T^2}{4X^2} - \frac{3,600D}{X}}.$$

By considering positive sign, we will get high values of crest speed, which is practically not possible, so negative sign should be considered:

$$V_m = \frac{T}{2X} - \sqrt{\frac{T^2}{4X^2} - \frac{3,600D}{X}} \qquad \textbf{(5.6)}$$

Or, $$V_m = \frac{\alpha\beta}{\alpha+\beta}T - \sqrt{\left(\frac{\alpha\beta}{\alpha+\beta}\right)^2 T^2 - 7,200\left(\frac{\alpha\beta}{\alpha+\beta}\right)D}$$

Analysis of quadrilateral speed–time curve

Quadrilateral speed–time curve for urban and suburban services for which the distance between two stops is less. The assumption for simplified quadrilateral speed–time curve is the initial acceleration and coasting retardation periods are extended, and there is no free-running period. Simplified quadrilateral speed–time curve is shown in Fig. 5.8.

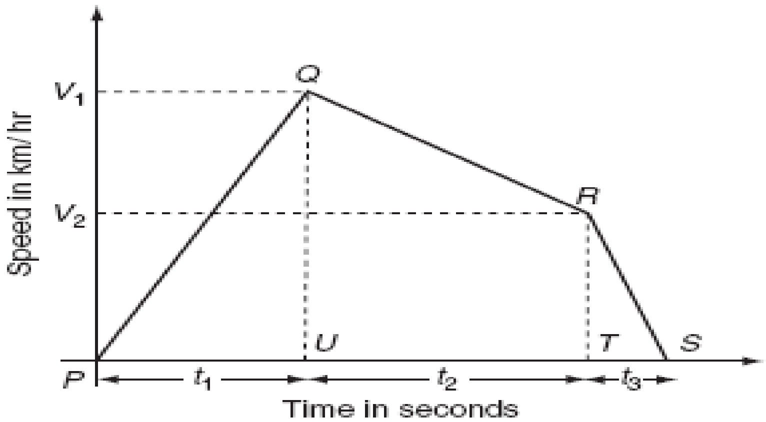


Fig.5.8 Quadrilateral speed–time curve

Let $V1$ be the speed at the end of accelerating period in km/h, $V2$ be the speed at the end of coasting retardation period in km/h, and βc be the coasting retardation in km/h/sec.

Time for acceleration,

$$t_1 = \frac{V_1 - 0}{\alpha} = \frac{V_1}{\alpha}$$

Time for coasting period,

$$t_2 = \frac{V_2 - V_1}{\beta}$$

Time period for braking retardation period,

$$t_3 = \frac{V_2 - 0}{\beta} = \frac{V_2}{\beta}$$

Total distance travelled during the running period *D*: = the area of triangle *PQU* + the area of rectangle *UQRS* + the area of triangle *TRS*.

= the distance travelled during acceleration + the distance travelled during coastingretardation + the distance travelled during breaking retardation.

But, the distance travelled during acceleration = average speed × time for Acceleration

$$= \frac{0 + V_1}{2} \times t_1 \text{ km/h} \times \text{sec}$$

$$= \frac{V_1}{2} \times \frac{t_1}{3,600} \text{km.}$$

The distance travelled during coasting retardation= $\frac{V_2 + V_1}{2} \times t_2 \text{ km/h} \times \text{sec}$

$$= \frac{V_2 + V_1}{2} \times \frac{t_2}{3,600} \text{km}$$

The distance travelled during breaking retardation = average speed × time for breaking retardation

$$= \frac{0 + V_2}{2} \times t_3 \text{km/h} \times \text{sec}$$

$$= \frac{V_2}{2} \times \frac{t_3}{3,600} \text{km.}$$

∴ Total distance travelled:

∴ Total distance travelled:

$$D = \frac{V_1}{2} \times \frac{t_1}{3,600} + \frac{(V_1 + V_2)}{2} \frac{(t_2)}{3,600} + \frac{V_2}{2} \times \frac{t_3}{3,600}$$

$$= \frac{V_1 t_1}{7,200} + \frac{(V_1 + V_2) t_2}{7,200} + \frac{V_2 t_3}{7,200}$$

$$= \frac{V_1}{7,200}(t_1 + t_2) + \frac{V_2}{7,200}(t_2 + t_3)$$

$$= \frac{V_1}{7,200}(T - t_3) + \frac{V_2}{7,200}(T - t_1)$$

$$= \frac{(V_1 + V_2)T}{7,200} - \frac{V_1 t_3}{7,200} - \frac{V_2 t_1}{7,200}$$

$$= \frac{(V_1 + V_2)T}{7,200} - \frac{V_1 V_2}{7,200\beta} - \frac{V_1 V_2}{7,200\alpha}$$

$$= \frac{\mathrm{T}}{7,200}(V_1 + V_2) - \frac{V_1 V_2}{7,200}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right)$$

$$7,200D = (V_1 + V_2)\mathrm{T} - V_1 V_2\left(\frac{1}{\alpha} + \frac{1}{\beta}\right). \quad \mathbf{(5.7)}$$