# MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

**(Autonomous Institution – UGC, Govt. of India)**

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Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India

# DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

**DIGITAL NOTES for INDUSTRIAL AND ALLIED ELECTRICAL SYSTEMS**

***For***

**B.Tech (EEE) – IV YEAR – II SEMESTER**

**Prepared by**

***Mr. H.RAMESH, Assistant Professor/ EEE***

# MALLA REDDY COLLEGE OF ENGINEERING AND TECHNOLOGY

**IV B.Tech EEE II Sem** **L T/P/DC**

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## (PROFESSIONAL ELECTIVE-IV)

## (R18A0222) 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.
- Introduce various methods of effectively and efficiently utilizing electrical energy for different and desired applications.
- Teach the various electrical lighting principles and their applications.

## UNIT - I

**ILLUMINATION:** Introduction, terms used in illumination, laws of illumination, polar curves, and 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, Types of earthing, requirements of commercial installation, deciding lighting scheme and number of lamps.

## 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, 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. Adhesive weight and coefficient of adhesion.

## TEXT BOOKS:

1. J.B. Gupta, “Utilization of Electric Power and Electric Traction”, Kataria & Sons publishers, Delhi, IX Edition, 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. Open shaw Taylor, Orient Longman PrivateLimited,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.
- Applications of electrical equipment’s in different types of industries.
- Work in the areas of UPS systems and traction systems production, commissioning and maintenance.

# UNIT-1
# ILLUMINATION

**Syllabus:** Introduction, terms used in illumination, laws of illumination, polar curves, and 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.

**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 $=10^{-10}m$). 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 $0.0000156 \times 10^{-6}$m to $0.001 \times 10^{-6}$m are not in thevisible 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 and7500 Å. The color of the radiation corresponding to the wavelength is shown in Fig. 1.1.

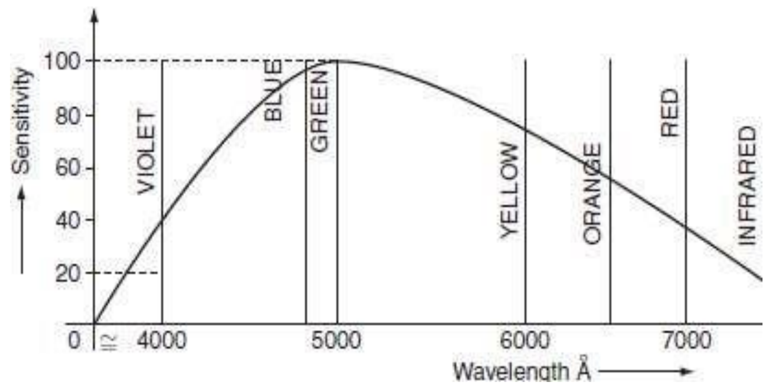



**Fig.** 1.1.Wavelength

**Relative Sensitivity:**

The reacting power of the human eye to the light waves of different wave lengths 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 wave lengths and red to the long wave lengths, orange, yellow, and green being in the middle of the visible region of wave length. The color corresponding to 5,500Å is not suitable for most of the applications since yellowish green. The relative sensitivity at any particular wavelength ($\lambda$) is known as relative luminous factor ($K\lambda$).

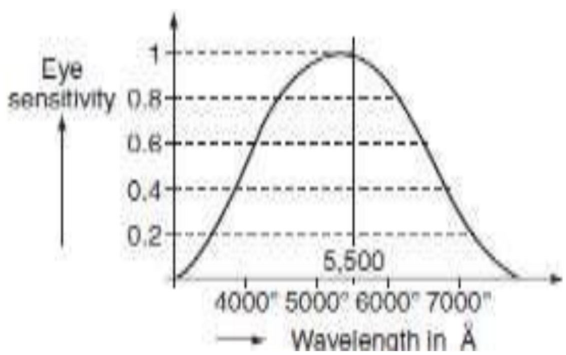



**Fig. 1.2** The average relative sensitivity

**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 watt hours, which denoted by the symbol 'Q'.

**Luminous flux:**

It is defined as the energy in the form of light waves radiated per second from aluminous body. It is represented by the symbol '∅' 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. A fraction of the remaining radiant flux is in the form of light wave's lies in between the visual range of wavelength, i.e. between 4,000 and 7,000 Å, as shown in Fig. 1.3.

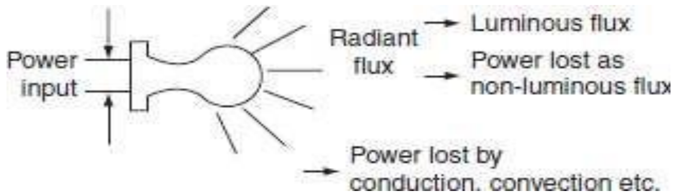



**Fig. 1.3** Flux diagram

**Radiant efficiency:**

When an electric current is passed through a conductor, some heat is produced to I2R 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'.

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

**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 is equals to the radius of the circle.

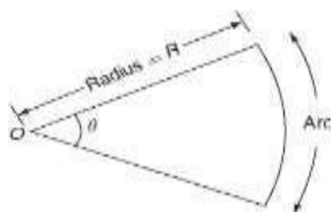



**Fig. 1.4** Plane angle

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

**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 steradians

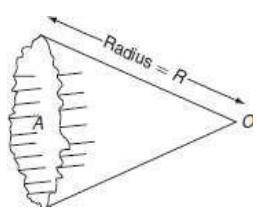



**Fig.1.5** Solid angle

$$\text{Solid angle } (\omega) = \frac{Area}{Radius^2}$$

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

$$\omega = \frac{Area\ of\ sphere}{Radius^2}$$

$$\omega = \frac{4\pi R^2}{R^2} = 4\Pi \text{ steradians}$$

**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.

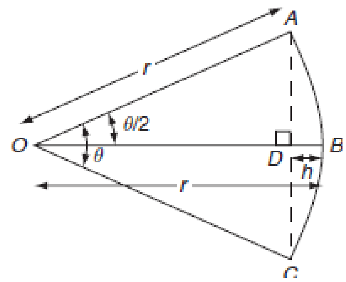



**Fig.1.6** Sectional view for solid angle

From the Fig. 1.6. BD = OB – OD

$$h = r - r\cos(\frac{\theta}{2}) \qquad [\text{from } \Delta ODA, OD = r\cos\frac{\theta}{2}]$$

$$h = r\,(1-\cos\frac{\theta}{2})$$

The surface area of the segment = 2πrh

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

$$\text{Solid angle } (\omega) = \frac{Area}{Radius^2}$$

$$= \frac{2\pi r^2(1-cos\frac{\theta}{2})}{r^2}$$

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

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

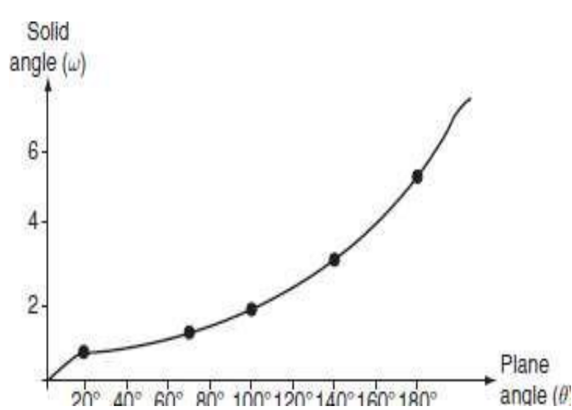



**Fig. 1.7** Relation between solid angle and plane angle

**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).

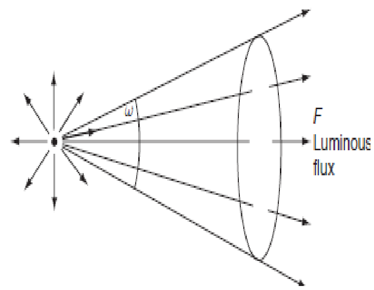



**Fig. 1.8** Luminous flux emitting from the source

It is denoted by the symbol 'I' and is usually measured in 'candela'. Let 'F' be the luminous flux crossing a spherical segment of solid angle 'ω'. Then luminous intensity lumen/ steradians or candela is,

$$I = \frac{F}{\omega}$$

**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.

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

**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/$m^2$ or meter candela

$$\text{Illumination (E)} = \frac{luminous\ flux}{Area}$$

$$E = \frac{\emptyset}{A} = \frac{CPX\omega}{A} \text{ Lux}$$

**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 = $\frac{1\,lumen}{(ft)^2}$

1 foot candle = $\frac{lumen}{(\frac{1}{3.28})^2}$

1foot candle = 10.76 lux or m-candle

**Brightness:**

Brightness of any surface is defined as the luminous intensity per 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 A cosθ.

The unit of brightness is candela/$m^2$ or candela/$cm^2$ or candela/$(ft)^2$

Brightness, L =$\frac{I}{Acos\theta}$

**Relation between I, E, and L:**

Let us consider a uniform diffuse sphere with radius r meters and luminous intensity I candela. Then,

Brightness, L =$\frac{I}{\pi r^2}$

Luminous intensity (I) = $\frac{\emptyset}{\omega}$

Illumination (E) = $\frac{\emptyset}{A} = \frac{I\omega}{4\pi r^2}$

Area of sphere = $4\pi r^2$ and solid angle of sphere =$4\pi$

E= $\frac{I \times 4\pi}{4\pi r^2}$

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

Multiplying numerator and denominator with$\pi$

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

E = $\frac{\pi I}{\pi\, r^2}$

**E = $\boldsymbol{\pi L}$**

**Mean horizontal candle power (MHCP):**

It is defined as the mean of candle powers in all directions in the horizontal plane containing the source of light.

**Mean spherical candle power (MSCP):**

It is defined as the mean of the candle powers in all directions and in all planes from the source of light.

**Mean hemispherical candle power (MHSCP):** It is defined as the mean of candle powers in all directions above or below the horizontal plane passing through the source of light.

**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.

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

**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.

$$\text{Lamp efficiency} = \frac{\text{luminiousflux}}{\text{Powerinput}}$$

**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.

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

**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.

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

**Depreciation factor:**

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

$$\text{Depreciation factor} = \frac{1}{\text{Maintenance factor}}$$

**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.

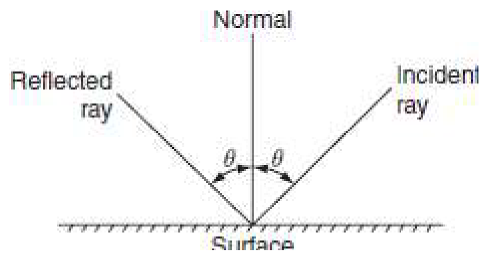



**Fig.1.9** Reflected ray

**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.

**Problems:**

**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 MSCP of the lamp and

2. The efficiency of the lamp.

**Solution:**

Given V = 200 V

I = 1.2 A

Flux = 2,860 lumens.

1. MSCP = $\frac{Total\ flux}{4\pi}$

$= \frac{2860}{4\pi}$ =227.59

2. Lamp efficiency = $\frac{luminiousflux}{Powerinput}$

$= \frac{luminiousflux}{V \times I} = \frac{2860}{200 \times 1.2}$ = 11.91

**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 80lumens/W and the coefficient of utilization is 0.65.Find the average illumination.

**Solution:**

Given,

Room area = 6 × 9 = 54$m^2$.

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

$$\text{Illumination E} = \frac{luminous\ flux}{Area}$$

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

$$E = \frac{41600}{54} = 770.37 \text{ lux}$$

**Example 1.3:** The luminous intensity of a lamp is 600 CP. Find the flux given out.

**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 250milli-lumens/m2 in all directions. Calculate the candlepower of the globe and the percentage of light absorbed by the globe.

**Solution:**

Flux emitted by the globe = brightness × globe area

$$= \left(\frac{250}{1000}\right) \times \left(4\pi \left(\frac{40}{2}\right)^2\right)$$

= 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.

The percentage of light absorbed by the globe = $\frac{143.36}{1400} \times 100 = 10.24\%$

**LAWS OF ILLUMINATION:**

Mainly there are two laws of illumination.

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

1. **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.

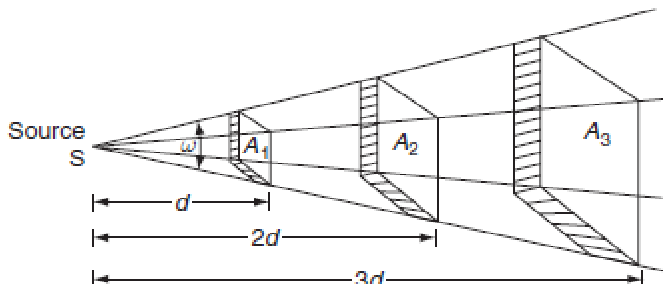



**Fig. 1.10** Inverse square law

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

Luminous flux reaching the area $A_1$ = luminous intensity × solid angle

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

∴ Illumination '$E_1$' on the surface area '$A_1$' is:

$$E_1 = \frac{\text{Flux}}{\text{Area}} = \frac{IA_1}{d^2} \times \frac{1}{A_1}$$

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

Similarly, illumination '$E_2$' on the surface area $A_2$ is:

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

and illumination '$E_3$' on the surface area $A_3$ is:

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

From Equations$E_1, E_2, E_3$:

$$E_1 : E_2 : E_3 = \frac{I}{d^2} : \frac{I}{(2d)^2} : \frac{I}{(3d)^2}$$

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

**2. 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.

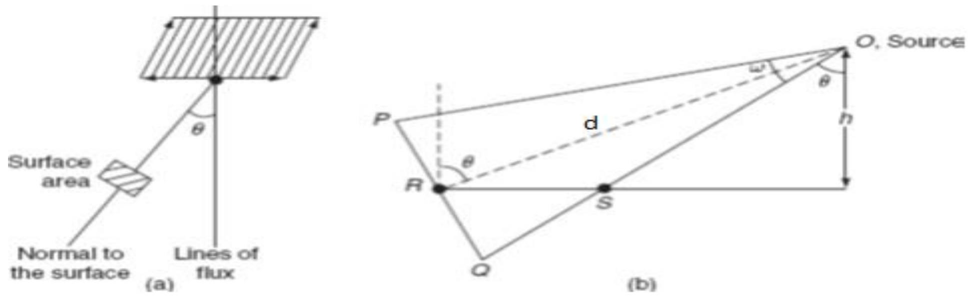



**Fig. 1.11** Lambert's cosine law

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:

$$PQ = RS\cos\theta$$

The illumination of the surface PQ, $E_{PQ} = \frac{flux}{area\ of PQ}$

$$= \frac{I\times\omega}{area\ of PQ} = \frac{I}{area\ of PQ} \times \frac{area\ of\ PQ}{d^2} \qquad (\omega = {}^{area}/_{radius^2})$$

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

The illumination of the surface RS, $E_{RS} = \frac{flux}{area\ of RS}$

$$= \frac{flux}{area\ of {}^{PQ}/_{cos\theta}} [\ PQ = RS\cos\theta]$$

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

From Fig. 1.11(b): $cos\theta = \frac{h}{d}$

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

Substituting 'd' in above Equation

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

$$E_{RS} = \frac{I}{d^2}\ cos\theta = \frac{I}{h^2} cos^3\theta$$

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, the above Equation 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.

**Problems:**

**Example 1.5:** The illumination at a point on a working plane directly below the lamp is to be 60lumens/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.

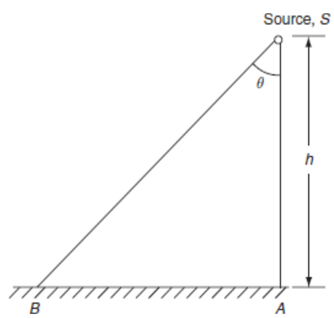
**Solution:**

Given data:

Candle power of the lamp = 130 CP.

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

From the below fig. the illumination just below the lamp, i.e., at point A:




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

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

The illumination at point 'B':

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

$$= \frac{130}{(2.8)^2} \{\frac{2.8}{\sqrt{2.8^2+1.471^2}}\}^3$$

$$E_B = 11.504\ lux$$

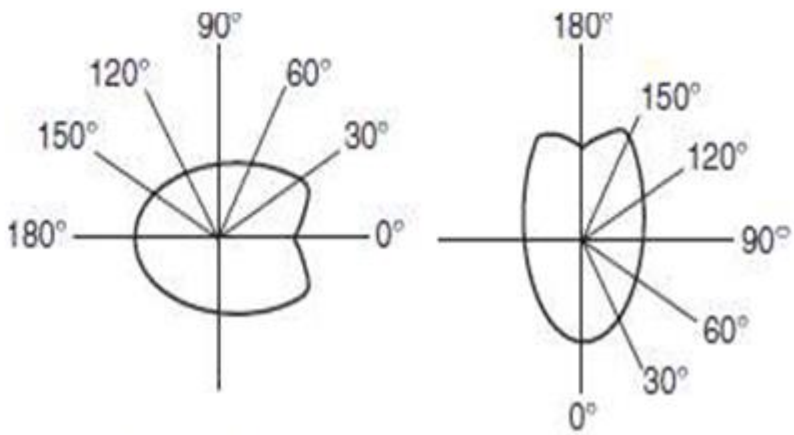
**POLAR CURVES:**

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:

1. 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.

2. A 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'.




(a) Horizontal polar curve (b) vertical polar curve

**Fig 1.12.** Typical polar curves for an ordinary lamp.

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 $XOX'$ axis. A simple Rousseau's curve is shown in Fig. 1.13.

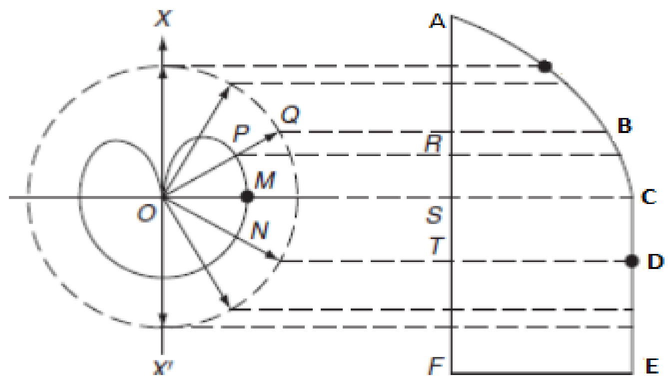



**Fig. 1.13** Rousseau's curve

**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 $\mathrm{XO}X'$ and is equal to the vertical diameter of the circle.
- Draw any line 'OPQ' in such a way that the line meeting the polar curve at point 'P' and the circle at point 'Q'. Now let the projection be 'R' onto the parallel line 'AF'.
- Erect an ordinate at 'R' as, RB = OP.
- Similarly draw the other ordinates, 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 ABCDEFA 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

$$\text{The mean ordinate of the curve} = \frac{area\ of\ ABCDEFA}{length\ of\ AF}$$

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 (2-3)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. 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.

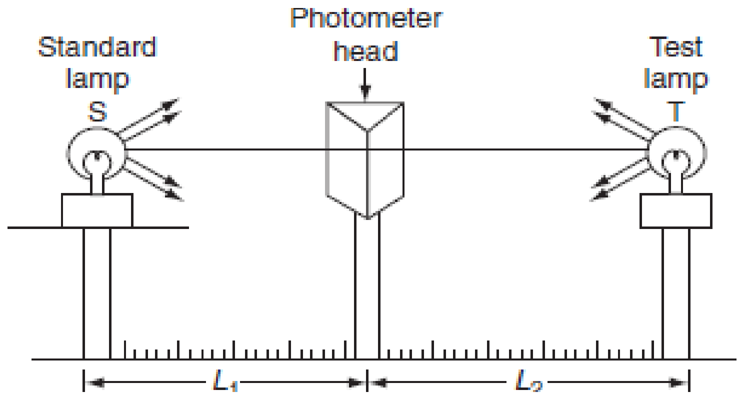



**Fig.1.14** Measurement of candle power

$$Candle power of standard source \propto L_1^2$$

$$Candle power of test source \propto L_2^2$$

$$Candle power of test source Candle power of standard source \propto \frac{L_1^2}{L_2^2} = S\frac{L_1^2}{L_2^2}$$

In order to obtain the accurate candle power of test source, the distance of the sources from the photometer head should be measured accurately.

The photometer heads that are most common in use are:

(1) Bunsen grease spot photometer

(2) Lumer - Brodhun photometer

**SOURCES OF LIGHT:**

**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 LIGHT:**

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,
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.

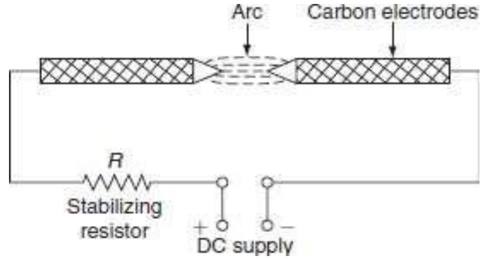



**Fig 1.15** Carbon arc lamp

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 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.

**2. 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 series with the electrodes to stabilize the arc.

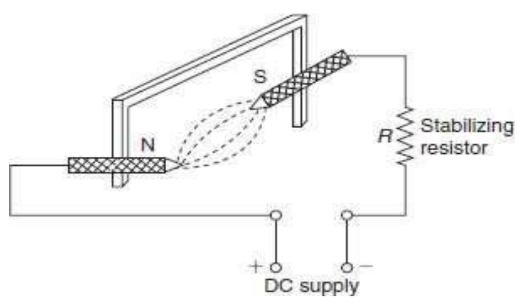



**Fig. 1.16** Flame arc lamp

**3. 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.

**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 ($\alpha$) is –0.0002 to – 0.0008.
- The efficiency of carbon filament lamp is low; because of its low operating temperature, large electrical input is required. The commercial efficiency of carbon lamp is 3 – 4.5 lumens/W approximately.
- Carbon has high resistivity ($\rho$), which is about 1,000–7,000 μΩ-cm and its density is 1.7–3.5.

**Osmium:**

- The melting point of osmium is 2,600°C.
- It is very rare and expensive metal.
- The average efficiency of osmium lamp is 5 lumens/W.

**Tantalum:**

- The melting point of tantalum is 3,000°C. 2 Resistivity ($\rho$) is 12.5 μΩ-cm.
- The main drawback of the negative temperature coefficient of carbon is overcome in tantalum. It has positive temperature coefficient ($\alpha$) and its value is 0.0036.
- The density of tantalum is 16.6.
- The efficiency of tantalum lamp is 2 lumens/W.

**Tungsten:**

- The working temperature of tungsten is 2,500–3,000°C.
- Its resistance at working temperature is about 12–15 times the cold resistance.
- It has positive temperature coefficient of resistance of 0.0045.
- Its resistivity is 5.6 12.5 μΩ-cm.
- The density of tungsten is 19.3.
- The efficiency of tantalum when working at 2,000°C is 18 lumens/W.
- 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 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 oxides 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 toothier melting point and then hammered at red-hot position and rerolled into wires.

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.

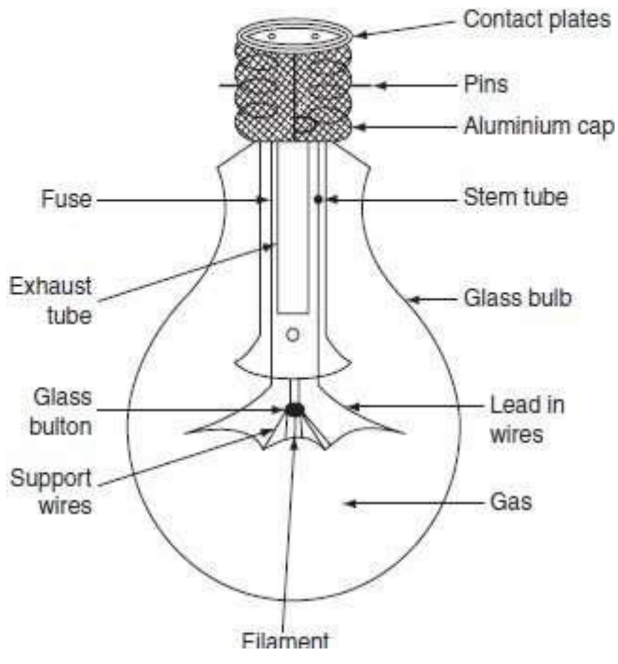



**Fig. 1.17** Incandescent lamp

**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.

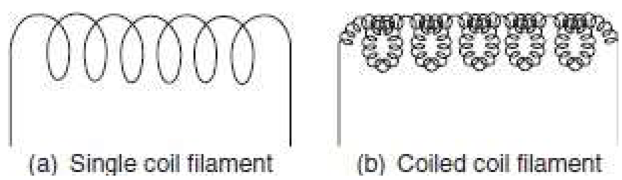



**Fig. 1.18** Various filaments used in incandescent lamps

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.1.19

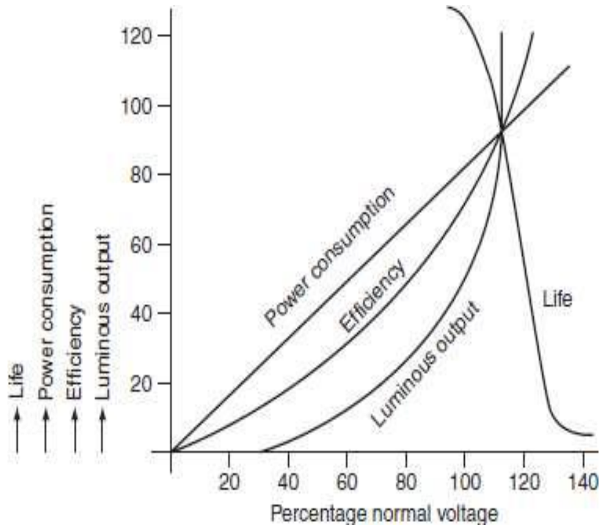



**Fig.1.19**. Performance characteristics of incandescent lamp

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.
- Luminous efficiency $\propto(\text{voltage})^2$.
- Life ∝ (voltage)–13 (for vacuum lamps).
- 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,

$$P = I^2R = I^2\frac{\rho l}{a}(\therefore \text{R} = \frac{\rho l}{a})$$

$$= \frac{I^2 \times \rho l}{(\pi d^2/_4)}(\therefore \text{a} = \pi d^2/_4)$$

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

Where, I is the current taken by the lamp in A,

a is the filament cross-section in sq. m,

ρ is the resistivity of the filament at working temperature in Ω-m,

l is the length of the filament in m

d 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.

$$\text{Heat dissipated} \propto \text{surface area} \times \text{emissivity}$$

$$\text{Heat dissipated} \propto \pi dl \times e$$

At the steady state condition, the power input should be equal to the heat dissipated. From above two Equations we can write that

$$I^2 \times \frac{4\rho l}{\pi d^2} \propto \pi dl \times e I^2 4\rho l \ \propto \pi^2 d^3 l \times e$$

$$I^2 \propto d^3 \text{ (or) } I \propto d^{3/2}$$

If two filaments are made up of same material, working at same temperature and efficiency but with different diameters, then from the above Equation.

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

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

$$\text{Lumen output} \propto I_1 d_1 \propto I_2 d_2$$

$$I_1 d_1 \propto I_2 d_2 = Constant$$

**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 lamps. 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 luminance. 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.

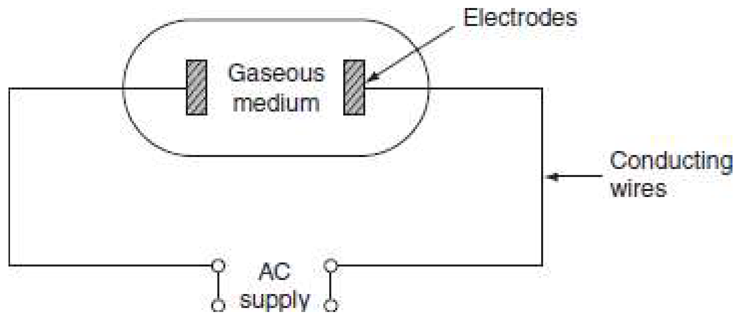



**Fig.1.20.** Discharge lamps

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 are negative, i.e., gaseous discharge lamp possesses 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 lamps, sodium vapor lamps, and mercury vapor lamps.

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, and then the invisible UV rays absorbed by the phosphors and radiate 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**

The discharge lamps suffer from the following drawbacks.

1. The starting of the discharge lamps requires starters and transformers; therefore, the lamp circuitry is complex.

2. High initial cost.

3. Poor power factor; therefore, the lamps make use of the capacitor.

4. Time required to give its full output brilliancy is more.

5. These lamps must be placed in particular position.

6. These lamps require stabilizing choke to limit current since the lamps have negative resistance 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.

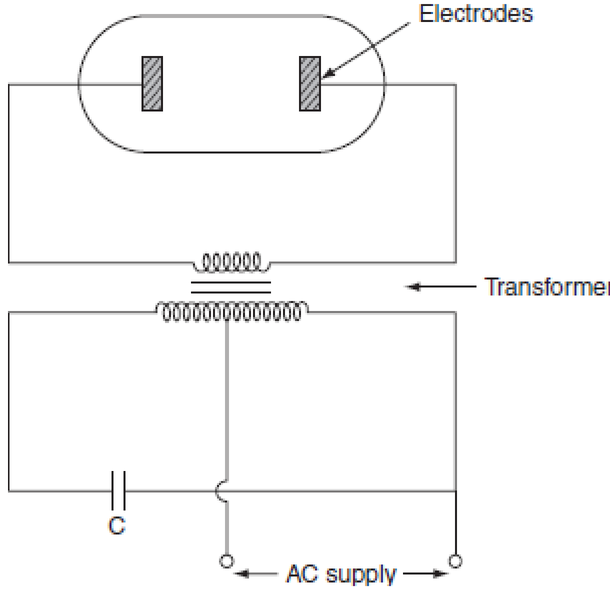



**Fig.1.21**. Neon lamps

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 electromagnetic radiation reddish in color. The sizes of electrodes used are equal for AC 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

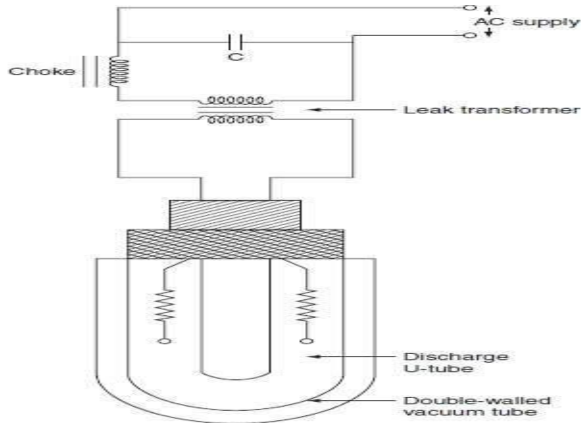



**Fig.1.22** Sodium vapor lamp

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 long U tube 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 thee 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 are300°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.

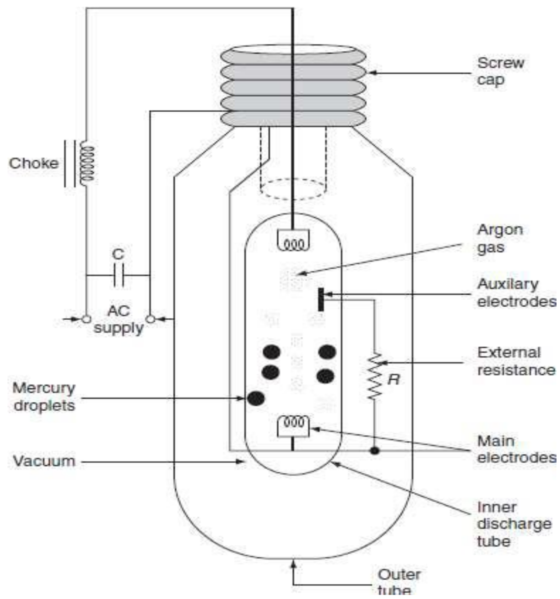



**Fig.1.23**. MA type lamp

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. 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. 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 is30–40 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.

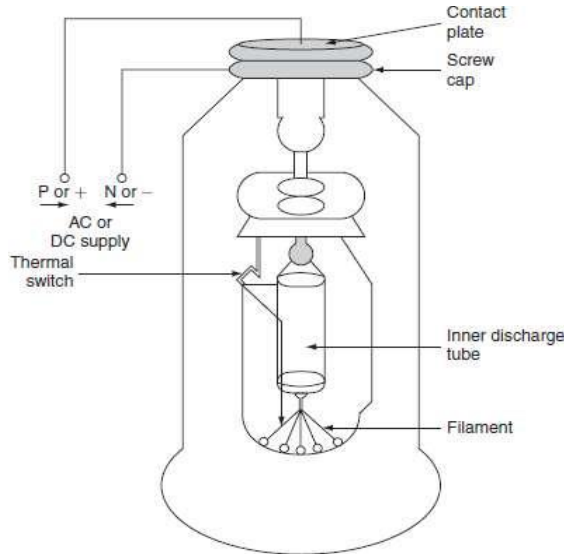



**Fig.1.24.** MAT type lamp

**MB type lamp:**

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

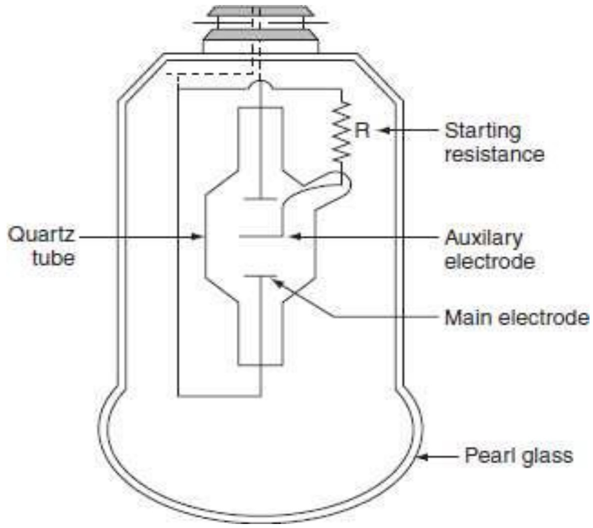



**Fig.1.25** MB type lamp

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.

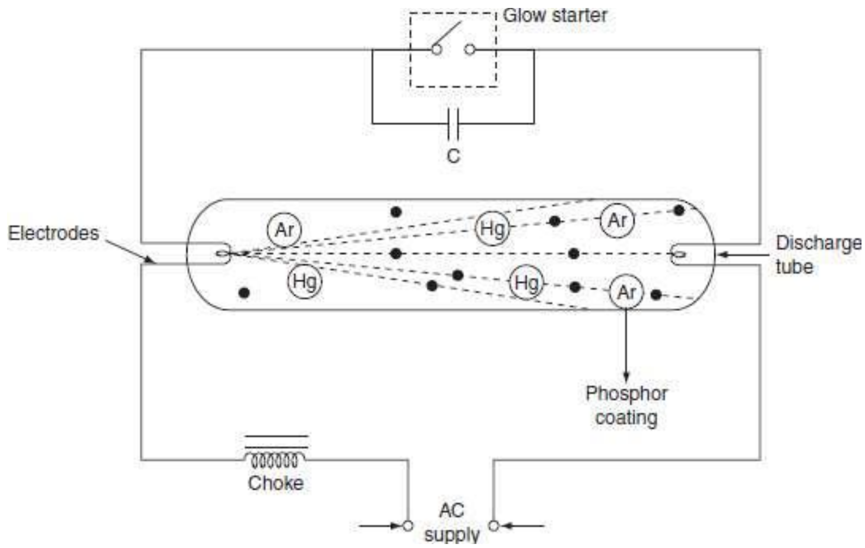



**Fig.1.26.** Fluorescent lamp

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.

| | | |
|---|---|---|
| 1 | Zinc silicate | Green |
| 2 | Calcium tungstate | Green |
| 3 | Magnesium tungstate | Bluish while |
| 4 | Cadmium silicate | Yellowish Pink |
| 5 | Zinc beryllium silicate | Yellowish while |
| 6 | Cadmium borate | Pink |

**Advantages of fluorescent lamp:**

- Compared to filament lamps, the efficiency is 3 to 4 times more in fluorescent lamps means these lamps has High efficiency.
- The life of the lamp is three times of the ordinary filament lamp.
- The quality of the light obtained is much superior. Gives diffused, glare free, shadow less and cool white light.
- These lamps can be mounted on low ceiling, where other light sources would be unsatisfactory.
- Lower power consumption.
- No warming up period is required as in the case of other discharge lamps.
- Low heat radiation
- Different color lights can be obtained using different types of fluorescent powders.

**Disadvantages of fluorescent lamp:**

- 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.

**Comparison between Tungsten Filament Lamps and Fluorescent Lamps:**

| INCANDESCENT LAMPS | FLUORESCENT LAMPS |
|---|---|
| 1. Initial cost is less.<br>2. Fluctuation in supply voltage has less effect on light output, as the variations in voltage are absorbed in choke.<br>3. It radiates the light, the color of which resembles the natural light.<br>4. It works on Ac as well as DC<br>5. The luminous efficiency of the lamp is high that is about 8 – 40 lumens/w<br>6. Different color lights can be obtained by using different colored glasses<br>7. Brightness of the lamp is more.<br>8. The reduction in light output of the lamp is comparatively high, with the time<br>9. The working temperature is about $2000^0c$<br>10. The normal working life is 1000 hrs<br>11. No stroboscopic effect<br>12. Filament lamps convert 10% of electrical energy in to light and 90% into heat energy.<br>13. It is filled with inert gases or $N_2$.<br>14. Incandescent lamps produces light by heating a metallic filament until it starts to radiate light<br>15. These lamps are widely used for domestic, industrial and street lighting.<br>16. The lumpiness efficiency increases with the increase in the voltage of the lamp. | 1. Initial cost is more.<br>2. Fluctuation in supply voltage has comparatively more effect on the light output.<br>3. It does not give light close to the natural light.<br>4. Change of supply needs additional equipment.<br>5. The luminous efficiency is poor which is about 8 – 10 lumens/w<br>6. Different color lights can be obtained by using different composition of fluorescent powders.<br>7. Brightness of the lamp is less<br>8. The reduction in light output of the lamp is comparatively low, with the lamp<br>9. The working temperature is about $50^0c$<br>10. The normal working life is 5000 - 7500 hr<br>11. Stroboscopic effect is present<br>12. Fluorescent lamps convert 30% of electrical energy in to light and 70% into heat energy.<br>13. It is filled with mercury vapor.<br>14. Fluorescent lamps produced light by exciting a gas and causing it to glow<br>15. These lamps are widely used for domestic, industrial and flood lighting.<br>16. The lumpiness efficiency increases with the increase in voltage and the increase in the length of the tube. |

**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. Diffusion
4. Absorption

**1. 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.
- 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. Surface that is almost free from reflection is called a matt surface.

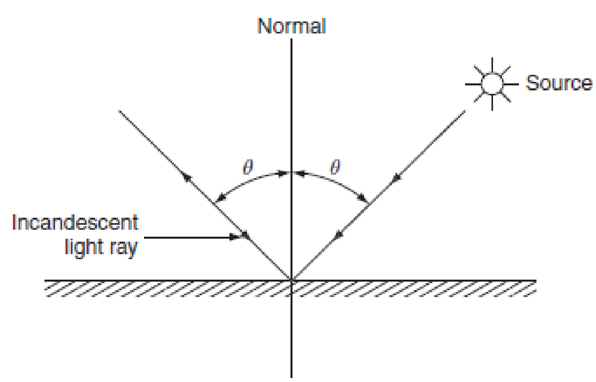



**Fig. 1.27** Specular reflection

**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. In this reflection, observer will be able to see the illuminated surface but not the light source.

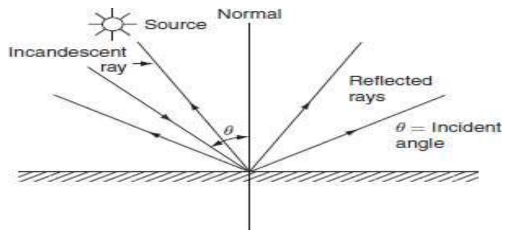



**Fig. 1.28** Diffuse reflection

**2. Refraction:**

When a light ray is incident on the surface separating two media, the direction of the ray changes. This phenomenon is known as the Refraction of light. The speed of light is maximum in the vacuum. In any medium, light travels with less speed. Due to this, the direction of light changes at the interface of two different media. The frequency of the incident light remains constant but the speed and wavelength change.

When a light ray enters a denser medium, it bends closer to the normal whereas for a lighter medium, the ray shifts away from the normal. Below Figure shows the refraction of light ray from dense medium to rare medium where $\mu 1$ and$\mu 2$ are the refractive indices of two medium, $\theta$ is the angle of incidence, and $\alpha$ is the angle of refraction. The angle of light ray with normal is comparatively less in dense medium than in rare medium.

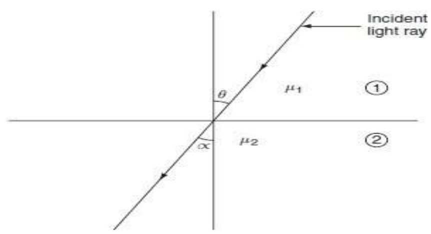



**Fig. 1.29** Refraction

**Laws of Refraction:**

Refraction is governed by the two laws as follows,

1. The incident ray, refracted ray and the normal to the refracting surface at the point of incidence, belong to the same plane.
2. **Snell's Law**: The ratio of the sine of the angle of incidence (angle between the incident ray and the normal) to the sine of the angle of refraction (angle between the refracted ray and the normal) is constant. The constant depends on the two media and the wavelength of the incident light.

$$\frac{\sin \theta}{\sin \alpha} = Constant$$

**3. 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.

**4. Absorption:**

Light absorption is a process by which light is absorbed and converted into energy. The absorption of light is therefore directly proportional to the frequency. If they are complementary, light is absorbed. If they are not complementary, then the light passes through the object or gets reflected.

An example of this process is photosynthesis in plants. However, light absorption doesn’t occur exclusively in plants, but in all creatures/inorganic substances. Absorption depends on the electromagnetic frequency of the light and object’s nature of atoms.

Absorption depends on the state of an object‘s electron. All electrons vibrate at a specific frequency, which is known as their "natural" frequency. When light interacts with an atom of the same frequency, the electrons of the atom become excited and start vibrating. During this vibration, the electrons of the atom interact with neighboring atoms and convert this vibration energy into thermal energy.

Consequently, the light energy is not to be seen again, that is why absorption differs from reflection and transmission. And since different atoms and molecules have different natural frequencies of vibration, they selectively absorb different frequencies of visible light.

**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. Semi direct 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.

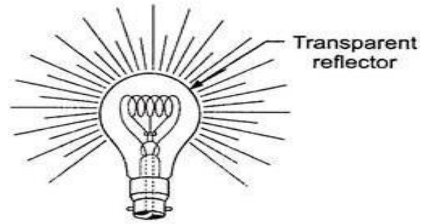



**Fig. 1.30** Direct lighting

**2. Semi direct lighting schemes:**

In semi direct 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 of the systems with reference to working place.

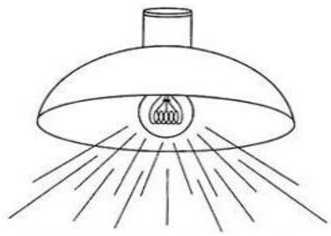


**Fig. 1.31** Semi direct lighting

**3. Indirect lighting schemes:**

In this lighting scheme, 90% of total light is thrown upwards to the ceiling for diffuse reflection by using inverted or bowl reflectors. In such scheme, the ceiling acts as the lighting source and glare is reduced to minimum. This system provides shadow less illumination, the resulting illumination is softer and more diffused, the shadows are less prominent and the appearance of the room is much improved over that which results from direct lighting. It is used for decoration purposes in cinemas theatres and hotels etc. and in workshops where large machines and other obstructions would cause trouble some shadows of direct lighting is employed.

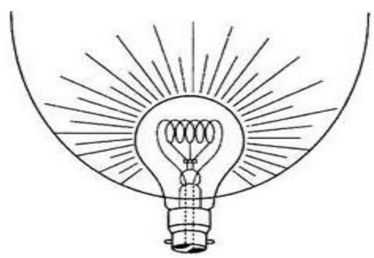


**Fig. 1.32** Indirect lighting

**4. 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. This scheme is widely preferred for indoor lighting decoration purpose.

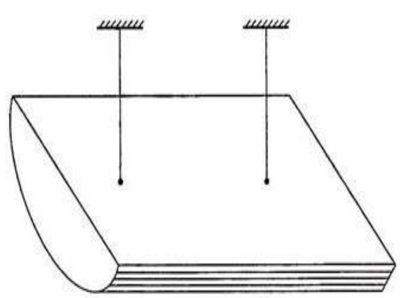


**Fig. 1.33** Semi Indirect lighting

**5. General lighting scheme:**

This scheme of lighting use special diffusing glasses to spread the light uniformly on tile working plane. It produces the equal illumination in all directions. Mounting height of the source should be much above eye level to avoid glare.

Following Figure gives the idea of all the above five types in a schematic diagram with percentage division of light illumination.

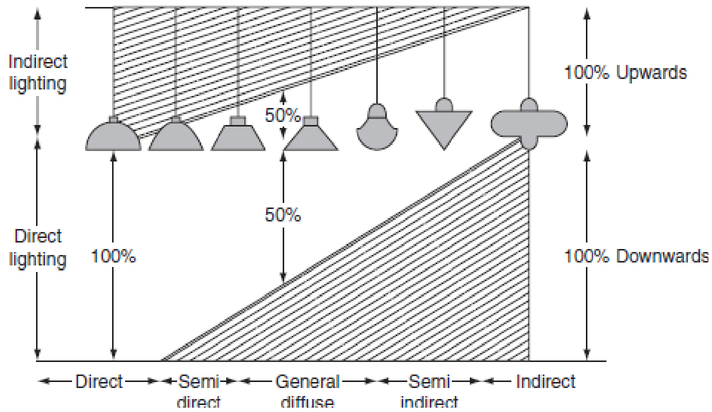



**Fig. 1.34** Lighting schemes

**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.

- 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. 1.35. An object resides over the road at 'P' in between the lamps$S_1$, $S_2$, and $S_3$ and the observer at 'Q'.

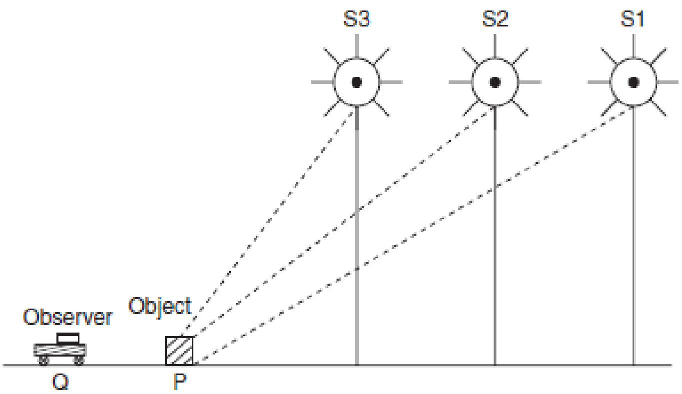



**Fig.1.35** Specular reflection for street lighting

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. Normally Illumination level, mounting height, and the types of lamps for street lighting all are depend upon the class of street lighting installation.

1. Road junctions
2. Important shopping centers.
3. Poorly lighted sub-urban streets.
4. Average well-lighted street.

Generally an average number of 8 to 15 lumens per square meter is considered sufficient illumination on the street. Mercury vapor lamps and sodium discharge lamps has been found most economical due to lower power consumption for a given amount of light. Color consideration does not matter much in street lighting. 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.

**FLOOD LIGHTING:**

Flood lighting means flooding of large surface areas with light from powerful projectors.

Followings are the main purpose of employing flood lighting

**(i) Beautification:**

For enhancing beauty of building at night such as public place, ancient building and monuments, religious building on important festive occasions etc.

**(ii) Industrial and Commercial Flood-Lighting:**

For illumination railway yards, sports stadiums, car parks, construction site, quarries etc.

For flood lighting it is necessary to concentrate the light from light source into a narrow beam. The type of reflector and its housing used for concentrating the light into narrow beam is known as flood light projector. The reflecting surface is made of silvered glass or stainless steel. Metal reflectors being more robust are usually preferred. The casing and its mounting are arranged in such a manner that the beam can be in horizontal and a vertical direction on site. When higher wattage of projector lamp i.e. 500 W or 1000 W is used in projectors, then ventilation may be provided for cooling properly.

**Projectors are classified according to the beam spread:**

**1. Narrow Beam Projectors:**

In this type of projector beam is spread between 12 – 25°. These are used for distance more than 70 meters.

**2. Medium Angle Projectors:**

Projectors with beam spread between 25 – 40°. These are used for distance between 30 to 70 meters.

**3. Wide Angle Projectors:**

These are the projectors with beam spread between 40 – 90° and are used for distance below 30 meters.

**Location and Mounting of Projectors:**

One of the most important factors which affect the selection of projector is the location of the projector.

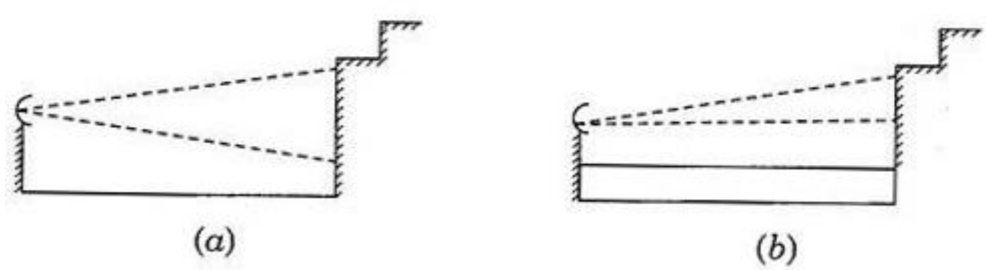



**Fig.1.36** Specular reflection for street lighting

(a) Shows symmetric projector help 20 to 35 meters away from the surface to be flood lighted and providing approximately parallel beam spread of 25° to 30°.

(b) Shows the case when the projector cannot be located away from the building. In such a case, an asymmetric reflector mounted in a basement area or on a bracket attached to the building is used which directs more intense light towards the top of the building.

**Flood-Lighting Calculations:**

The following points are taken into consideration while estimate the number and size of projectors:

**1. Illumination Level Required:**

The illumination level required depends upon the type of building, the purpose of flood-lighting.

**2. Type of Projector:**

The type of projector depends upon the area covered by the beam and illumination required. Beam angle of the projector is decided keeping in view the distance of projector from the surface.

**3. Number of Projectors:**

Number of projectors required for any desired intensity on particular surface is obtained from the following relation.

$$N = \frac{A \times E \ \times depriciation\,factor \ \times waste\ light\ factor}{Utilization\,factor \ \times lamp\,wattage \ \times efficiancy\ of\ lamp}$$

where,

N = Number of projectors

A = Area of surface in $m^2$ to be illuminated

E = Illumination level required in lumens/$m^2$

**The other factors required for flood lighting calculations are:**

i. Depreciation factor
ii. Utilization factor and
iii. Waste light factor.

**PROBLEMS:**

**1.** The front of a building 35 × 18 m is illuminated by 15 lamps; the wattage of each lamp is 80 W. The lamps are arranged so that uniform illumination on the surface is obtained. Assuming a luminous efficiency of 20 lumens/W, the coefficient of utilization is 0.8, the waste light factor is 1.25, DF = 0.9. Determine the illumination on the surface**.**

Given data

Area(A) = 35 × 18m = 630 $m^2$

The number of lamps N = 15.

Luminous efficience η = 20 lumens/W.

UF = 0.8, DF = 0.9.

Waste light factor = 1.25

Lamp wattage = 80w

Determine Illumination E =?

$$N = \frac{A \times E \times depriciationfactor \times wastelightfactor}{Utilizationfactor \times lampwattage \times efficiancyoflamp}$$

$$15 = \frac{630 \times E \times 0.9 \ \times 1.25}{0.8 \ \times 80 \ \times 20}$$

$$E = \frac{15 \times 0.8 \times 80 \times 20}{630 \ \times 0.9 \ \times 1.25}$$

E = 27.08 lux

**2**. Two lamps hung at a height of 12 m from the floor level. The distance between the lamps is 8 m. Lamp one is of 250 CP. If the illumination on the floor vertically below this lamp is 40 lux, find the CP of the second lamp.

Given data

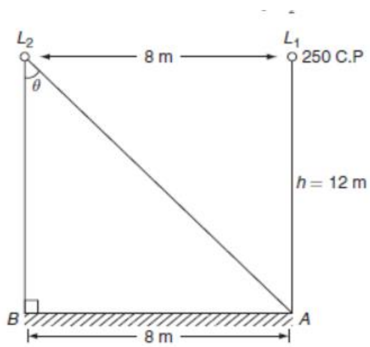
The candle power of the lamp$L_1$, $I_1$ = 250 CP.

The illumination of lamp $L_1$ is just below the lamp E = 40 lux.

The distance between the lamps = 8m

Height of the lamps from the ground h = 12m

Find candle power of lamp $L_2$, $I_2$ =?




The illumination at the point A = the illumination due to the lamp $L_1$ + the illumination due to the lamp $L_2$

$$E = \frac{I_1}{h^2} + \frac{I_2}{h^2} cos^3\theta$$

$$40 = \frac{250}{12^2} + \frac{I_2}{12^2} \left(\frac{12}{\sqrt{12^2+8^2}}\right)^3$$

$$40 = 1.736 + \frac{12I_2}{}$$

$$40 \ - 1.736 = \frac{12I_2}{}$$

**3.** The front of a building 25 × 12 m is illuminated by 20, 1,200-W lamps arranged so that uniform illumination on the surface is obtained. Assuming a luminous efficiency of 30 lumens/W and a coefficient of utilization of 0.75. Determine the illumination on the surface. Assume DF = 1.3 and waste light factor 1.2.

Given data,

Area(A) = 25 × 12m = 300m$^2$

The number of lamps N = 20.

Luminous efficiency η = 30 lumens/W.

UF = 00.75, DF =1.3

Waste light factor = 1.2

Lamp wattage = 1200w

Determine Illumination E =?

$$N = \frac{A \times E \ \times depriciation\ factor\ \times waste\ light\ factor}{Utilization\ factor\ \times lamp\ wattage\ \times efficiancy\ of\ lamp}$$

$$20 = \frac{300 \times E\ \times 1.3\ \times 1.2}{0.75\ \times 1200\ \times 30}$$

$$E = \frac{20 \times 0.75\ \times 1200 \times 30}{300 \times 1.2\ \times 1.3}$$

E = 1153.84 lux

# 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, Types of earthing, requirements of commercial installation, deciding lighting scheme and number of lamps.

**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.

(or)

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.

Typical house wiring circuit is shown in below fig.

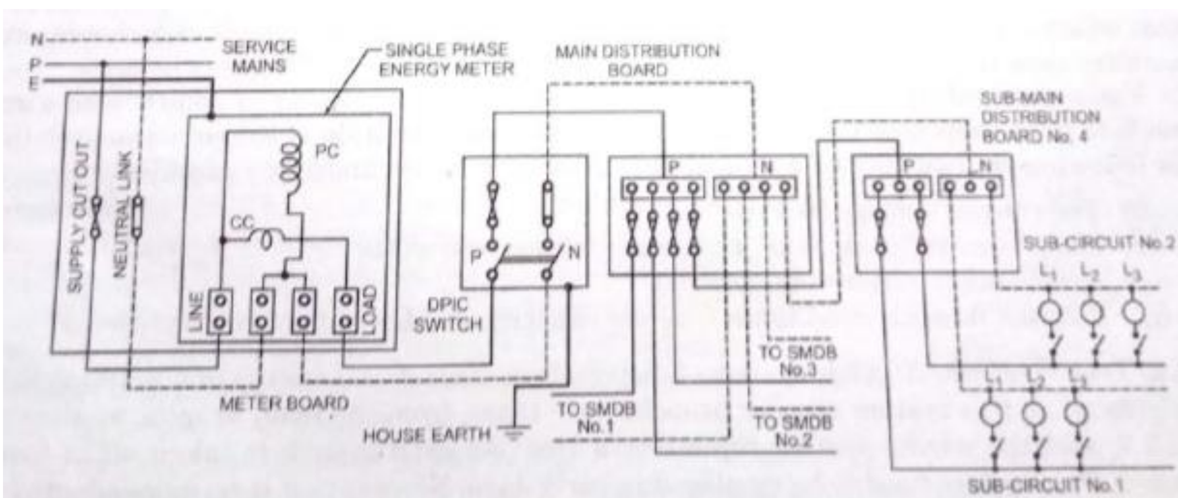



**Fig.2.1.** Typical house wiring circuit

**Methods of Electrical Wiring**:

Systems w.r.to Taking Connection Wiring can be done using two methods which are

1. Joint box system or Tee system
2. Loop – in system

**1. Joint Box system or Tee 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. The disadvantage is the number of T connection made in wiring system result in weakness if not properly made. This method is suitable for temporary installations and it is cheap.

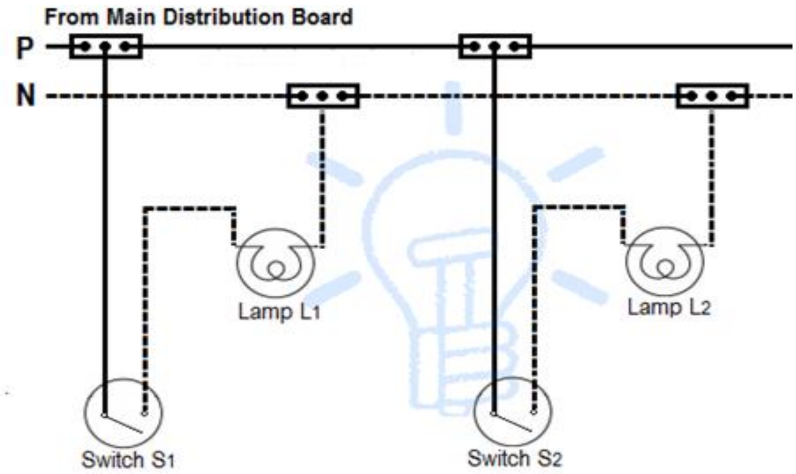



**Fig.2.2.** Joint Box System

**2. Loop-in or Looping System:**

This system is widely used in the market. In this system lights, fans, and any other device are connected in parallel. So that the power received by this system is received by each device individually. When new power is required on a light or switch, it is connected from board to board without giving any cut in the wire as opposed to the joint box system.

This one circuit is carried from board to board through series. Until the last board of this series arrives. In this system, the phase or line conductor is looped inside the switchboard or box. In any condition these wires should not be separated from each other otherwise the circuit of the front circuit will open and will not work.

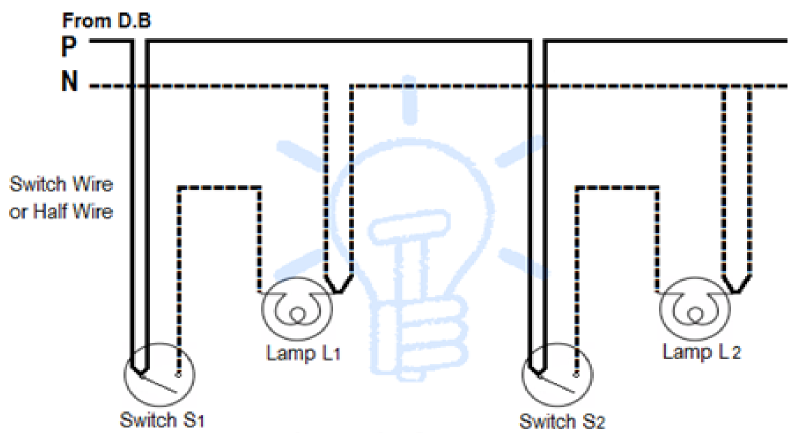



**Fig.2.3.** Loop-in System

**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.

**DIFFERENT TYPES OF ELECTRICAL WIRING SYSTEMS:**

The types of internal wiring usually used are

a) Cleat wiring
b) Wooden casing and capping wiring
c) Batten Wiring(CTS or TRS)
d) Lead sheathed or metal sheathed wiring
e) Conduit wiring

**a) Cleat Wiring:**

In this system of internal wiring the cables used are either Vulcanized Indian Rubber (VIR) or Polyvinyl chloride (PVC) insulated wires. The cables are compounded held on walls or ceilings by means of porcelain cleats, Plastic or wood.

The cleats are made in two halves, one base and the other cap. The base is grooved to accommodate the cables and the cap is put over it and the whole of it is then screwed on the wooden plugs previously cemented in to the wall and ceiling. The cleats used are of different sizes and different types in order to accommodate cables of various sizes and different number of cables respectively. The cleats are of three type’s one groove, two groove and three grooves to accommodate one, two and three cables respectively.

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. Only in temporary army campus or festival related panels this wiring is used.

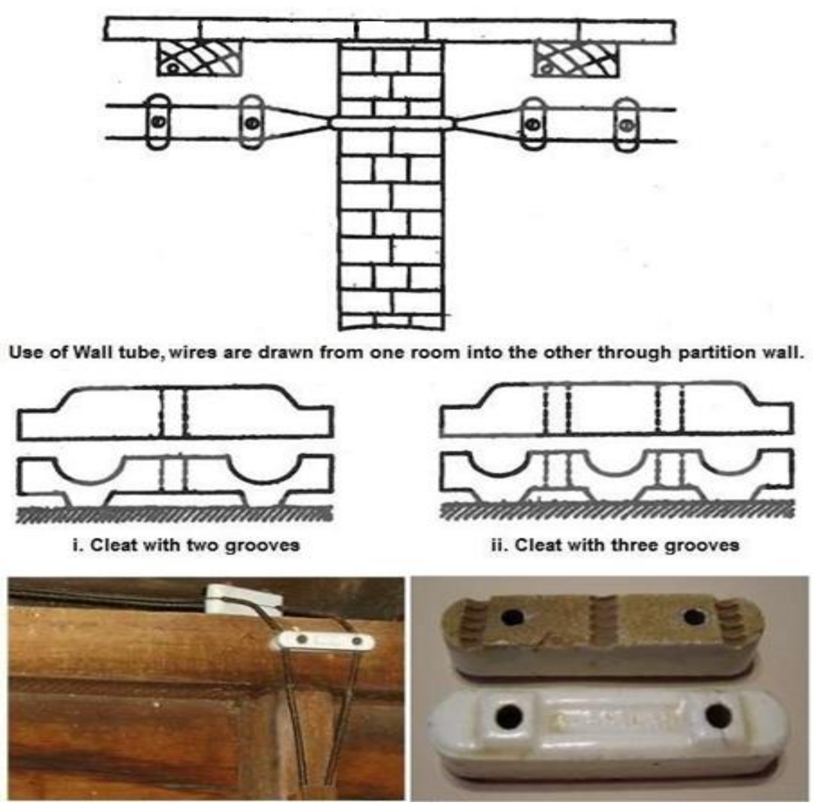



**Fig.2.4.** Cleat wiring

**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 and dismantlement is easy and simple and quick.
- ➢ Material is recoverable after the dismantlement.
- ➢ 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 occurring 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 is not lasting, reliable and sustainable wiring system.

**b) Wooden casing and capping wiring:**

This is one of the simplest forms of electrical wiring system. Wooden Casing and Capping wiring system was famous wiring system in the old days 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 of rectangular cross section. The casing is made up of a strip of wood with parallel grooves cut length wise so as to accommodate VIR or PVC 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. The color of casing channel and cap are normally white or grey. The casing channels and caps are available in market in standard size.


**Fig.2.5.** Wooden casing and capping wiring.

**Advantages of Casing Capping Wiring:**

- It is cheap wiring system as compared to sheath and conduit wiring systems.
- It is strong and long-lasting wiring system.
- Customization can be easily done in this wiring system.
- If Phase and Neutral wire is installed in separate slots, then repairing is easy.
- Stay for long time in the field due to strong insulation of capping and casing..
- It stays safe from oil, Steam, smoke and rain.
- No risk of electric shock due to covered wires and cables in casing & capping.
- Replacement and alteration of defective wire is easy.
- It provides protection against mechanical damage.

**Disadvantages Casing Capping Wiring:**

- There is a high risk of fire in casing & capping wiring system.
- Not suitable in the acidic, alkalis and humidity conditions
- Costly repairing and need more material.
- Material can’t be found easily in the contemporary
- White ants may damage the casing & capping of wood.
- It requires better workmanship; the labor cost is high.
- This type of wiring can be used only on surface.
- Internal consideration of moisture may cause damage to the insulation.

**c) Batten Wiring (CTS or TRS):**

In batten wiring system TRS (Tough rubber sheathed) /CTS (Cab tire sheathed) cables are used. 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.


**Fig.2.6.** Batten Wiring.

**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 installing in the humidity, Chemical effects, open and outdoor areas.
- Not safe from external wear & tear and weather effects (because, the wires are openly visible to heat, dust, steam and smoke). And also High risk of fires.
- Heavy wires can't be used in batten wiring system. And also need more cables and wires.
- Only suitable below then 250V.

**d) Lead Sheathed Wiring:**

This 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 lead sheath is earthed at each and every junction to provide a path to ground for the leakage current. The wiring system is very expensive. It is suitable for low voltage applications. 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.

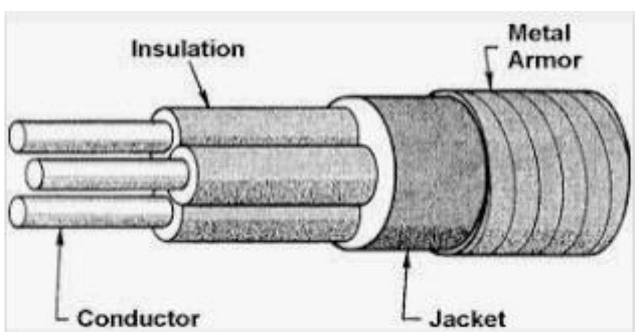



**Fig.2.7.** Lead Sheathed Wiring

**Advantages of Lead Sheathed Wiring:**

- These wires are safe from fire, moisture and mechanical damages.
- It has long life
- It can be done in damp places, open areas even which are exposed to sun and rains also
- It has good appearance.

**Disadvantages of Lead Sheathed Wiring:**

- Skilled persons are required so the labor cost is high.
- It is costly because of lead covering.
- Extension is not so easy.
- Fault location is not so easy.

**e) Conduit Wiring:**

In this system of wiring steel tubes or PVC pipes know as conduits are installed on the surface of wall by means of saddles or buried under plaster and VIR and PVC are drawn afterwards by means of GI wire.

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

(i) Surface Conduit Wiring

(ii) Concealed Conduit Wiring

**(i) Surface 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.


**Fig.2.8.** Surface conduit wiring.

**(ii)Concealed Conduit wiring**

If the conduit 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.

**Fig.2.9.** Concealed conduit wiring.

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.

**Types 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

**Metallic 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)

**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, and63 mm (diameter) or 1/2, 5/8, 3/4, 1, 1.25, 1.5, and 2 inch in diameter.

**Advantage of Conduit Wiring Systems:**

- It is the safest wiring system (Concealed conduit wring)
- Appearance is very beautiful (in case of concealed conduit wiring)
- No risk of mechanical wear & tear and fire in case of metallic pipes.
- Customization can be easily done according to the future needs.
- Repairing and maintenance is easy.
- There is no risk of damage the cables insulation.
- It is safe from corrosion (in case of PVC conduit) and risk of fire.
- It can be used even in humidity, chemical effect and smoky areas.
- No risk of electric shock (In case of proper earthing and grounding of metallic pipes).

- It is reliable and popular wiring system.
- Sustainable and long-lasting wiring system.

**Disadvantages of Conduit Wiring Systems:**

- It is expensive wiring system (Due to PVC and Metallic pipes, Additional earthing for metallic pipes Tee(s) and elbows etc.
- Very hard to find the defects in the wiring.
- Installation is not easy and simple.
- Risk of electric shock (In case of metallic pipes without proper earthing& grounding system)
- Very complicated to manage additional connection in the future.

**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 | Wooden Casing and 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 | High skilled | Semi-skilled | High 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 |

**Table 2.1.** Comparison of different wiring systems.

**General rules and guidelines for installation:**

The wiring installation shall generally be carries out in conformity with the requirements of the Indian electricity rules. The general rules, which are to be kept in mind in execution of internal wiring work, are:

1. Every installation is to be properly protected near the point of entry of supply cables by a two-pole linked main switch and a fuse unit. In a two-wire installation if one pole is permanently earthed, no fuse, switch or circuit breaker is to be inserted this pole. A 3-pole switch and fuse unit is to be used in 3-phase supply.
2. The conductor used is to be of such a size that it may carry load current safely.
3. The conductors installed are to be safe in all respects.
4. Every sub-circuit is to be connected to a distribution fuse board.
5. Every line (phase or positive) is to be protected by a fuse of suitable rating as per requirements.

6. A switch board is to be installed so that its bottom lies 1-25 meters above the floor.
7. All plugs and socket-outlets are to be 3-pin type, the appropriate pin of socket being connected permanently to the earthing system.
8. Adequate number of socket-outlets is to be provided at suitable places in all rooms so as to avoid use of long lengths of flexible cords.
9. Only 3-pin, 5 A socket-outlets are to be used in all light and fan sub-circuits and only 3-pin, 15 A socket-outlets are to be used in all power sub-circuits.
10. All socket outlets are to be controlled by individual switches, which are to be located immediately adjacent to it.
11. For 5 A socket-outlets, if installed at a height of 25 cm above the floor level, the switch may, if desired, be installed at a height 1-30 meters above the floor level. In situations where a socket-outlet is accessible to children, it is recommended to use shuttered or interlocked socket outlets.
12. In case an appliance requiring the use of a socket outlet of rating higher than 15 A is to be used, it is to be connected through a double pole witch of appropriate rating. In no case a socket-outlet of rating higher than 15 A is to be installed.
13. Socket-outlets are not to be located centrally behind the appliances with which these are used. Socket-outlets are to be installed either 25 cm or 1.30 meters above the floor level as desired.
14. No socket-outlet is to be provided the bath room at a height less than 1.30 meters.
15. Depending on the size of the kitchen, one or two 3-pin 15 A socket-outlets are to be provided to plot-in hot plates and other appliances. Dining rooms, bed rooms, living rooms, and study rooms, if required, each is to be provided with at least one 3-pin, 15 A socket-outlet.
16. All incandescent lamps unless otherwise required, are to be hung at a height of 2.5 meters above the floor level.
17. Unless otherwise specified, all ceiling fans are to be hung 2.75 meters above the floor.
18. Lights and fans may be wired on a common circuit. Each sub-circuit is not to have more than a total of ten points of lights, fans and socket outlets. The load on each sub-circuit is to be restricted to 800 watts. If a separate circuit is installed for fans only, the number of fans in that circuit is not to exceed ten.
19. The load on each power sub-circuit is to be normally restricted to 3,000 watts. In no case more than two outlets are to be in a power sub-circuit.
20. No fuse and switch is to be provided in earthed conductor.
21. Every circuit or apparatus is to be provided with a separate means of isolation such as a switch.
22. All apparatus requiring attention are to be provided with means of access to it.
23. In any building, light and fan wiring and power wiring are to be kept separate.
24. In 3-phase, 4-wire installation the load is to be distributed equally on all the phases.

25. No additional load is to be connected to an existing installation unless it has been ascertained that the installation can safely carry the additional load and that the earthling arrangements are adequate.
26. Lamp holders used in bath rooms are to be constructed or shrouded in insulating materials and fitted with protective shield and earth continuity conductor is not to be of size less than 7/0.915 mm.
27. The metal sheaths or conduits for all wiring and metal coverings of all consuming apparatus or appliances is to be properly earthed in order to avoid danger from electrical shock due to leakage or failure of insulation.
28. Each sub-circuit is to be protected against excessive current (that may occur either due to overload or due to failure of insulation) by fuse or automatic circuit breaker.
29. All live conductors are to be insulated or otherwise safe guarded to avoid danger.
30. After completion of work the installation is to be tested before energizing the system.

**ELECTRICAL LOAD:**

The electrical load is the calculation of how much power is required to run everything that consumes electricity in your home. When making significant electrical additions to a home, everything that will use electricity to run is calculated to find the electrical load.

**Why is electrical load calculation important?**

The electrical load of a house determines many things, including the amperage of your electrical panel. Finding the electrical load is an important part of determining whether you need to change your electrical service, as it will tell you if the power supplied to your home (amps) isn't enough for your electricity use.

Changing the electrical load of your house also indicates a change in your energy bill. For example, if you get a new HVAC system that doesn't use as much electricity, your electrical load and your energy bill will be lower.

**Load Details:**

| | |
|---|---|
| Lamps | -- 2 x 60 W = 120 W |
| Tube lights | -- 2 x 40 W = 80 W |
| Fans | -- 2 x 80 W = 160 W |
| Sockets (5 A) | -- 2 x 100 W = 200 W |
| Power sockets (15 A) | -- 1 x 1000 W = 1000 W |

Total light load = 560 W

Total power load = 1000 W

No. Of sub circuits:

No of sub circuits for light load = 1 (< 800 W or 10 points)

No of sub circuits for power load = 1 (< 3000 W or 2 points)

**SIZE OF WIRE:**

Size of the cable completely depends on the current carrying capacity. It should carry the max circuit current continuously without overheating.

In domestic wiring, the wire or cable used must not be of size less than 1/1.12mm or 1.0 $mm^2$ In copper (or) 1/1.4 mm or 1.5 $mm^2$ In aluminum wire

**For light load**:

Load current = Total wattage / voltage

= 560 / 230

=2.43 A

From current rating tables the size of the conductor selected is 1.5 $mm^2$ (1 / 1.4mm) PVC cable

**For power load:**

Load current = Total wattage / voltage

=1000/230

=4.34 A

From current rating tables the size of the conductor selected is 2.5 $mm^2$ (1 / 1.8mm) PVC cable

**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. 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.

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 specify the capacity (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 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 are 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.

**MAIN SWITCH:**

The "main or main switch" is the name of the master switch that connects or disconnects all circuits to your house. In a circuit breaker box the first and biggest switch is usually the main (about 60 to 100 amps) and under it or to the side is a row of smaller breakers, maybe 10 or 15 or 20 amps each, that go to each area of the house, like kitchen, or bathroom, or living room lights, or living room sockets.

(or)

From the Public Utility KWH Meter, the first electric switch that totally controls all the circuits in your home is called the Main Switch. If this Main Switch is a Circuit Breaker in a Panel Board, it is called a Main Beaker then all the branch circuit breakers are controlled by this Main Breaker. A Main Switch can also be a Fused Disconnect Switch

**What are the uses of main switch?**

The purpose of the main switch is obviously mainly used for the overall control of electrical equipment systems. When encountering sudden power events, it can be controlled by the main switch. It is convenient to protect the electrical equipment of the system.

At the same time, when a system, such as a house, a factory, etc., needs to be overhauled for centralized electrical equipment, if the power of the system needs to be turned off, the safety inspection can be performed by turning off the main switch.

**Here are two main rating for a switch:**

**Current Rating:** The indicated current rating in amperes on switch nameplate shows the maximum ampacity the switch can carry in the connected circuit.

**Voltage Rating:** This is the maximum voltage a switch can be used and installed in the circuit.

**DISTRIBUTION BOARD:**

Distribution board (also known as panel board, breaker panel, electric panel, DB board or DB box) is a component of an electricity supply system that divides an electrical power feed into subsidiary circuits while providing a protective fuse or circuit breaker for each circuit in a common enclosure.

**1. Uses of Distribution Boards:**

**i. Electrical Distribution:** It is from where you can distribute and control the electrical supply to different sections of your house. It arranges the electrical distribution into a subsidiary or miniature circuits.

**ii. Electrical Security:** A circuit breaker or fuse will protect each miniature circuit. Fuses are now out of use, due to their lack of reusability. These circuit breakers will be discussed below.

**2. Types of Distribution Boards:**

Based on usage, location, and amperage, there are several types of distribution boards available today. They are used based on the electrical code in the state or district.

**i. Main Breaker Panel:** This type is either used for one whole commercial or residential unit. They are downstream to the supply from the meter cable. They contain the main circuit breaker that can cut off all supplies to the unit. They also indicate the amperage rating i.e. the entire electrical current the circuit can safely take.

**ii. Main Lug Panel:** This type is used when there is a main breaker panel upstream. They have a separate disconnect or that can help disconnect it during fires and other calamities.

**iii. Sub-panel:** Like main lug panels, they take the supply from the main breaker panel and split it into smaller circuits for specialized appliances and sections of the house. They, however, do not have separate disconnects.

**iv. Transfer Switches:** This is a variant of a subpanel, which is used in series with backup power generators, to switch from the main supply. These are especially useful in stormy regions when power cuts are frequent.

**3. Components of Distribution Boards:**

The distribution board houses several electromechanical devices:

**i. Main Circuit Breaker:** This is the main electromechanical device that can cut off power from the meter cable.

**ii. Miniature Circuit Breakers (MCB):** A miniature circuit breaker controls the supply to various miniature circuits on the main circuit. They switch off if they detect an over current i.e. current that supersedes the circuit's current rating. They can be single-pole, double-pole, triple-pole, and four-pole, based on the capacity of each circuit and the required energy input of the appliances connected.

**iii. Residual Current Circuit Breaker (RCCB):** Put simply, RCCBs are lifesavers, mandatory in many states' electrical codes. They can detect if the current is being leaked into a human body or into water (i.e. an earthing fault), and then automatically switch off. They are highly sensitive circuit breakers used in series with MCBs and can detect any slight imbalance between the phase conductors.

**iv. Molded Case Circuit Breaker (MCCB):** These devices have the same function as MCBs, except with a far higher current rating. This means it has more versatility and can interrupt larger current ranges, allowing it to be used in both residential and industrial applications.

**v. Isolators:** These are manually controlled electromechanical devices for isolating a part of the circuit for maintenance. They are often used in series with MCBs for when an MCB fails. Electricians use this to cut off the current in a circuit so that they can repair the circuit without getting shocked.

**vi. Bus bars:** Bus bars are copper or aluminum conducting strips that carry a large amount of current from the incoming meter line to the various circuit breakers in the distribution board.

**vii. Switches:** These are present on all circuit breakers and automatically switch off in case of any detection in over current and short circuits.

**vi. Identification Labels:** These stickers help name the different miniature circuits based on the rooms they control, so that end users can understand which switch they have to flip to turn off or turn on a specific section of the house/unit.

**4. Safety Tips When Using Distribution Boards:**

**i. Covering:** The distribution board must always be covered when not being manually handled. This is to prevent corrosion in the wires and fixtures from moisture, humidity, dust, etc. The unoccupied openings of distribution boards must be covered with a blanking plate.

**ii. Location:** Do not install the distribution board in an area where there can be contact with water. Some basements are disqualified because of this. Many electrical codes deem that they must not be placed at an inconvenient height of 2200 mm above the floor. It is preferable to install it in an out-of-the-way location where children cannot reach it and where interior aesthetics are not disturbed. Also, these boards should not be installed near a fixed cooking appliance, due to fire hazards.

**iii. Warning Indication:** Place a warning sign on the doors of the concealed metal box which houses the distribution board. This will prevent people from carelessly touching hazardous components.

**iv. Dangerous Symptoms:** If you detect a burning smell at the distribution panel, it is a serious fire hazard to your house. Turn off the power and contact a professional electrician. Also, if circuit breakers keep tripping despite you turning off appliances, this could indicate that your circuitry or board is damaged and faulty. You will need to replace it.

**PROTECTION DEVICE:**

The circuit protection device is an electrical device used for preventing an unnecessary amount of current otherwise a short circuit. To ensure the highest security, there are many protection devices available in the market which offers you a total range of protection devices for circuits such as a fuse, circuit breakers, RCCB, gas discharge tubes, thyristors and more.

**Different types of Protection Devices:**

The different types of circuit protection devices examples include the following.

- Fuse
- Circuit Breaker
- PolySwitch
- RCCB
- Inrush Current Limiter
- Crowbar vs. Clamping
- ESD Protection
- Surge Protection Device

- Lightning Protection
    - Metal Oxide Varistor
    - Gas Discharge Tube

**Fuse:**

In electrical circuits, a fuse is an electrical device used to protect the circuit from over current. It consists of a metal strip that liquefies when the flow of current through it is high. Fuses are essential electrical devices, and there are different types of fuses available in the market today based on specific voltage and current ratings, application, response time, and breaking capacity. The characteristics of fuses like time and current are selected to give sufficient protection without unnecessary disruption.

**Fig.2.10.** Fuse

**Circuit Breaker:**

A circuit breaker is one kind of electrical switch used to guard an electrical circuit against short circuit otherwise an overload which will cause by excess current supply. The basic function of a circuit breaker is to stop the flow of current once a fault has occurred. Not like a fuse, a circuit breaker can be operated either automatically or manually to restart regular operation.

Circuit breakers are available in different sizes from small devices to large switch gears which are used to protect low current circuits as well as high voltage circuits.

**Fig.2.11.** Circuit breaker

**Poly Switch or Resettable Fuse:**

A resettable fuse is a passive electronic component used for protecting electronic circuits from over-current mistakes. This device is also called as a poly switch or multi fuse or poly fuse. The working of these fuses is same as PTC thermistors in particular situations, however, work on mechanical transforms instead of charge-carrier-effects within semiconductors.

Resettable Fuses are used in several applications like power supplies in computers, nuclear or aerospace applications where substitution is not easy.

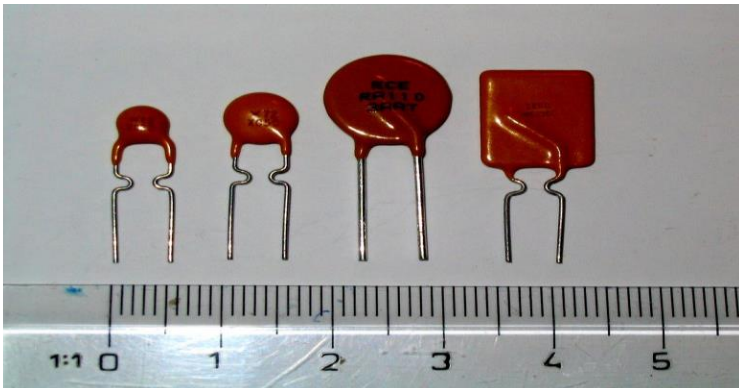



**Fig.2.12.** Poly Switch

**RCCB or RCD:**

The RCD-residual current device (or) RCCB- residual current circuit breaker is a safety device which notices a problem in your home power supply then turns OFF in 10-15 milliseconds to stop electric shock. A residual current device does not give safety against short circuit or overload in the circuit, so we cannot change a fuse instead of RCD.

RCDs are frequently incorporated with some type of circuit breaker like an MCB (miniature circuit breaker) or a fuse, which guards against overload current in the circuit. The residual current device also cannot notice a human being due to by mistake touching both conductors at a time.

These devices are testable as well as resettable apparatus. A test button securely forms a tiny leakage condition; along with a reset button again connects the conductors after an error state has been cleared.


**Fig.2.13.** RCCB

**Inrush Current Limiter:**

This is one type of electrical a component used to stop inrush current for avoiding regular damage to apparatus and evade tripping circuit breakers and blowing fuses. The best examples of inrush current limiter device are Fixed resistors as well as NTC thermistors.

They present a high resistance firstly, which stops huge currents from flowing by turn-on. Because the flow of current will continues, NTC thermistors heat-up, permitting high flow of current throughout normal operation. These thermistors are generally much superior to measurement kind thermistors, which are intentionally planned for power applications.


**Fig.2.14.** Inrush Current

**Lightning Protection:**

The lightning protection includes MOV (metal oxide varistor) and gas discharge tube

(i) **Metal Oxide Varistor:**

A varistor or VDR (voltage dependent resistor) is an electronic component and the resistance of this is changeable and depends on the applied voltage. The term varistor has been taken from the variable resistor. When the voltage of this component increases then the resistance decreases. In the same way, when an extreme voltage increases then the resistance will decrease significantly.

This performance creates them appropriate to guard electrical circuits throughout voltage flows. Origins of a flow can comprise electrostatic discharges as well as lightning strikes. The most frequent type of voltage-dependent resistor is the MOV (metal oxide varistor).

(ii) **Gas Discharge Tube:**

A gas discharge tube or gas-filled tube is a collection of electrodes in a gas inside a temperature resistant envelope and insulating. These tubes use phenomena allied to electric discharge within gases, also work through ionizing the gas by an applied voltage enough to reason electrical conduction through the fundamental phenomena of the Townsend expulsion. An expulsion lamp is an electrical device which uses a gas-filled tube such as metal halide lamps, fluorescent lamps, neon lights, and sodium-vapor lamps. Specific gas-filled tubes namely thyratrons, ignitrons, and krytrons are employed as switching devices in various electrical devices.

The required voltage to begin and maintain discharge is reliant on the force, geometry of the tube, and composition of the fill gas. Even though the cover is normally glass, power tubes frequently employ ceramics, as well as military tubes frequently employ glass wrinkled metal.

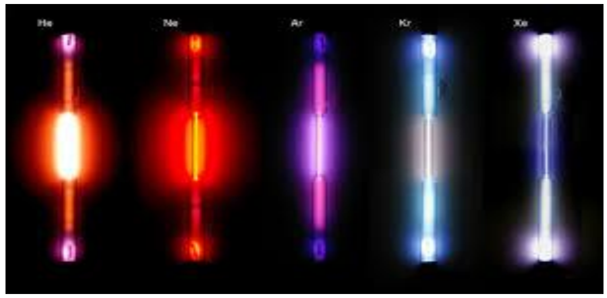



**Fig.2.15.** Gas discharge tube

**Crowbar vs. Clamping:**

The terms Crowbar vs. Clamping is regularly used to explain how overvoltage protection devices work in a temporary event. A crowbar protection device decreases the voltage under the system's operating voltage. As the impermanent is complete, the crowbar device retunes and lets the circuit to function usually. Throughout a temporary occurrence, a clamping device grasps the voltage just higher than the operating voltage of the system.

**ESD Protection:**

This device protects an electrical circuit from an ESD (Electrostatic discharge), in order to avoid a breakdown of a device. Murata has a wide array of ESD protector devices comprising particular devices very small devices, for high-speed communication, & included noise filters. ESD Protection devices can also be utilized to change Zener diodes (TVS), varistor, as well as suppressors.


**Fig.2.16.** Electrostatic discharge

**Surge Protection Device:**

The term SPD stands for Surge Protection Device is one type of component used in an electrical fitting security system. The SPD device is allied in parallel in the power supply circuit, which can be used on all stages of the power supply system. The surge protection device is the most frequently used and also well-organized kind of over-voltage protective devices


**Fig.2.17.** Surge Protection Device

**EARTHING:**

Have you ever experienced a mild shock when you touch certain appliances while in operating condition? Sometimes these shocks can be dangerous and can lead to major hazards. To avoid mish happenings, it is always advisable to have a proper earthing done to the building. This process of sharing the charges with the earth is called earthing. Earthing is a simple way for the leakage of current and hence protects the devices from electrical damage.

Grounding is also one such safety process that protects the entire power system from malfunctioning and is mainly used for unbalancing the load when the electric system overloads.

Earthing is defined as "the process in which the instantaneous discharge of the electrical energy takes place by transferring charges directly to the earth through low resistance wire." The electrical earthing is done by connecting the non-current carrying part of the equipment or neutral of supply system to the ground. Low resistance earthing wire is chosen to provide the least resistance path for leakage of fault current.

**Purpose / Necessity of Earthing:**

The main purpose of earthing is

- To save human life from electric shock
- To avoid risk of fire due to earth leakage current through unwanted path.
- To maintain the line voltage constant
- To ensure that no current carrying conductor rises to a potential with respect to earth than its desired insulation.

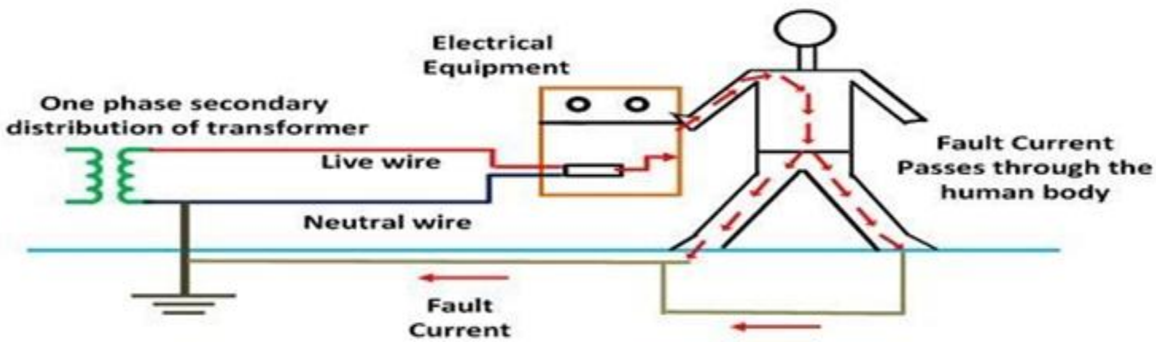



**Fig.2.18.** Electrical system without earthing

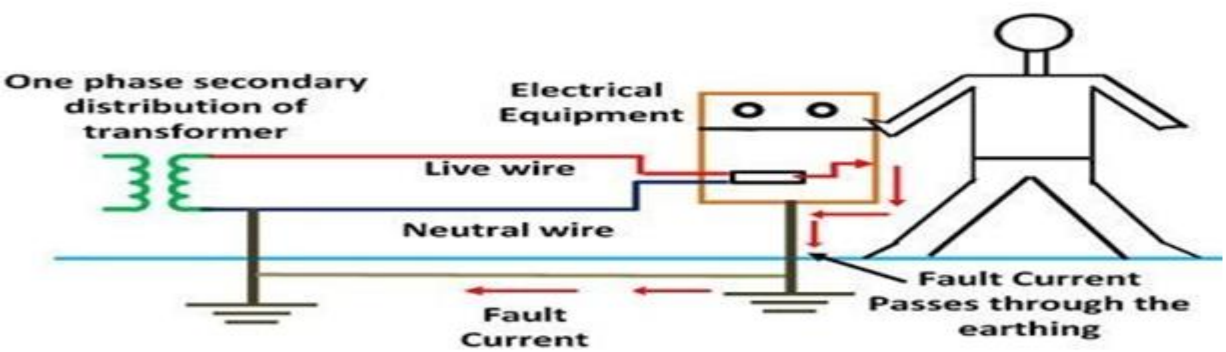



**Fig.2.19.** Electrical system with earthing

**Importance of Earthing:**

The earthing is essential because of the following reasons

- The earthing protects the personnel from the short circuit current.
- The earthing provides the easiest path to the flow of short circuit current even after the failure of the insulation.
- The earthing protects the apparatus and personnel from the high voltage surges and lightning discharge.

**Advantages of Earthing**:

- Earthing is safe and the best method of offering safety. We know that the earth's potential is zero and is treated as Neutral. Since low equipment is connected to earth using low resistance wire, balancing is achieved.
- Metal can be used in electrical installations without looking for its conductivity, proper earthing ensures that metal does not transfer current.
- A sudden surge in voltage or overload does not harm the device and person if proper earthing measures are done. To Protect Electric system and buildings form lighting.
- It prevents the risk of fire hazards that could otherwise be caused by the current leakage.

**Different Terms used in Electrical Earthing:**

**Earth:** The proper connection between electrical installation systems via conductor to the buried plate in the earth is known as Earth.

**Earthed:** When an electrical device, appliance or wiring systems connected to the earth through earth electrode, it is known as earthed device or simple "Earthed".

**Solidly Earthed:** When an electric device, appliance or electrical installation is connected to the earth electrode without a fuse, circuit breaker or resistance/Impedance, It is called "solidly earthed".

**Earth Electrode:** When a conductor (or conductive plate) buried in the earth for electrical earthing system. It is known to be Earth Electrode. Earth electrodes are in different shapes like, conductive plate, conductive rod, metal water pipe or any other conductor with low resistance.

**Earthing Lead**: The conductor wire or conductive strip connected between Earth electrode and Electrical installation system and devices in called Earthing lead.

**Earth Continuity Conductor:** The conductor wire, which is connected among different electrical devices and appliances like, distribution board, different plugs and appliances etc. in other words, the wire between earthing lead and electrical device or appliance is called earth continuity conductor. It may be in the shape of metal pipe (fully or partial), or cable metallic sheath or flexible wire.

**Sub Main Earthing Conductor**: A wire connected between switch board and distribution board i.e. that conductor is related to sub main circuits.

**Earth Resistance:** This is the total resistance between earth electrode and earth in Ω (Ohms). Earth resistance is the algebraic sum of the resistances of earth continuity conductor, earthing lead, earth electrode and earth.

**Methods and Types of Electrical Earthing:**

Earthing can be done in many ways. The various methods employed in earthing (in house wiring or factory and other connected electrical equipment and machines) are discussed as follows.

1. Plate earthing
2. Pipe earthing
3. Rod earthing
4. Strip or wire earthing

**1. Plate Earthing:**

In plate earthing system, a plate made up of either copper with dimensions **60cm x 60cm x 3mm** or galvanized iron (GI) of dimensions **60cm x 60cm x 6mm** is used as earth electrode. A pit is dug about **3 meters** deep from ground level and earth plate is buried with its face vertical. The space around the earth plate is filled with coke or charcoal and salt in alternate layers for a distance of about **15cm** around the plate to increase the dampness and moisture around the plate

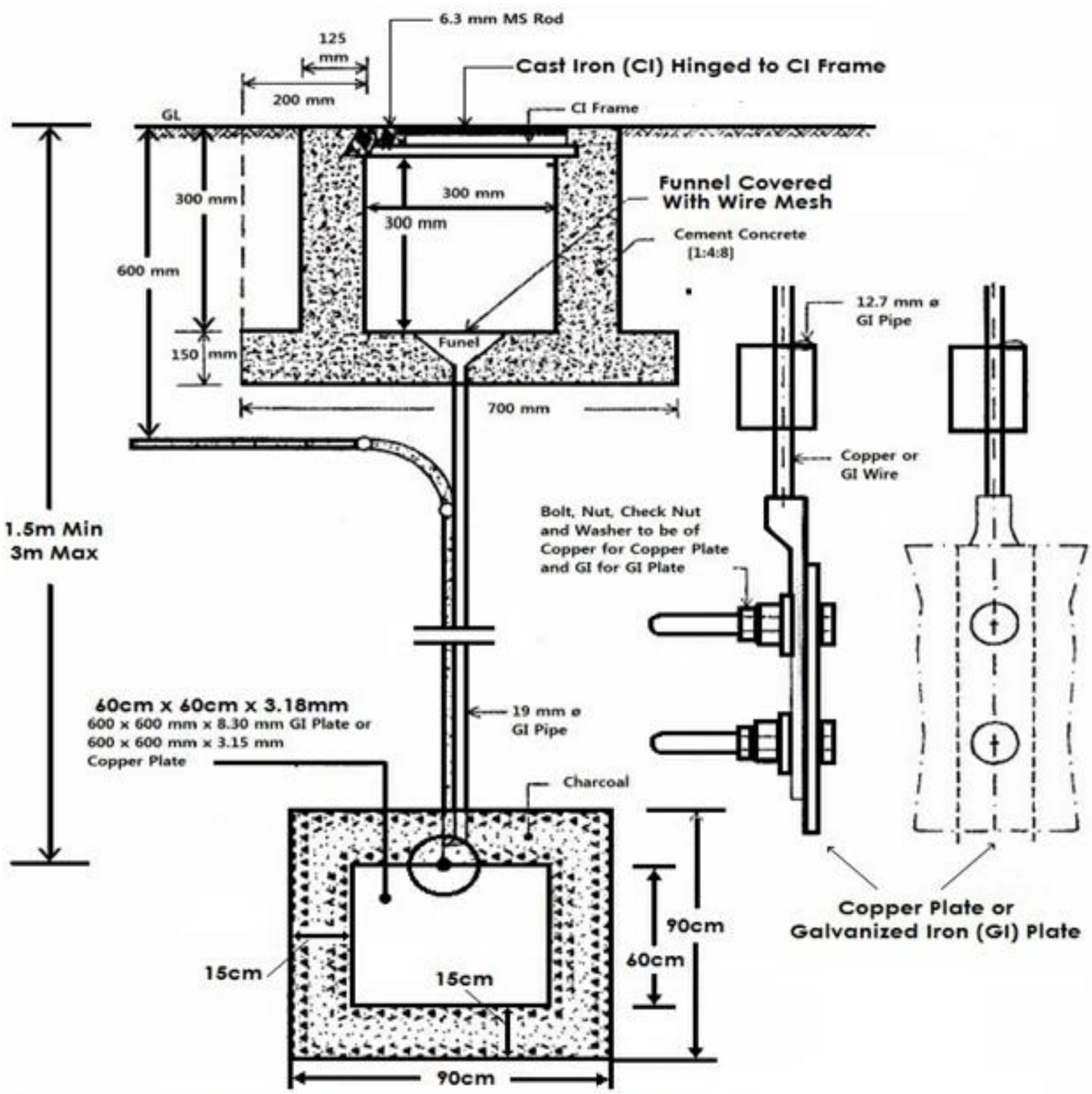



**Fig.2.20.** Plate earthing

**2. Pipe Earthing:**

It is a common system of earthing in which a square pit of sides 40cm each is dug about 4 to 5 meters deep. A GI pipe of 38mm diameter and 2.5 meter long is placed vertically in a pit to work as a earth electrode. The depth at which the pipe is placed depends up on the moisture of the ground, but the pipe is placed at a minimum depth of 3.75m. The pipe is provided with a tapered casting at the lower end in order to facilitate the driving.

The pipe in the pit is surrounded by pieces of coke or charcoal and salt in alternate layers for a distance of about 15cm to increase the dampness and moisture around the pipe. The pipe as 12mm diameter hole, so that water poured from top is made to spread in the charcoal and salt layer to the hole to decrease the earth resistance. Another pipe of 19mm diameter and minimum length of 1.25m is connected to this pipe through a 38*19mm reducing socket.

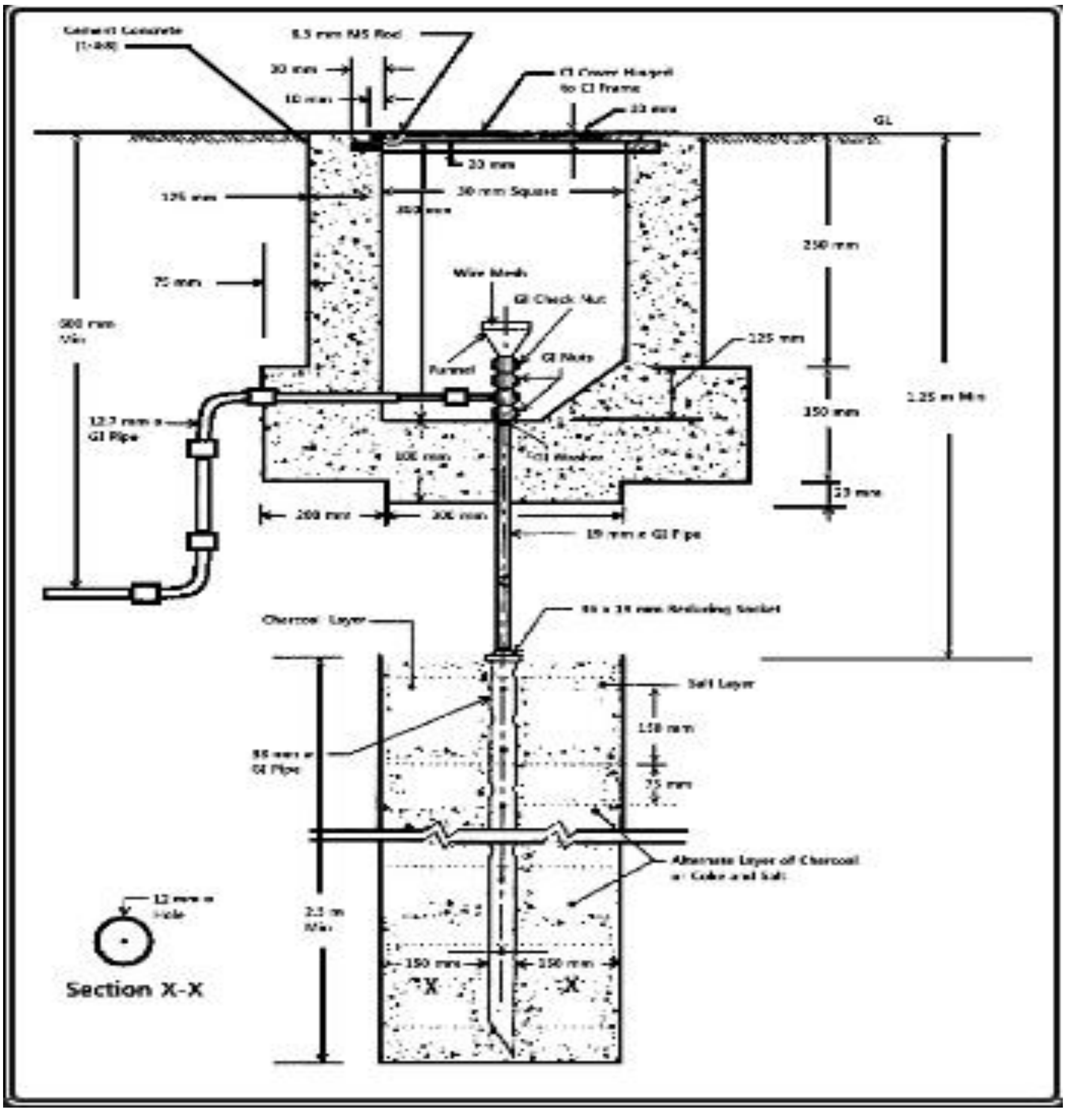



**Fig.2.21.** Pipe earthing

At the top, a cement concrete work is made for the protection of pipe from the mechanical damage and is provided with a funnel with wire mesh to pour water. The funnel is connected to n19mm diameter pipe by means of bolts and nuts. In summer season the moisture in the soil decreases which causes increasing earth resistance, hence 3 or 4 buckets of water are put for every few days.

Another pipe of 13mm diameter is connected to the 19mm pipe near the wire mesh through which earth wire is carried at a depth of 16cm from the surface of the ground. The cement concrete work at the top is covered with a iron plate for periodic opening and checking.

**3. Rod Earthing:**

In the system of earthing solid rod of 12.5mm diameter of copper or 16mm diameter of solid GI or steel rod of length not less than 2.5meter is driven vertically down words in to the earth either by manually or by hammer. Some time it is required to drive more than on rod to reduce the earth resistance to a desired value.

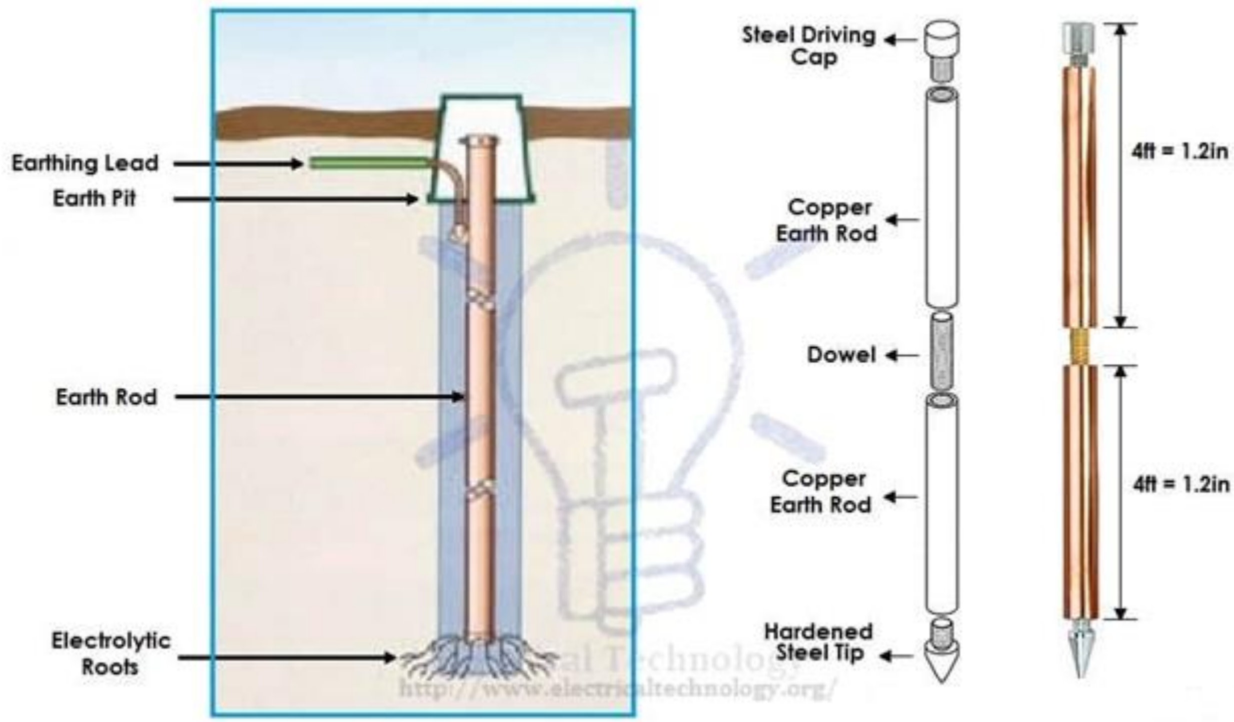



**Fig.2.22.** Rod Earthing

**4. Strip or Wire Earthing:**

This system is employed in places where the soil is rock because in rocky areas the soil excavation work is difficult.

In this system a wire of strip of cross section 25mm* 1.6mm (3.0mm$^2$ if around) of copper or 25mm* 4mm (6.0mm$^2$ if around) of GI or steel is buried in the ground in horizontal trenches of minimum depth of 1/2 meter (1 1/2) feet the length of the wire or strip depends on the requirement of earth resistance, but the should not be less than 15meters. In order to achieve required resistance, sometimes more than one wire or strip is laid in parallel to each other.

**Fig.2.23.** Strip Earthing

**General Method of Electrical Earthing Installation (Step by Step):**

The usual method of earthing of electric equipments, devices and appliances are as follow:

1. First of all, dig a 5x5ft (1.5×1.5m) pit about 20-30ft (6-9 meters) in the ground. (Note that, depth and width depends on the nature and structure of the ground)
2. Bury an appropriate (usually 2' x 2' x 1/8" (600x600x300 mm) copper plate in that pit in vertical position.
3. Tight earth lead through nut bolts from two different places on earth plate.
4. Use two earth leads with each earth plate (in case of two earth plates) and tight them.
5. To protect the joints from corrosion, put grease around it.
6. Collect all the wires in a metallic pipe from the earth electrode(s). Make sure the pipe is 1ft (30cm) above the surface of the ground.
7. To maintain the moisture condition around the earth plate, put a 1ft (30cm) layer of powdered charcoal (powdered wood coal) and lime mixture around the earth plate of around the earth plate.
8. Use thimble and nut bolts to connect tightly wires to the bed plates of machines. Each machine should be earthed from two different places. The minimum distance between two earth electrodes should be 10 ft (3m).
9. Earth continuity conductor which is connected to the body and metallic parts of all installation should be tightly connected to earth lead. Make sure to use the continuity by using continuity test.
10. At last (but not least), test the overall earthing system through earth tester. If everything is going about the planning, then fill the pit with soil. The maximum allowable resistance for earthing is 1Ω. If it is more than 1 ohm, then increase the size (not length) of earth lead and earth continuity conductors. Keep the external ends of the pipes open and put the water time to time to maintain the moisture condition around the earth electrode which is important for the better earthing system.

**SI specification for Earthing:**

Various specifications in respect to earthing as recommended by Indian Standards are given below. Here are few;

- An earthing electrode should not be situated (installed) close to the building whose installation system is being earthed at least more than 1.5m away.
- The earth resistance should be low enough to cause the flow of current sufficient to operate the protective relays or blow fuses. It's value is not constant as it varies with weather because it depends on moisture (but should not be less than 1 Ohm).
- The earth wire and earth electrode will be the same material.
- The earthing electrode should always be placed in a vertical position inside the earth or pit so that it may be in contact with all the different earth layers.

**Earth Resistance:**

The earth resistance should be low enough to cause flow of current to earth. The following maximum permissible values of earth resistances will give satisfactory results.

- Large power stations =0.5Ω
- Major sub-stations =1.0Ω
- Small sub-stations =2.0Ω
- In all other cases =5.0Ω

**Factors effecting earth resistance:**

The resistance of the earth depends on the following factors

- Condition of soil
- Moisture content of soil
- Temperature of soil
- Depth of electrode at which it is embedded
- Size and spacing of earth electrode
- Material of earth electrode
- Quality and quantity of coal and salt in the earth pit

**Methods of reducing earth resistance:**

The earth resistance can be reduced from the following methods

1. **By Pouring Water:** The water increases the dampness and moisture content of earth which causes in reduction of earth resistance.
2. **Increase In Cross Sectional Area Of Earth Electrode:** By increasing the area of earth electrode the earth resistance can be reduced. But the decrease of resistance is not in direct proportional to the area. It is found that to reduce the resistance value by one sixth, the increase in area is 36times more for the same soil condition and depth of electrode. Hence this method is not recommended.

3. **Increase in Depth:** The increase in depth below the ground level will reduce the resistance of the earth system.
4. **Electrodes In Parallel:** The earth resistance can be reduced by connecting the number of electrodes in parallel.

**Selection of earthing:**

The type of earthing to be provided depends on many factors such as type of soil, type of installation etc.

- **Rod earthing:** In areas where the soil is loose or sandy
- **Strip/wire earthing:** in rocky areas
- **Pipe** earthing:

  1. for domestic installation such as heaters, coolers, refrigerators, geysers, electric iron etc
  2. for 11kv/400v distribution transformers.
  3. for motors of rating up to 100 H.P. induction motors.
  4. For conduit pipe in a wall, all wall brackets.
  5. for distribution poles etc.

- **Plate earthing:** large installations such as;

  1. For transmission towers
  2. All sub stations
  3. Generating stations

**Measurement of earth resistance:**

**Earth Tester/ Megger:**

- For measuring soil resistivity and earth resistance Earth Tester / Megger is used
- It has a voltage source, a meter to measure Resistance in ohms, switches to change instrument range, Wires to connect terminal to Earth Electrode and Spikes.
- Earth resistance is measured by using Four Terminal Earth Tester Instrument. The terminals are connected by wires

  P = Potential spike

  C = Current spike

- The distance between the spikes may be 1m, 2m, 5m, 10m etc., depending on space available.
- All spikes are equidistant and in straight line to maintain electrical continuity. Take measurement in different directions.

**Deciding lighting scheme and number of lamps:**

**The lighting scheme should be such that it may:**

- Provide adequate illumination,
- Provide light distribution all over the working plane as uniform as possible,
- Provide light of suitable colour, and
- Avoid glare and hard shadows as far as possible.

**The following factors are required to be considered while designing the lighting scheme:**

**1. Illumination Level:**

This is the most vital factor because a sufficient illumination is the basic means whereby we are able to see our surroundings, unless they are themselves light sources, since only when illuminated do the objects take on the necessary brightness. It is the task of illumination to give objects a distributed brightness. Body colors have property of reflecting light in different degrees.

It is this differential brightness which gives essential perception of details. For each type of work there is a range of brightness most favorable to output, i.e., which causes minimum fatigue and gives maximum output in terms of quality and quantity.

**Degree of illumination, to give necessary brightness to the objects depends upon:**

- The size of the object to be seen and its distance from the observer-greater the distance of the object from observer and smaller the size of the object, greater will be the illumination required for its proper perception and
- Contrast between the object and back ground—greater the contrast between the colour of the object and its back ground, greater will be the illumination required to distinguish the object properly. Objects which are seen for longer duration of time require more illumination than those for casual work. Similarly moving objects require more illumination than those for stationary object.

**Illumination level required, as per ISI, in various parts of a building is given below:**

| Location | Illumination Level in Lux |
|---|---|
| Entrances, hallways | 100 |
| Living room | 300 |
| Dining room | 150 |
| Bed room General | 300 |
| Dressing tables, bed heads | 200 |
| Tables games | 300 |
| Games or recreation room | 100 |
| Kitchen | 200 |
| Kitchen sink | 300 |
| Laundry | 200 |
| Bathroom | 100 |
| Bathroom mirror | 300 |
| Sewing | 700 |
| Workshop | 200 |
| Stairs | 100 |
| Garage | 70 |
| Study | 300 |

**Table 2.2** Illumination levels

**Illumination level required, as per ISI, for various types of traffic routes is given below:**

| Classification of Lighting Installation | Type of Road | Average Level of Illumination on Road Surface |
|---|---|---|
| Group $A_1$ | Important traffic routes carrying fast traffic. | 30 |
| Group $A_2$ | Other main roads carrying mixed traffic like main city streets, arterial roads, through ways etc. | 15 |
| Group $B_1$ | Secondary roads with considerable traffic like principal local traffic routes, shopping streets etc. | 8 |
| Group $B_2$ | Secondary roads with light traffic. | 4 |

**Table 2.3** Illumination levels

**2. Uniformity of Illumination:**

The human eye adjusts itself automatically to the brightness within the field of vision. If there is a lack of uniformity, pupil or iris of the eye has to adjust more frequently and thus fatigue is caused to the eye and productivity is reduced. It has been found that visual performance is best if the range of brightness within the field of vision is not greater than 3:1, which can be achieved by employing general lighting in addition to localized lighting.

Apart from the consideration of causing fatigue, local lighting without using matching general lighting creates psychological feeling of loneliness, gloom and unfriendliness. The modern trend is thus towards 'localized lighting plus general lighting' and towards the adoption of "general lighting oriented towards the working surface" especially in mass production factories, offices, drawing offices, shops etc.

**3. Colour of Light:**

The appearance of the body colour entirely depends upon the colour of the incident light. In general the composition of the light should be such that the colour appears natural, i.e., its appearance by artificial light is not appreciably different from that by daylight. Daylight fluorescent tubes nowadays make it possible to illuminate economically even large spaces with artificial daylight giving good colour rendering and at sufficiently high level. For certain applications such as street lighting, colour of light does not matter much if different components have not to be distinguished from each other by their colors, highly efficient discharge lamps, which cause colour distortion, can be used.

**4. Shadows:**

In lighting installations, formation of long and hard shadows causes fatigue to eyes and, therefore, is considered to be a shortcoming. Complete absence of shadows altogether again does not necessarily mean an ideal condition of lighting installations. Contrary, perhaps to popular opinion, a certain amount of shadow is desirable in artificial lighting as it helps to give shape to the solid objects and makes them easily recognized. Objects illuminated by shadow less light appear flat and uninteresting, contours are lost, and it is difficult for the eye to form a correct judgment of the shape of an object. However, there is one exception to this, i.e., in drawing offices, where we are to see flat surfaces, shadow less light is essential otherwise shadows will hinder the work.

**Hard and long shadows can be avoided by:**

i. Using large number of small luminaries mounted at a height not less than 2.5 meters and
ii. By using wide surface sources of light using globes over filament lamps or by using indirect lighting system.

**5. Glare:**

It may be direct or reflected, i.e., it may come directly from the light source or it may be reflected brightness such as from a desk top, nickel led machine parts, or calendared paper. Direct glare from a source of light is the more common, and is more often a hindrance to vision. A glance at the Sun proves that an extremely bright light source causes acute eye discomfort. Light sources of far less brilliancy than the Sun, such as the filament of an incandescent lamp, or the incandescent mantle of a gas lamp, also cause discomfort by a direct glare. Reflected glare is a glare which comes to the eyes as glint or reflection of the light source in some polished surface.

Toleration of bright light sources in the intermediate vicinity is made possible by locating them at such a height as to place them above the ordinary range of vision. Metal reflectors for industrial lighting are ordinarily provided with a skirt around the rim of the reflector.

**6. Mounting Height:**

The mounting height will largely be governed by the type of the building and type of lighting scheme employed. In the case of direct lighting, in rooms of large floor area, the luminaries should be mounted as close to the ceiling as possible. Lowering them not only will make the illumination less uniform, but will also bring them more into the field of vision, thus increasing the glare, without causing an appreciable increase in the coefficient of utilization. In the unusual case of small rooms with high ceilings, there is something to be gained by lowering the luminaries, but even here a better solution might be to use filament lamps with focusing reflectors and to mount them high. In the case of indirect and semi-indirect lighting, it would of course be desirable to suspend the luminaries far enough down from the ceiling in order to give reasonably uniform illumination on the ceiling.

In practice this is usually taken to mean that the length of the suspension tubes should be one-quarter to one-third the horizontal spacing between the rows of luminaries. Unfortunately it is often impossible to suspend them as far down as this, because it is quite generally recognized that there should be a minimum clearance of 2.5 meters between the luminaries and the floor. It follows that in rooms having low ceilings, the illumination on the ceiling is unavoidably non-uniform. This is not objectionable, because the ceiling is not a working plane

**7. Spacing of Luminaries:**

Correct spacing is of great importance to provide uniform illumination over the whole area and thus do away with comparatively dark areas which are so often found when the fittings are badly spaced.

In the case of direct and semi-direct luminaries the ratio of the horizontal spacing between rows to the height of the luminaries above the working plane depends to quite an extent on the candle power-distribution curve of the luminaries. With fluorescent luminaries it is good practice to aim at a value of unity for this ratio, and to set an upper limit of 3/4. In the case of tungsten lamps combined with focusing reflectors, the ratio of spacing to height should be about 0.6.

In the case of indirect and semi-indirect luminaries, it is good practice to aim at a horizontal spacing between rows approximately equal to a height of the ceiling above the working plane, and in no case should the horizontal spacing exceed 1½ times this height.

In the case of fluorescent luminaries, it is a common practice to join two or more luminaries end to end so that they can share a common outlet. In fact it often works out well to use continuous rows of luminaries, especially when the specified illumination is fairly high.

**8. Color of Surrounding Walls:**

The illumination in any room depends upon the light reflected from the walls and ceilings. White walls and ceilings reflect more light as compared to colored ones.

**Commercial electrical installations:**

Commercial electricians generally handle the installation and maintenance of electrical components in businesses. This includes office buildings, housing developments, hospitals, and schools. These typically involve security systems, air conditioning systems, cabling, lighting, and other equipment.

Commercial electrical installations are very different from residential ones in several essential ways. In business premises, new wiring remains fully accessible and out in the open, typically safeguarded by conduits to protect against hazards.

Electrical wiring in business premises uses thermoplastic materials featuring nylon high resistance coating inside the conduit to protect wiring. If flammable liquids, gases, or other hazardous substances are in the environment, the electrician will make sure wiring and outlets are installed a safe distance away from these components. Depending on the potential hazards nearby, special insulation might be used to further shield the wiring.

The majority of commercial installations require 3-phase power installation. This involves a 208-volt wide leg with a neutral wire and two 120-volt legs. These voltage qualities are essential to keep motors and wiring operating properly in commercial environments.

**How do residential electrical installations differ from commercial ones?**

Domestic installations don’t require the same level of voltage and phase power as commercial spaces. Most residential installations require single-phase power, rather than the 3-phase power of commercial wiring. Residential wiring involves two hot wires covered with black and red insulation, plus a white, neutral wire. Single-phase residential electrical wiring also requires a green wire for grounding.

In addition, most residential wiring electricians install a 2-phase circuit with 240 voltage power for appliances like water heaters, stoves, and dryers.

**Key Aspects and Parameters Of Electrical Setups In Commercial Premises**

While commercial electrical installations vary according to the building, environment and any hazardous components, some key aspects are always involved. They include:

- Convenience Outlets
- Lighting
- Distribution Panel Board
- Service Entrance
- Branches and Feeders
- Emergency Lighting and Signals

**Convenience Outlets**

Commercial premises always require the acting electrician to install numerous convenience outlets in the form of sockets. Wall outlets are essential to power all your equipment, electronics, devices, and any other plug-in items.

The kind of electrical sockets used for business electrics depends on your work environment. Factors such as the number of occupants using the workspace at any one time will affect how many outlets you need. Besides this, your commercial space’s other electrical components (like cables) will change the type of sockets you require.

**Lighting:**

There are endless components to consider regarding the lighting scheme in your business’s space. Electricians typically install lights in the latter part of the fit out process, so it is best to begin with general light wiring, then move to the more complicated lighting components.

**Distribution Panel Board**

Your commercial space’s distribution panel board is responsible for transmitting electricity throughout the building using subsidiary circuits. The panel board is also comparable to a breaker or fuse.

If you want faster reactionary speed, choose distribution boards with extensive wiring capacity and accessible door handles.

**Service Entrance**

In commercial applications, the service entrance is the location where grid electricity enters your premises for routing to the rest of the service or building.

The service entrance might be overhead wires connected to a utility pole, or a more complicated set up such as a trough with multiple switches.

**Branches and Feeders**

If your business requires extra speed, things like branch circuits and feeders could be necessary depending on your distribution and service boards. Speak to our expert team to determine whether you can get a speed jump by having these installed.

**Emergency Lighting and Signals**

Emergency lights and fire signals are fitted and the end part of the electrics install. The safest way to put them in is to have them near simple wiring for speed and efficiency.

**Main Differences between Residential and Commercial Electrical Work:**

Residential wiring refers to any electrical work or wiring that’s meant for residential buildings and houses. This type of wiring is confined to homeowners.

On the other hand, commercial wiring is incredibly complicated and is designed for commercial buildings such as warehouses, hospitals, and malls.

Each of these types of wiring requires different amounts of electricity as well as different atmospheric conditions. That’s why both commercial and residential wiring require different expertise when it comes to repairs and installation.

Read on as we explain the differences between commercial and residential buildings when it comes to wiring, licensing, accessibility, quality, and phases of power required.

1. **Power:**

Three-phase power is utilized for commercial buildings. This includes a neutral wire, as well as a 120-volt leg and a 208-volt leg. Residential buildings use a single power phase with 120-volt wires and a neutral wire. Utility companies are also required to supply different amounts of power for commercial versus residential buildings.

Commercial buildings are larger so they require a lot more power when compared to residential buildings.Bates-Electric.com states that it’s also important for the electrical company to ensure that they don’t overload the property with power by dividing the electrical load into phases. This goes for commercial and residential building requirements.

2. **Wires:**

The wiring required for a commercial building is patently different from that of a residential building. Commercial building wiring is typically protected inside a series of tube-like conduits. The wires are also installed in open spaces to make for easy access.

Residential home wiring is protected inside layers of plastic sheathing and comes in the form of thin wire. The sheathing is designed to protect anyone who might accidentally touch the wires which are often located in the attic or crawl space.

As you can see, conduits aren't utilized with residential wiring.

3. **Quality**

The quality and grade of electrical materials that are utilized for commercial buildings are different from those utilized for residential buildings. Commercial buildings require the use of extremely durable materials that are resistant to heat, corrosion, and chemical exposure in order to handle the demand and rigor of supplying power to a large building. Commercial buildings also require backup power that is able to handle variable temperature changes and unexpected emergencies. Whereas, residential sites don't have the same requirements.

4. **Location**

Accessibility also makes a difference between commercial and residential buildings.
In residential buildings, visible electrical wiring is a no-no, especially if you have children or pets in the house that like to touch and play with everything.

For best results, it's recommended to hide electrical wires behind the drywall so that it's not easily accessible.

5. **License**

Electricians who work in commercial buildings require different licensing compared to electricians who work in residential buildings.

In addition to licensing, commercial sector electricians are required to undergo a certified commercial electrician apprenticeship program to prove their skills.

Adversely, residential electricians only require state licensing as well as a license by a relevant local agency. They're not required to acquire any additional certification.

# UNIT - III

# ELECTRIC HEATING AND WELDING

**Syllabus:** 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.

**HEAT:**

Heat is the form of energy that is transferred between two substances at different temperatures. The direction of energy flow is from the substance of higher temperature to the substance of lower temperature. Heat is measured in units of energy, usually calories or joules. Temperature is the measure of hotness or coldness of matter. Stated another way, temperature is the average kinetic energy per molecule of a substance.

**MODES OF TRANSFER OF HEAT:**

The transmission of the heat energy from one body to another because of the temperature gradient takes place by any of the following methods:

1. Conduction
2. Convection
3. Radiation

**Conduction:**

This phenomenon takes place in solid, liquid and gas. In this mode, the heat transfers from one part of substance to another part without the movement in the molecules of substance.

The rate of the conduction of heat along the substance depends upon the temperature gradient. Heat transfer is proportional to the difference of temperature between two faces.

The amount of heat passed through a cubic body with two parallel faces with thickness 't' meters, having the cross-sectional area of 'A' square meters and the temperature of its two faces $T_1$°C and $T_2$°C, during 'T' hours is given by

$$Q = \frac{kA}{t}(T_1 - T_2)\ T\ \text{MJ}$$

Where k is the coefficient of the thermal conductivity for the material and it is measured in MJ/m3 /°C/hr.

**Ex:** Refractory heating, the heating of insulating materials, etc.

**Convection:**

This phenomenon takes place in liquid and gas. In this mode, the heat transfer takes place from one part to another part of substance or fluid due to the actual motion of the molecules. The rate of conduction of heat depends mainly on the difference in the fluid density at different temperatures.

**Ex:** Immersion water heater.

The amount of heat absorbed by the water from heater through convection depends mainly upon the temperature of heating element and also depends partly on the position of the heater. Heat dissipation is given by the following expression.

$$H = a (T_1 - T_2)^b \ W/m^2$$

Where 'a' and 'b' are the constants whose values are depend upon the heating surface and $T_1$and $T_2$ are the temperatures of heating element and fluid in °C, respectively.

**Radiation:**

This phenomenon is confined to surfaces. The complete process in which energy is emitted by one body, transmitted through an intervening medium or space, and absorbed by another body. It is dependent on surface. Ex: Solar heaters.

The rate of heat dissipation through radiation is given by Stefan's Law.

Heat dissipation $H = 5.72\times10^4 \text{ ke } [\left[\frac{T_1}{1000}\right]^4 - \left[\frac{T_2}{1000}\right]^4] W/m^2$

Where

$T_1$ is the temperature of the source in Kelvin,

$T_2$ is the temperature of the substance to be heated in Kelvin,

k is the radiant efficiency = 1 for single element, 0.5-0.8 for several elements

e = emissivity = 1, for black body = 0.9 for resistance heating element.

From above Equation, the radiant heat is proportional to the difference of fourth power of the temperature, so it is very efficient heating at high temperature.

**ELECTRIC HEATING:**

Electric heating is a process in which electrical energy is converted in to "heat energy." Electric heating works on the principle of "joule heating." (An electric current through a resistor converts electrical energy in to heat energy).

Electric heating is based on the principle of that when electric current passes through a medium heat is produced. Let us take the case of solid material which as resistance R ohms and current flowing through it is I amps for t seconds than heat produced in the material will be $H = I^2Rt$ joules.

**Domestic application of electric heating:**

- Room heater for heating the building
- Immersion heater for water heating
- Hot plates for cooking
- Geysers
- Electric iron
- Electric kettles
- Electric oven for baking products
- Electric toasters etc…

**Industrial applications of electric heating:**

- Melting of metals
- Electric welding
- Molding of glass for making glass appliances
- Baking of insulators
- Molding of plastic components
- Heat treatment of pointed super passes
- Making of plywood

**Advantages of electric heating:**

The various advantages of electric heating over other types of heating

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.

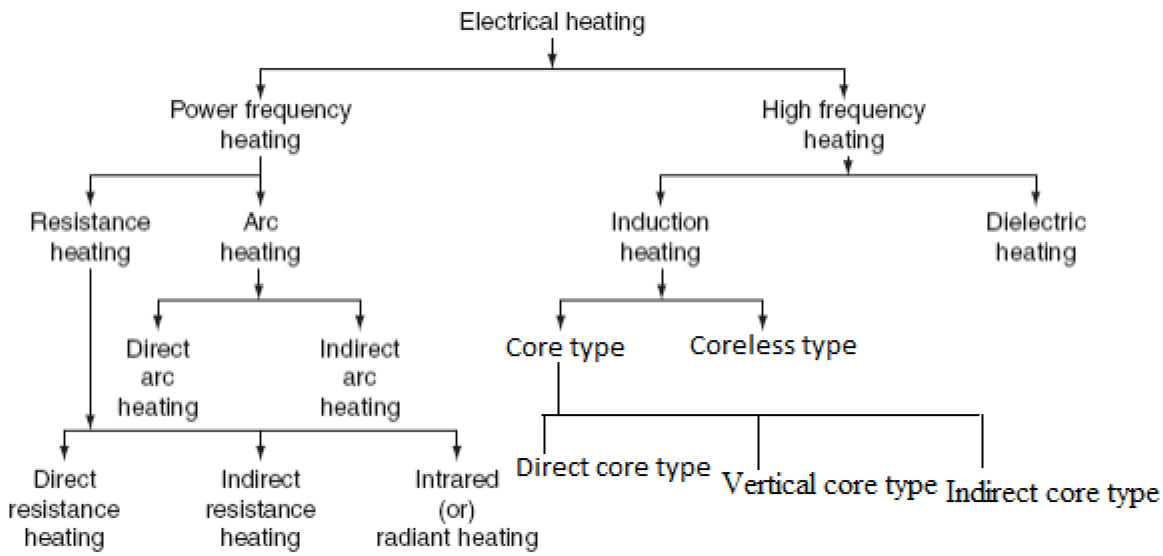
xi. **High temperature:** High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

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.




In general electric heating can be classified as power frequency heating and high frequency heating

**POWER FREQUENCY HEATING:**

Power frequency heating can be classified in to 2 type's i.e.

1. Resistance heating
2. Arc heating

**1. 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 $I^2R$ 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,

a) Direct resistance heating
b) Indirect resistance heating
c) Infrared (or) radiant heating.

**a) Direct resistance heating:**

In this type of heating electric current is passed directly through the body to be heated. Since the body has resistance, current causes heat generation in the body. Hence it raises the body temperature. (Or) In this method, the electric current is made to pass through the charge (or) substance to be heated.

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. 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.

**Applications:**

- Electrode boiler for heating water
- Resistance welding
- salt bath furnace

**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.

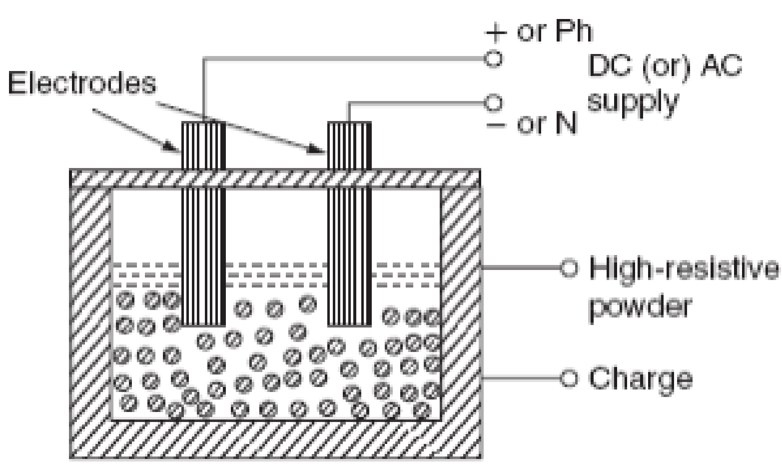



**Fig.3.1.** Salt bath furnace

**Electrode boiler:**

It is used to heat the water by immersing three electrodes in a tank as shown in the below Fig. 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 $H_2$ at negative electrode and $O_2$ 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.

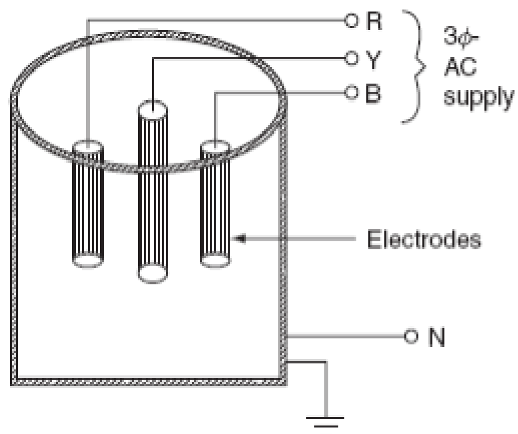



**Fig.3.2.** Electrode boiler

**b) 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.

In the indirect resistance heating method, high current is passed through the heating element. In case of industrial heating, sometimes 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 the below fig. 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.

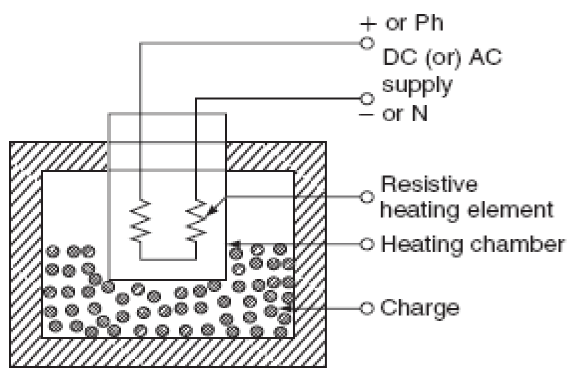



**Fig.3.3.** Indirect resistance heating

**Applications:**

- Resistance ovens
- Cooking
- Heat treatment of metals
- Immersion heaters or water heater
- Room heaters

**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 land 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 the below fig.

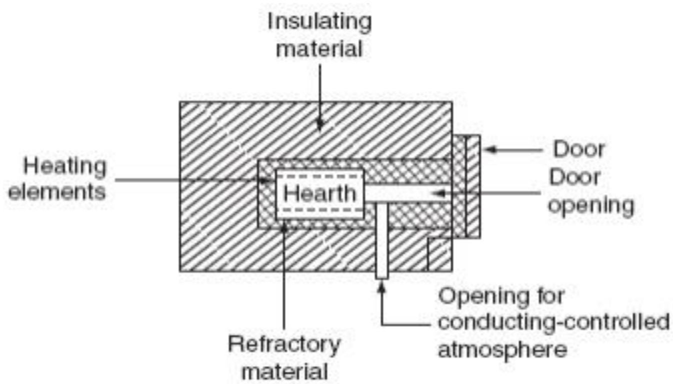



**Fig.3.4.** Resistance oven

Resistance oven consists of a heating chamber in which heating elements are placed as shown in the above fig. the inner surface of the heating chamber is made to suit the character of the charge and the type of furnace and oven. This type of insulation is used for heating chamber it 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:** 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 ($\Delta T$) and is given by

$$H_{oven} = MS\Delta TJ.$$

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

2. **Heat used in raising the temperature of containers (or)carriers:** Heat used in raising the temperature of containers (or) carriers can be calculated exactly same way as for oven or furnaces
3. **Heat conducted through the walls:** 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 outside temperatures of the container $T_1$ and $T_2$ in °C, respectively, and the thermal conductivity of the container walls '$k$' in m$^3$/°C/hr and is given by:

   Heat loss by conduction = $\frac{kA}{t}(T_1 - T_2)$ W
4. **Heat loss due to the opening of oven door:** 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/m$^2$ of the door area, if the door is opened for a period of 2

**Efficiency:**

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

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

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

**c) 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, for low and medium temperature applications. Where as 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.

**Applications:**

- Used for drying clothes in the textile industry
- Dry the wet paints on an object.

**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 $I^2Rt$ or $\frac{V^2}{Rt}$.

Therefore, the temperature of the furnaces can be controlled either by:

- Changing the resistance of elements.
- Changing the applied voltage to the elements (or) current passing through the elements.
- 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 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:

- **Variable number of elements:** If '$R$' be the resistance of one element and '$n$' be the number of elements are connected in so that the equivalent resistance is R/n.

  Heat developed in the furnace is: H = $\frac{V^2}{(R/n)} = \frac{V^2}{R} \times n$

  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.
- **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.

**2. ARC HEATING:**

If the high voltage is applied across an air gap, the air in the gap gets ionized under the influence of electrostatic forces and becomes conducting medium, current flows in the form of a continuous spark, known as arc. A very high voltage is required to establish an arc but very small voltage is sufficient to maintain it, across the air gap. The high voltage required for striking an arc can be obtained by using a step-up transformer fed from a variable AC supply.

Another method of striking the arc by using low voltage is by short circuiting the two electrodes momentarily and with drawing them back. Electrodes made up of carbon or graphite and are used in the arc furnaces when the temperature obtained is in the range of 3000-3500 $^0$C. There are two types of arc heating and they are

1. Direct arc heating
2. Indirect arc heating

**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.

**HIGH FREQUENCY HEATING:**

The main difference between the power frequency heating and the high-frequency heating is that in the conventional methods, the heat is transferred either by conduction convection or by radiation, but in the high-frequency heating methods, the electromagnetic energy converted into the heat energy inside the material.

The high frequency heating can be applied to two types of materials. The heating of the conducting materials, such as Ferro-magnetic and non-Ferro-magnetic, is known as induction heating. The process of heating of the insulating materials is known as dielectric heating.

The heat transfer by the conventional method is very low of the order of 0.5–20 W/sq. cm. And, the heat transfer rate by the high-frequency heating either by induction or by dielectric heating is as much as 10,000 W/sq. cm. Thus, the high-frequency heating is most importance for tremendous speed of production

This high frequency heating can be classified in to two types

1. Induction heating.
2. Dielectric heating.

**Advantages of high-frequency heating:**

- Dielectric heating is appropriate for non-conducting materials such as plastic, wood, and synthetic compounds.
- When the heat is generated during the complete mass of material, then we get consistent heating. By using a conventional heating method, it is not achievable to get this.
- To complete this process very little time is necessary when contrasted to another method.

**Disadvantages of high-frequency heating**:

- This method is suitable for the highest dielectric loss materials
- The dielectric heating overall efficiency will be very low
- The radio interface can be caused due to high frequencies.
- The equipment used for dielectric heating is so costly so it is used only where other techniques are unfeasible.

**Applications of High-Frequency Heating:**

- There are many industries that use dielectric heating techniques like paper, textiles, food, chemicals, and plastic.
- There are many applications like baking, drying, welding, polymerization and defrosting.
- These come under the techniques of dielectric heating or high frequency.
- These two are electromagnetic wave energy forms.

**1. 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 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 below fig.

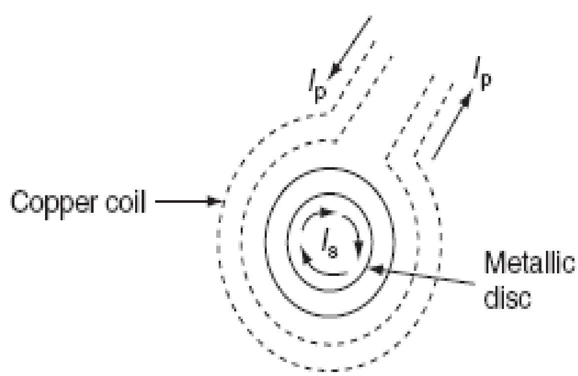



**Fig.3.5.** Induction heating

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

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

Where $\rho$ is the specific resistance in Ω-cm, $f$ is the frequency in Hz, and $\mu$ is the permeability of the charge

There are basically two types of induction furnaces and they are

a. Core type or low-frequency induction furnace.
b. Coreless type or high-frequency induction furnace

**a. Core type or low-frequency induction 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,

- Direct core type.
- Vertical core type.
- Indirect core type

**Direct core type induction furnace:**

The core type furnace is essentially a transformer in which the charge to be heated forms single- turn secondary circuit and is magnetically coupled to the primary by an iron core as shown in below fig.

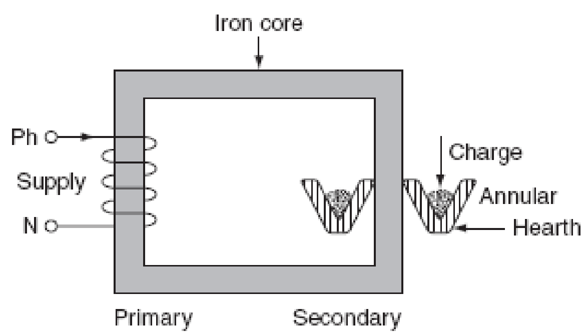



**Fig.3.6.** Direct core type induction furnace

It consists of an iron core, crucible (a ceramic or metal container in which metals or other substances may be melted) and primary winding connected to an A.C supply. The charge is kept in the crucible, which forms a single turn short circuited secondary circuit. The current in the charge is very high in the order of several thousand amperes. The charge is magnetically coupled to the primary winding. The charge is melted because of high current induced in it. When there is no molten metal, no current will flow in the secondary. To start the furnace molten metal is poured in the oven from the previous charge.

**This type of furnace has the following drawbacks:**

- 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 10HZ.
- 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.
- If current density exceeds about 5 amps/mm$^2$, 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 called 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.
- The crucible for the charge id of odd shape and inconvenient from the metallurgical point of view.
- The furnace cannot function if the secondary circuit is open. It must be closed. For starting the furnace either molten metal is poured into the crucible or sufficient molten metal is allowed to remain in the crucible from the previous operation. Such furnace is not suitable for intermittent services.

**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 below fig. It is also known as Ajax–Wyatt induction furnace.

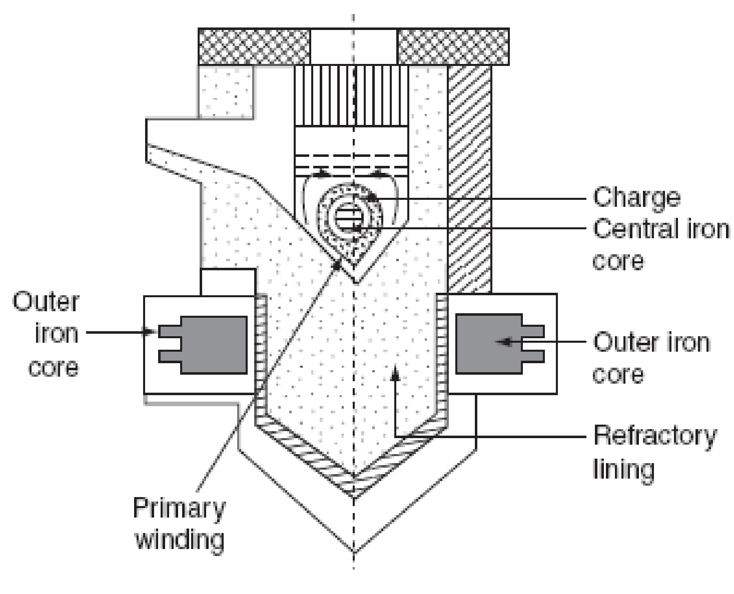



**Fig.3.6.** Vertical core type induction furnace

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 of vertical core type induction furnace:**

- 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.

**Indirect core type induction 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 below fig. In this type of furnace induction principle has been used for heating metals. In such furnace an inductively heated element is made to transfer its heat to the charge.

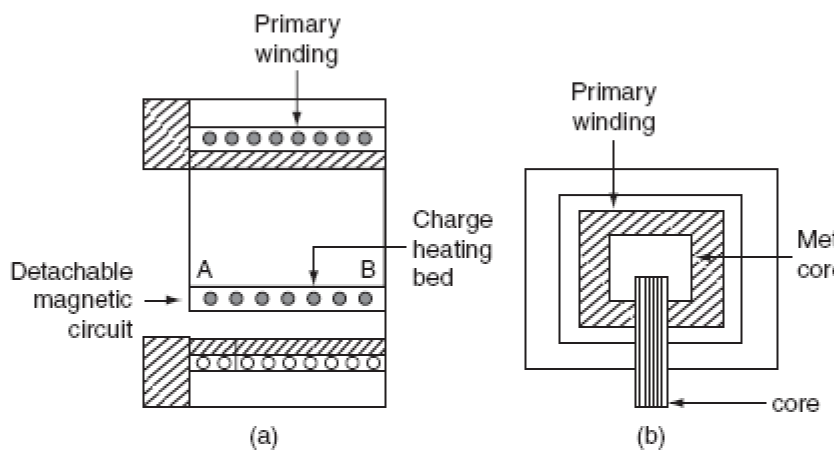



**Fig.3.7.** Indirect core type induction furnace

When the primary winding is connected to the supply, current is induced in the secondary of the metal container. 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.

It consists of a magnetic circuit AB is made up of a special alloy and is kept inside the chamber of the furnace. The special alloy will lose its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature. As soon as the furnace attains the critical temperature the reluctance of the magnetic circuit increases many times and the inductive effect correspondingly decreases thereby cutting off the heat supply.

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. Thus the temperature of the furnace can be controlled very effectively. The furnace operates at a power factor of around 0.8.

The main advantage of such furnace is wide variation of temperature control is possible.

**b. Coreless type or high-frequency induction furnace:**

It is a simple furnace with the absence core is shown in below fig. Coreless induction furnace also operates on the principle of transformer.

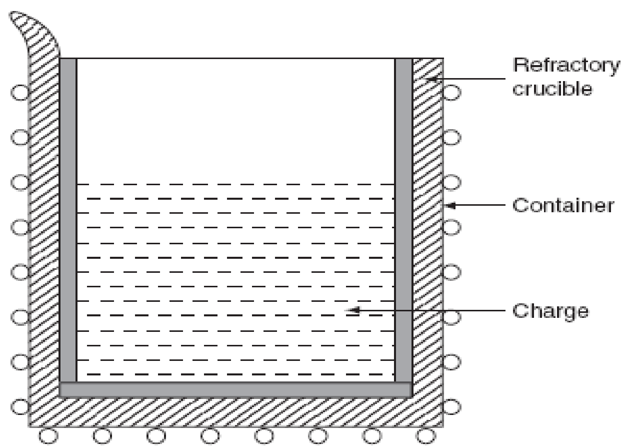



**Fig.3.8.** Coreless type induction furnace

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 non- conducting container that acts as secondary. If the container is made up of conducting material, charge can be conducting or non- conducting; whereas, if the container is made up of non-conducting material, charge taken should have conducting properties. In this furnace, heat developed in the charge due to eddy currents flowing through it.

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

$$W_e \propto B_m^2 f^2$$

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, '$\rho$' is the resistivity in Ω-cm, '$\mu$' 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 d/t = 8. Sub in the above equation.

$$f = \frac{16 \times \rho \times 10^9}{\pi^2 \mu d^2}$$

**Advantages of coreless type induction furnace:**

- 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.
- Absence of dirt, smoke, noise, etc.
- Accurate power control is possible

**2. DIELECTRIC HEATING:**

**Introduction:**

Whenever we hear the word 'fire' then the first thing that we understand from it is something related to 'heating'. So, basically, the fire was one of the major elements that were used in earlier days by human beings for purposes like cooking food, molding, or welding of metals, etc. However, with various technological advancements in recent years, so many alternatives have come into existence to perform such applications without the need for fire. Dielectric Heating is one of the valuable inventions relative to this field as through this a new way has evolved for such processes without the involvement of fire.

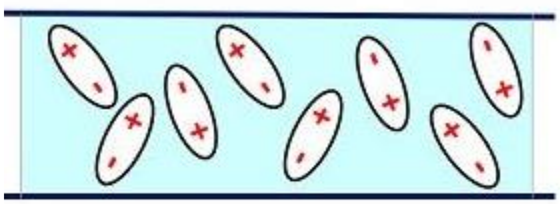
**What is dielectric?**

Dielectrics are basically insulators that possess very poor conducting ability relative to electric current. We know that every matter in this universe is composed of molecules whose elemental particle is an atom. When an external field is not present then the polar molecules within a material are randomly positioned within it. However, by applying an electric field, the material gets polarized; this is because the dipole moments of polar molecules get properly oriented.

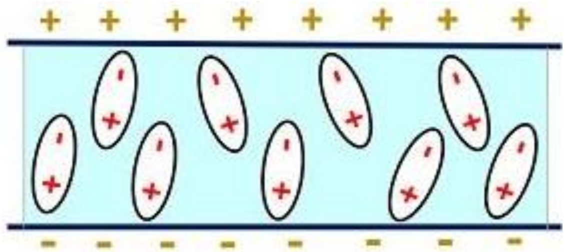
Basically, in conductors, the loosely bounded electrons drift through the material when it is connected to the external electric field. However, this is not the case with dielectrics as they do not have loosely bounded electrons or free electrons for such actions. But here dielectric polarization occurs.

**Dielectric Polarization:**

It is nothing but the presence of polar molecules in the proper orientation. To understand this, consider the below fig.



(a) Unpolarized



(b) Polarized with EF

**Fig.3.9.** Polarization

Here there are two conductive plates separated by dielectric material in both images. The first one is un polarized due to the absence of an electric field. However, in the second figure, it is seen that the arrangement is subjected to an electric field because of which there is a slight displacement of positive charges in the direction of the electric field and negative charges in the opposite direction of it. The minute charge separation within the dielectric is known as **polarization** and this leads to a reduction in the electric field within the dielectric.

**Operating Principle of Dielectric Heating:**

Dielectric Heating is a process of electric heating by which the temperature of a dielectric (non-conducting) material is raised by the application of an alternating electric field (high voltage ac signal). The increase in temperature results in heating the substance which is in contact with the external field.

Dielectric heating is sometimes called high frequency or radio-frequency heating, capacitive heating. This process allows uniform heating of non-metallic materials which are unable to conduct electricity.

The principle of operation of a dielectric heater is such that a non-conducting material is present between two electrodes and an external electric field is applied across these two electrodes. Basically, a wide range of frequency is provided to the electrodes.

The dielectric material which is present between the two electrodes can be anything such as wood, plastic, glass, etc. Though it is considered that a dielectric does not allow the flow of electric current through it, practically it is not possible. So, whenever these materials are provided with a high voltage alternating supply then even minute motion of charged particles results in the flow of current which leads to dielectric losses. This resultantly produces heat within the material.

**Circuit Operation of Dielectric Heating:**

Till now we have got the idea that the sole purpose of a dielectric heater is to heat up an insulating material. A dielectric heater is regarded as an electric heater as it transforms electrical energy into heat. We have already discussed induction heating (which is also a type of electric heating) in our previous content where the principle of electromagnetic induction is used to heat up the magnetic material without making direct contact with the source.

The below figure shows the circuit arrangement of a dielectric material and circuit diagram and phasor diagram which is formed by encapsulating an insulating material between two conducting plates forming a parallel plate capacitor arrangement.

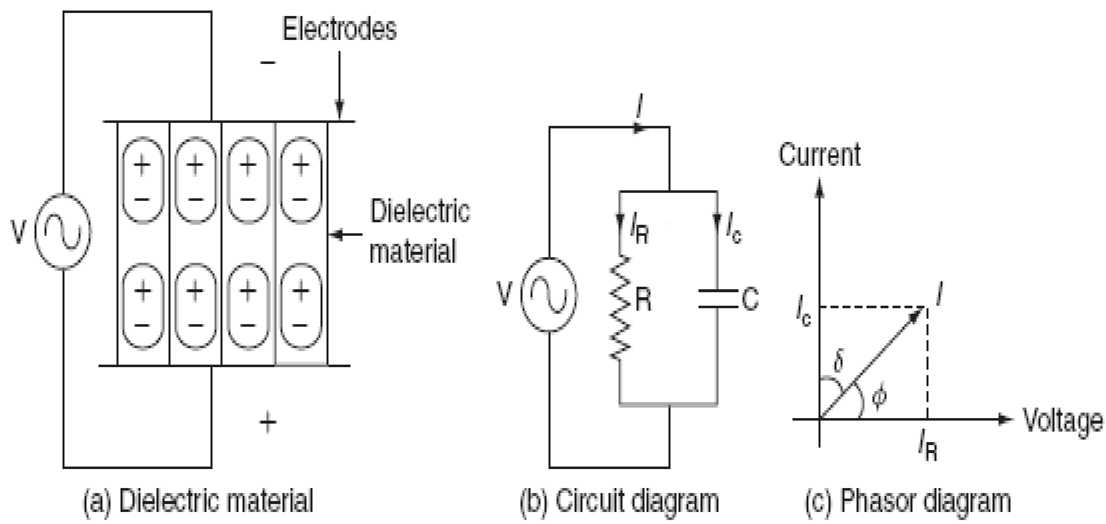



**Fig.3.10.** Dielectric heating

Here a very high-frequency ac voltage signal i.e., 20KV with frequency ranging between 10 to 50 MHz is provided across the whole capacitive arrangement. Dielectric loss results in the generation of heat. Now, the question arises. So, generally, when sinusoidal voltage is provided to the capacitor shown above then the capacitor draws some current. However, this current never leads the voltage by exactly 90°. This means that there exists some in-phase relationship between the supplied voltage and the flowing current. This resultantly produces power loss within the dielectric of the capacitive plates.

At the ordinary frequency range of 50 Hz, this loss is not that significant that it can cause heat generation and so can be neglected. However, at larger frequencies i.e., in the megahertz range, the loss becomes quite large and this heats up the dielectric. This property of the whole configuration is utilized for the purpose of heating the dielectrics (insulating materials).

It is to be noted here that the amount of dielectric loss produced depends on the supply voltage and frequency. Therefore, in order to get the high heating effect, one must need to provide a very high-frequency voltage signal as this will give rise to high dielectric loss and so high heating effect.

The power dissipated within the dielectric material will be given as

$$P = VI_R$$

$$\text{Since, } I_C = I \sin\boldsymbol{\theta} = I \cos\boldsymbol{\delta}$$

$$I_R = I \cos\boldsymbol{\theta} = I \sin\boldsymbol{\delta}$$

$$\text{Thus } P = VI \cos\boldsymbol{\theta}$$

And substituting the value of I from $I_C = I \sin\theta$ in the above equation, we will get,

$$P = V \frac{I_C}{\sin\theta} \cos\boldsymbol{\theta}$$

Furthermore, the above equation will be written as

$$P = VI_C \cot\boldsymbol{\theta}$$

From the phasor shown it is clear that, $\theta = 90° - \delta$

Therefore,

$$P = VI_C \cot (90^0 - \delta)$$

By trigonometric identity, $P = VI_C \tan (\delta)$

We know that, $I_C = \frac{V}{X_C}$ and $X_C = \frac{1}{2\pi fc}$

Therefore, on substituting, $X_C$ value in $I_C$

$$I_C = \frac{V}{\frac{1}{2\pi fc}} = 2\pi fcV$$

Suppose, the dielectric slab is of width b (in m) with area A (in $m^2$) having permittivity ε (in farad/m), then its capacitance will be,

$$C = \frac{\varepsilon A}{b} \text{farad}$$

Now substitute above $I_C$ value in equation $P = VI_C \tan (\delta)$

$$P = 2\boldsymbol{\pi} fcv^2 \tan (\delta)$$

Now substitute C value in above equation

$$P = 2\boldsymbol{\pi} f \left(\frac{\varepsilon A}{b}\right) v^2 \tan (\delta)$$

The volume of dielectric slab = Area * width = A * b (in $m^3$)

$$P = 2\boldsymbol{\pi} f\varepsilon Ab\left(\frac{V}{b}\right)^{\mathbf{2}} \tan (\delta)$$

Thus, the power loss per unit volume will be, $P_0 = 2\boldsymbol{\pi} f\varepsilon \left(\frac{V}{b}\right)^{\mathbf{2}} \tan (\delta)$ watts/$m^3$

Since, $\varepsilon = \varepsilon_0 \varepsilon_r$

$$P_0 = 2\pi f \varepsilon_0 \varepsilon_r \left(\frac{V}{b}\right)^2 \tan(\delta) \text{watts/m}^3$$

Where, 'V' is the applied voltage in volts,

'f' is the supply frequency in Hz,

$\varepsilon_0$ is the absolute permittivity of the medium = $8.854 \times 10^{-12}$ F/m,

$\varepsilon_r$ is the relative permittivity of the medium = 1for free space,

A is the area of the plate or electrode ($m^2$),

b is the thickness of the dielectric medium,

tan δ is the loss angle in radian.

Thus, from this equation, we can say that the power loss per unit volume of dielectric is directly proportional to

- The operating frequency,
- The square of voltage gradient and

**Advantages:**

- It is inexpensive.
- Unlike other electric heating techniques, it offers uniform heating.
- Dielectric heating provides the good heating ability to non-conducting materials like plastics.
- It takes moderate time for heating.
- Heat controllability is easy.
- The heat produced depends on the applied frequency.
- A fast-heating process causing an efficient rise in temperature by eliminating temperature difference within the non-conducting material.

**Disadvantages:**

- Its efficiency is only 50%, which is considered as its major drawback.
- Only the materials possessing high dielectric losses can be heated up.
- Sometimes radio interference exists because of high-frequency input.

**Applications of Dielectric Heating:**

The various applications of dielectric heating are as follows:

1. **Food processing**: In the field of food processing, it is used for various applications such as concentrating liquids within bottles, food cooking without outer shell removal, defrosting, dehydrating, germicidal heating, etc.
2. **Preheating of plastic preform**: It is one of the significant applications of dielectric heating as no other method can perform this in a uniform manner.

The raw plastic material in the form of biscuits or tablets are called plastic preform and to convert a bulk of these biscuits or tablets into a specific shape they are Kept inside the required mould Basically, to get them in desired shape uniform heating up to a certain level is required before putting them in the mould.

3. **Sterilization**: This process suits sterilizing medical equipment and aiding items like bandages, cotton, scissors, and other gauge instruments.
4. **Diathermy**: To generate a specific body temperature in order to cure certain kinds of pains or diseases, body tissues and bones are subjected to dielectric heating.
5. **Electronic Sewing**: It is the process by which the plastic sheets of umbrellas, raincoats, medicine containers can be sealed or joined. The materials with plastic films are not joined by ordinary stitching thus by the application of heat, sealing is provided to the material under the presence of mechanical pressure.
6. The preparation of thermo plastic resins.
7. The heating of bones and tissues.
8. The processing of rubber, synthetic materials, chemicals, etc.
9. The heating for the dehydration such as milk, cream, and vegetables.
10. The heating for the general processing such as coffee roasting and chocolate industry
11. The drying of paper, wood, etc.
12. The gluing of wood.
13. The heat-sealing of plastic sheets.

## ELECTRIC WELDING:

### INTRODUCTION:

In olden days, the process of metal welding can be done by heating the metals and pressed jointly which is known as forge welding method. But at present, the welding technology has been changed by the arrival of electricity. In the 19th century, different types of welding are used such as thermal welding, gas welding, and electric welding. After this, there are different types of welding technologies have been invented like friction, ultrasonic, plasma, laser, electron beam welding. Although, the applications of welding technology mainly involves in a variety of industries. Like automobile industry, pipe-line fabrication in thermal power plants, machine repair work, machine frames, etc.

**Welding:**

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.

**Advantages of welding:**

- 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.

**Disadvantages of welding:**

- Welding gives out harmful radiations and fumes.
- Welding needs internal inspection.
- If welding is not done carefully, it may result in the distortion of work piece.
- 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.

**TYPES OF ELECTRIC WELDING:**

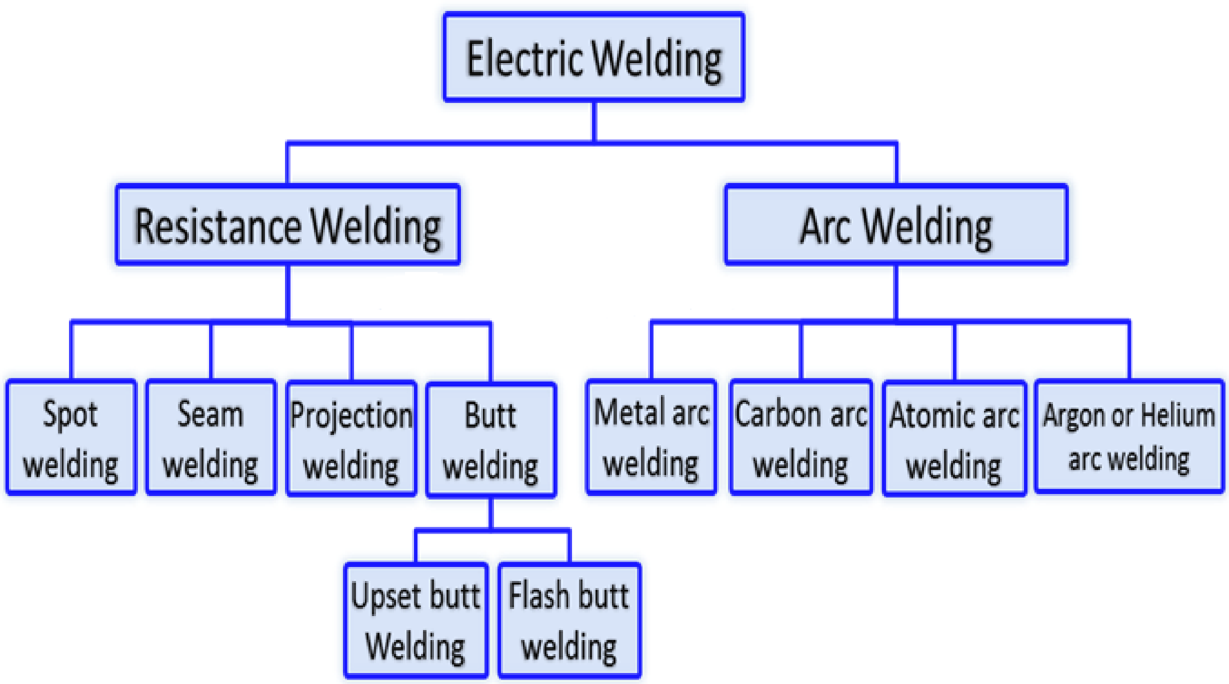



**Fig.3.11.**Classificationofelectricwelding

The selection of proper welding process depends on the following factors.

- 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, H' is a generated Heat, and the unit of heat is a joule

I is the current through the electrodes and the unit of this is ampere

R is the contact resistance of the interface and the unit of this is Ohms

t is the time for which current flows and the unit of this is seconds

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.

**Working process of Resistance welding:**

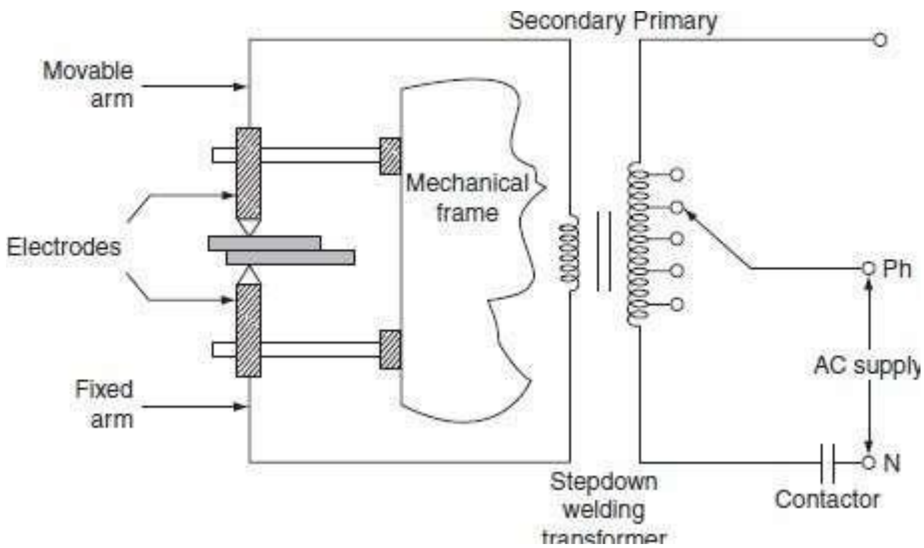



**Fig.3.12.** Electrical circuit for resistance welding

The electrical circuit diagram for resistance welding is shown in above fig. 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.

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, and 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 60to 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.

**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.

**Disadvantages:**

- Initial cost is very high.
- High maintenance cost.
- The work piece 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

**1) 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 below Fig.

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.

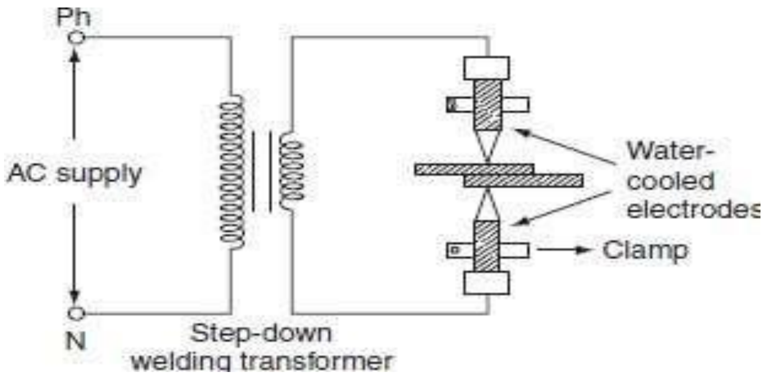



**Fig.3.13.** Spot welding

The welding current varies widely depending up on the thickness and composition of the plates. It varies from1,000 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 up on 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 work piece.

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 work piece, between the two work pieces to be joined as shown in above Fig.

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

- Using water-cooled electrodes shown in below Fig. By avoiding the heating of junction electrodes in which cold water circulated continuously.
- 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

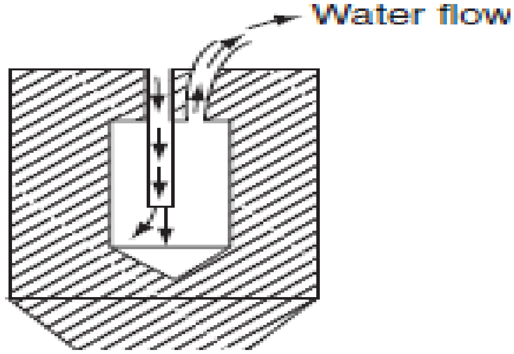



**Fig.3.13.** Water cooled electrode

**2) 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 below Fig.

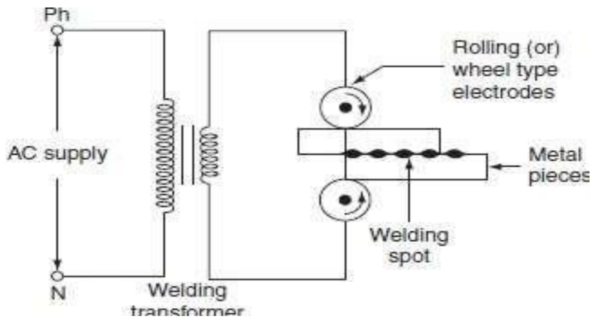



**Fig.3.14.**Seam welding

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 up on the number of welding current pulses. The two forms of welding currents are shown in below Fig.

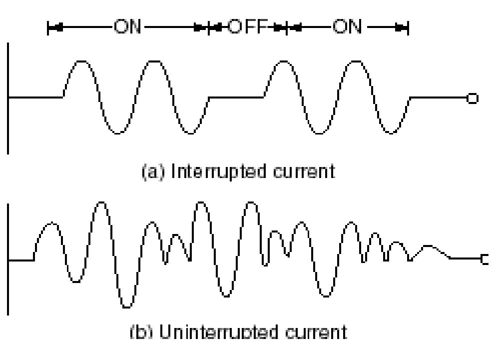



**Fig.3.15.**Welding current

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 work piece and cause builds up high heat as the welding progress; this will over heat the work piece 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.

**3) 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 below Fig.

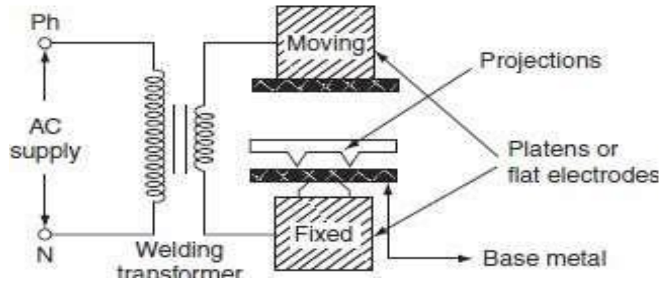



**Fig.3.16.**projection welding

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 contact 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.

**4) 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 two basic types of the butt welding process are,

a. Upset butt welding.
b. Flash 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 below Fig.

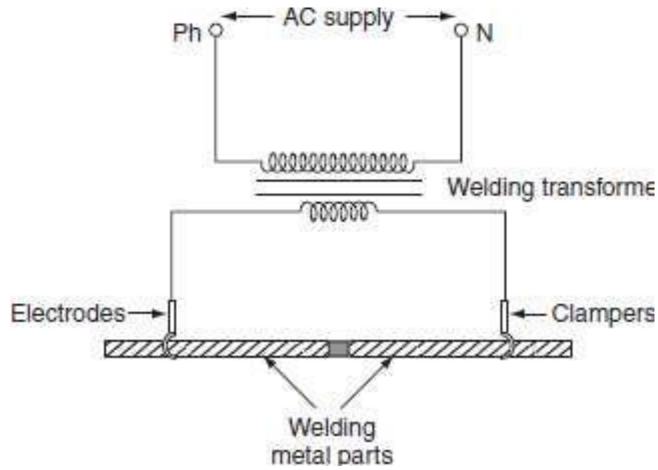



**Fig.3.17.**Upset butt welding

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 below Fig.

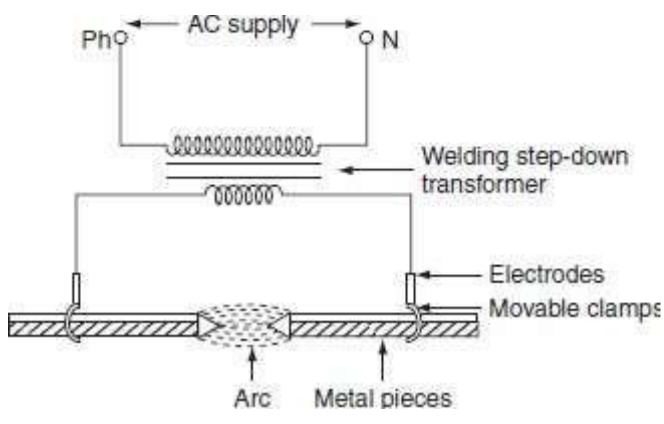



**Fig.3.18.**Flash butt welding

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 work pieces 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 butt 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.

**ARCWELDING:**

Arc welding is a welding process used to join metal to metal by using electricity to generate enough heat to melt metal and the melted metals, when cooled, resulting in a joint of the metals. It is a type of welding that uses a welding power supply to create an arc between a metal stick ("electrode") and the base material to melt the metals at the point of contact. Arc welders can use either direct current (DC) or alternating current (AC).

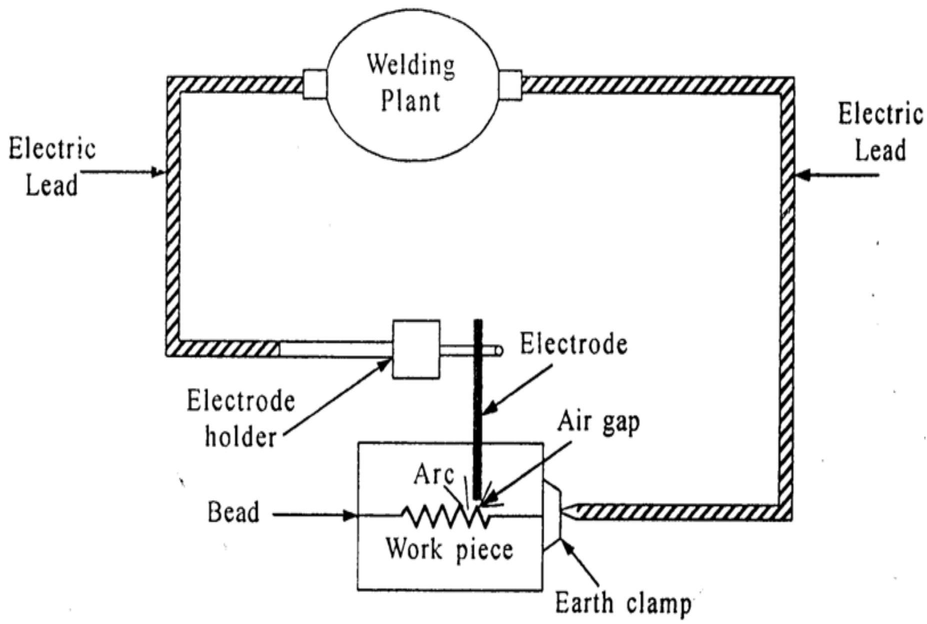



**Fig.3.19.** Arc welding

Arc welding processes can be manual, semi-automatic, or fully automatic. Arc welding was developed in the late 19th century and gained commercial importance in shipbuilding during World War II. Today it remains an important process for the manufacture of steel structures and vehicles.

Arc welding is a fusion welding process used to join metals. An electric arc from an AC or DC power source creates intense heat of about 6500°F, which melts the metal at the joint between two work pieces.

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 work piece 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 arc can either be guided manually or by machine along the joining line, while the electrode either only carries the current or conducts the current and at the same time melts into the weld pool in order to feed filler material to the joint.

Since the metals react chemically with oxygen and nitrogen in the air when they are heated by the arc too high temperatures, a protective gas or slag is used to minimize contact of the molten metal with the air. After cooling, the molten metals solidify to form a metallurgical bond.

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 below Fig.

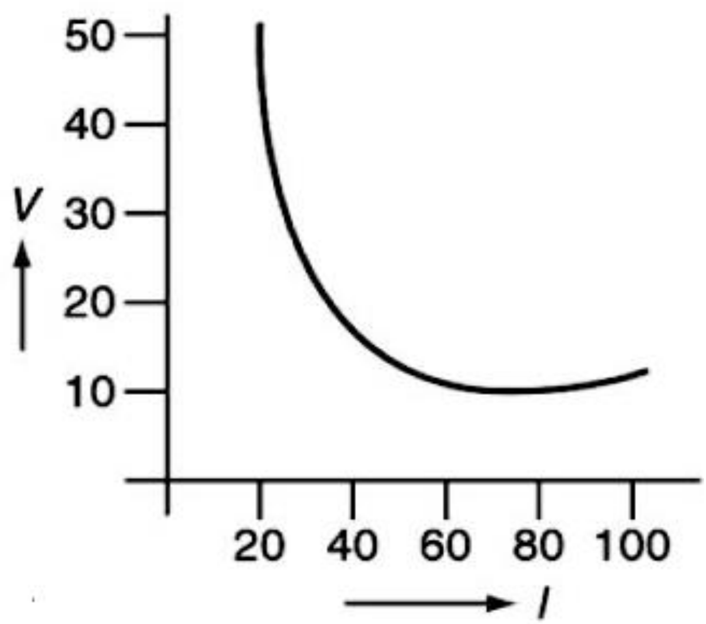



**Fig.3.20.**VI Characteristics of arc welding

It is 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 can 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. Usually 70–100V on AC supply and 50–60V on DC supply system is sufficient to strike the arc in the air gap between the electrodes. Once the arc is struck, 20–30V 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, there pair 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

**1. 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 below Fig.

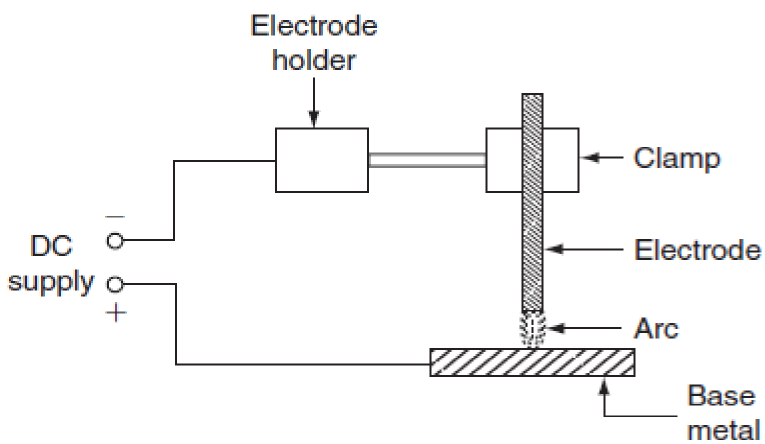



**Fig.3.21.**Carbon arc welding

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 3,900ºC. 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.
- Low cost of equipment and welding operation;
- High level of operator skill is not required;
- The process is easily automated;
- Low distortion of work piece.

**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.
- Unstable quality of the weld (porosity);
- Carbon of electrode contaminates weld material with carbides.

**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.

**2. 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 below Fig.

The arc produced between the work piece and the electrode results high temperature of the order of about 2,400$^{o}$C at negative metal electrode and 2,600$^{o}$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 work piece, forms complete weld.

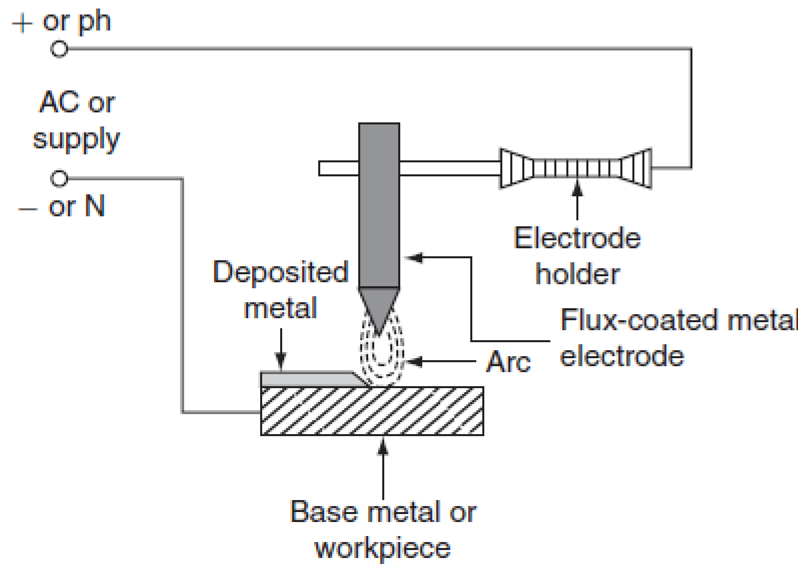



**Fig.3.22.** Metal arc welding

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.

**3. Atomic hydrogen arc welding:**

Atomic hydrogen arc welding, shown in below Fig. the heat for the welding process is produced from an electric arc struck between two tungsten electrodes in an atmosphere of hydrogen.

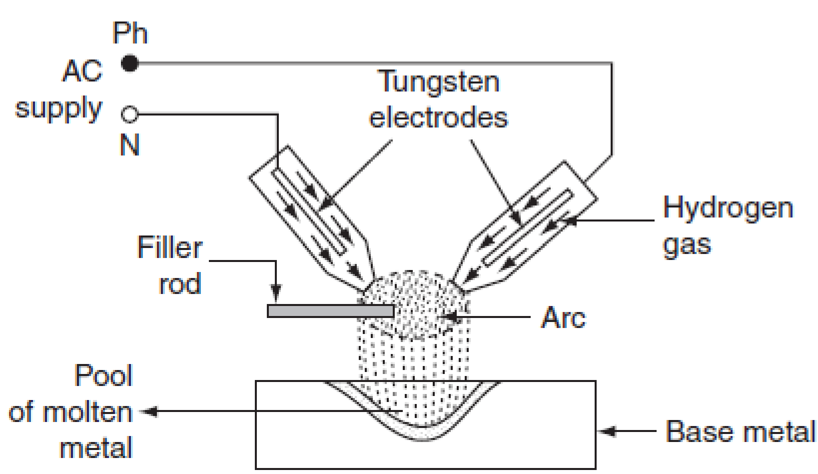



**Fig.3.23.** Atomic hydrogen arc welding

Here, hydrogen serves mainly two functions; one act as a protective screen for the arc and the other acts as a cooling agent for the glowing tungsten electrode tips. As the hydrogen gas passes through the arc, the hydrogen molecules are broken up into atoms, absorbs heat from the glowing tungsten electrodes so that these are cooled.

But, when the atoms of hydrogen recombine into molecules outside the arc, a large amount of heat is liberated. This extra heat is added to the intense heat of arc, which produces a temperature of about 4,000°C that is sufficient to melt the surfaces to be welded, together with the filler rod if used. Moreover hydrogen includes oxygen and some other gases that might combine with the molten metal and forms oxides and other impurities. Hydrogen also removes oxides from the surface of work piece. Thus, this process is capable of producing strong, uniform, smooth, and ductile welds.

In the atomic hydrogen arc welding, the arc is maintained between the two non-consumable tungsten electrodes under a pressure of about 0.5 kg/cm$^2$. In order to obtain equal consumption of electrodes, AC supply is used. Arc currents up to 150 A can be used. High voltage about 300 V is applied for this welding through a transformer. For striking the arc between the electrodes the open circuit voltage required varies from 80 to 100V.As the atomic hydrogen welding is too expensive, it is usually employed for welding alloy steel, carbon steel, stainless steel, aluminum, etc.

**Advantages:**

- Welding is faster in this welding process. Since hydrogen itself act as shielding gas, separate shielding gas is not required.
- There is very little distortion of the flame as the intense flame is obtained which can be concentrated at the joints. The electrodes remain cool as the hydrogen gas flow by the electrodes in the holder which also increases the electrodes life.
- The flow of hydrogen gas and the arc can be easily controlled by the operator and hence the heat produced can also be controlled. So, heat can be adjusted for welding different materials using this welding process.
- Alloys can be melted without fluxes and without surface oxidation due to the powerful reducing action of the atomic hydrogen.

**Disadvantages:**

- This process is more costly as compared to other welding processes.
- A skilled operator is required to operate this welding process.
- Large quantities of metal cannot be deposited using this welding process.
- This welding can be done on flat positions only.
- This welding process is riskier as hydrogen is a highly inflammable gas.

**Applications:**

- It is mainly used where rapid welding is required like in the case of stainless steel and other special alloys.
- It can be used for welding most of the ferrous and non-ferrous metals.
- It is also used for welding thin sheets of metal and small diameter alloys.
- This process is also used in repairing dies and tools, hard surfacing, and joining parts.
- It can also be used for very precision welding like correcting machining errors.

**4. Inert gas metal arc welding:**

It is a gas-shielded metal arc welding, in which an electric arc is stuck between tungsten electrode and work piece to be welded. Filler metal may be introduced separately into the arc if required. A welding gun, which carries a nozzle, through this nozzle, inert gas such as beryllium or argon is blown around the arc and onto the weld, as shown in below Fig.

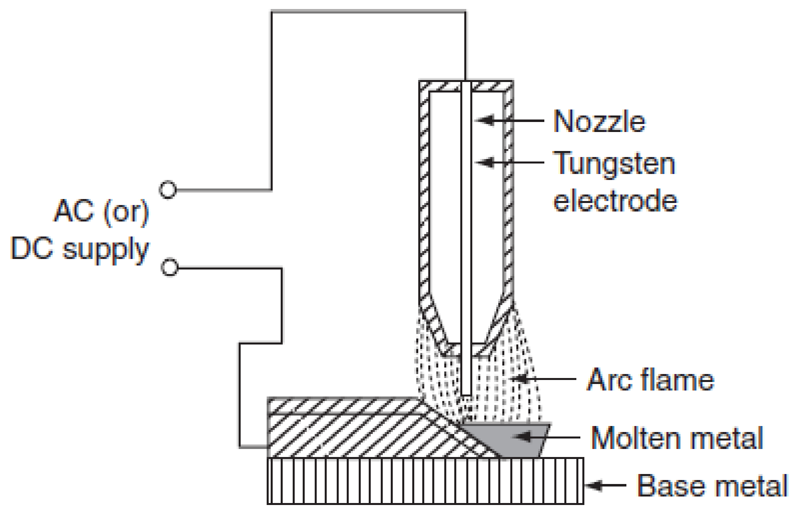



**Fig.3.24.** Inert gas metal arc welding

As both beryllium and argon are chemically inert, so the molten metal is protected from the action of the atmosphere by an envelope of chemically reducing or inert gas. As molten metal has an affinity for oxygen and nitrogen, if exposed to the atmosphere, thereby forming their oxides and nitrides, which makes weld leaky and brittle.

Thus, several methods of shielding have been employed. With the use of flux coating electrodes or by pumping, the inert gases around the arc produce a slag that floats on the top of molten metal and produces an envelope of inert gas around the arc and the weld.

**Advantages**

- Flux is not required since inert gas envelope protects the molten metal without forming oxides and nitrates so the weld is smooth, uniform, and ductile.
- Distortion of the work is minimum because the concentration of heat is possible.

**Applications**

- The welding is employed for light alloys, stainless steel, etc.
- The welding of non-ferrous metal such as copper, aluminum, etc.

**Electric Welding Equipment:**

Electric welding accessories required to carry out proper welding operation are:

1. Electric welding power sets.
2. Electrode holder to hold the electrodes.
3. Welding cable for connecting electrode and work piece to the supply.
4. Face screen with colored glass.
5. Chipping hammers to remove slag from molten weld.
6. Wire brush to clean the weld.
7. Earth clamp and protective clothing.

**1. Electric welding power sets:**

Welding power sets may be of different types and they can be selected depending upon the nature of available power supply (either DC or 1-φ AC). Sometimes diesel driven engine may be used under the absence of power supply, initial and running costs, the location of operation, required output and the type of work, and based on the available floor space.

Based on the nature of available supply, commonly used welding sets are:

i. DC welding sets and
ii. AC welding sets.

**i. DC welding sets:**

Commonly used DC welding sets are:

a) welding generator and
b) Rectifier set.

**(a) Welding generator:**

A DC generator is driven by a prime mover (electric motor or diesel engine) which produces DC current in either or reversed polarity. The current supplied by DC generator is alternating that can be converted to direct quantity by the use of a commutator. The differential compound DC generator is used as a welding generator as shown in below Fig, since it has drooping volt–amp characteristics. As the load current increases, the net flux due to the series and the shunt fields in opposition decrease and hence the generated EMF also decreases.

This drooping characteristics is important in view of arc stability and this steep characteristics of the differential compound generator is shown in below Fig.

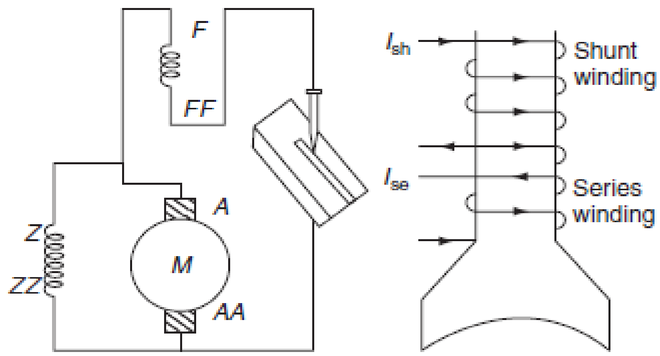



**Fig.3.25.**Welding generator

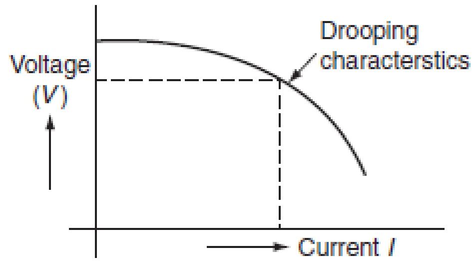



**Fig.3.26.** Drooping characteristics

**(b) Rectifier set:**

Rectifier set is a thyristor control electronic circuit or device, converts AC to DC supply. The power supply to the rectifier set is fed through a transformer. The rectifier consists of silicon diodes or metal plates coated with selenium compound. This allows unidirectional current. It is a fast controlled device and is reliable, but the cost of the set is too high.

The rectifier type welders are said to combine some of the desirable arcing characteristics of the DC welding. Such as easy arc starting, with those of welding transformers such as reduced no losses. In this case, the DC voltage can be controlled by regulating the transformer output.

**ii. AC welding set:**

Commonly used AC welding sets are single-phase or three-phase step-down transformers under the availability of AC supply. These transformers provide low voltage of the order of 80–100 V on open circuit for the welding operation. The welding transformers may be of air- or oil-cooled types, since AC supply passes through zero twice for every cycle, at which the welding arc would extinguish twice, which can be prevented by using coated electrodes, produce more complete ionization in the arc stream even though current passes through zero.

In the AC welding, i.e., the transformer welding set, the current control is achieved by using

(a) Magnetic shunt and

(b) A choke coil or reactor connected in series with primary and secondary winding.

The transformers are mostly used for the flux-shielded metal arc welding, the production welding on heavy gauge steel, some industrial welding operations, etc.

**2. Electrode holder:**

It is a device used to insert or hold the electrodes for carrying out the welding operation. Electrode jaws used to hold the electrode in holder must be completely insulated against thermal and electric shocks. Electric holders must be mechanically strong.

**3. Welding cables:**

Welding cables are conductors to carry current throughout the welding operation. Two electrode cables are necessary to connect the electrode and work piece to the welding power source. These cables must be insulated with rubber, and needs periodic inspection for proper welding operation.

**4. Chipping hammer and wire brush:**

A chipping hammer is a chisel-shaped device that is used to remove the slag formed over the molten weld. A wire brush is made up of stiff steel wire, surrounded by wood layer that removes the remaining slag articles and clean the weld after chipping hammer has done its job. Protective clothing (apron, gloves, etc.) are necessary to protect welder from the hot spattering particles, against the thermal shocks, etc.

**Comparison between AC and DC Wildings:**

| DC Welding | AC Welding |
|---|---|
| 1. Motor generator set or rectifier is required in case of the availability of AC supply | 1. Only transformer is required. |
| 2. The cost of the equipment is high. | 2. The cost of the equipment is cheap. |
| 3. Arc stability is more. | 3. Arc stability is less. |
| 4. The heat produced is uniform | 4. The heat produced is not uniform. |
| 5. Both bare and coated electrodes can be used. | 5. Only coated electrodes should be used. |
| 6. The operating power factor is high. | 6. 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 | 7. It is dangerous since no load voltage is high. |
| 8. The electric energy consumption is 5–10 kWh/kg of deposited metal. | 8. 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. | 9. Arc blow will not occur due to the uniform magnetic field. |
| 10. The efficiency is low due to the rotating parts. | 10. The efficiency is high due to the absence of rotating parts. |

# UNIT - IV

# INDUSTRIAL ELECTRICAL SYSTEMS

**Syllabus:** Industrial loads, motors, starting of motors, Lightning Protection, UPS System, Electrical Systems for the elevators, Battery banks, Selection of UPS and Battery Banks.

**ELECTRICAL LOAD:**

An electrical load is a device or an electrical component that consumes electrical energy and convert it into another form of energy. Electric lamps, air conditioners, motors, resistors etc. are some of the examples of electrical loads.

According to their nature they can be classified according to various different factors. Some popular classifications of electrical loads are Resistive, capacitive, inductive loads and combinations of these.

**Resistive Load:**

Resistive loads consume electrical power in such a manner that the current wave remains in phase with the voltage wave. That means, power factor for a resistive load is unity.

**Ex:** Incandescent lamps and electric heaters,Resistive welding, Water geysers, Filament based equipment

**Capacitive Load:**

A capacitive load causes the current wave to lead the voltage wave. Thus, power factor of a capacitive load is leading.

**Ex:** Capacitor banks, dielectric heating furnace, Reactive power compensation equipment, medium transmission loads, buried cables, capacitors used in various circuits such as motor starters etc.

**Inductive Load**

An inductive load causes the current wave to lag the voltage wave. Thus, power factor of an inductive load is lagging.

**Ex:** Transformers, motors, coils, induction motors, CFL lamps, florescent lamps, induction heating and welding, arc welding, vapor pressure lamps.

**Combination Loads:**

Most of the loads are not purely resistive or purely capacitive or purely inductive. Many practical loads make use of various combinations of resistors, capacitors and inductors. Power factor of such loads is less than unity and either lagging or leading.

**Ex:** Single phase motors often use capacitors to aid the motor during starting and running, tuning circuits or filter circuits etc.

**TYPES OF LOADS IN POWER SYSTEM:**

**Domestic Load / Residential Load:**

Domestic load consists of lights, fans, home electric appliances (including TV, AC, refrigerators, heaters etc.), small motors for pumping water etc. Most of the domestic loads are connected for only some hours during a day.

**Ex:** Lighting load in connected for few hour in night time

**Commercial Load:**

Commercial load consists of electrical loads that are meant to be used commercially, such as in restaurants, shops, malls etc. This type of load occurs for more hours during the day as compared to the domestic load.

**Municipal Load:**

This type of load consists of street lighting, water supply and drainage systems etc. Street lighting is practically constant during the night hours. Water may be pumped to overhead storage tanks during the off-peak hours to improve the load factor of the system.

**Irrigation Load:**

Motors and pumps used in irrigation systems to supply the water for farming come under this category. Generally, irrigation loads are supplied during off-peak or night hours.

**Traction Load:**

Electric railways, tram cars etc. come under traction loads. This type of loads reaches its peak during morning and evening hours.

**Industrial Load:**

Industrial load consists of load demand by various industries. It includes all electrical loads used in industries along with the employed machinery. Industrial loads may be connected during the whole day.

Industrial loads have constant demand and consider as base loads. Commercial loads are little affected by seasonal variations and weather conditions. load duration curve is shown in the below image. These loads mainly include industrial appliances like motors, furnaces, cranes, industrial lighting, computers, elevators, pumps. Industrial loads utilize more electrical energy supplied by the utility. This load does not vary with seasonal change having constant demand throughout the day.

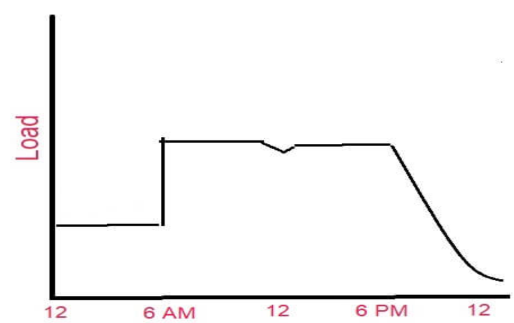



**Fig.4.1.** Industrial power system load curve

**CLASSIFICATION OF DIFFERENT TYPES OF ELECTRICAL MOTORS:**

An Electrical Motor is a machine that converts electrical energy into mechanical energy. It is used for generating torque to lift loads, move objects & various other mechanical works.

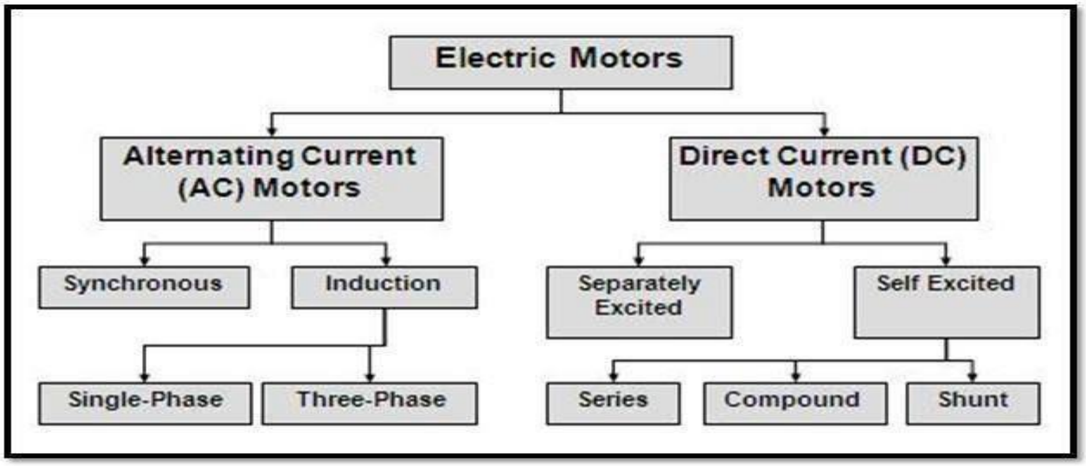



**Fig.4.2.** Classification of motors

**AC Motors:**

The AC electric motor converts AC (Alternating Current) electrical energy into mechanical energy. These electric motors are powered using a single-phase or three-phase alternating current. The basic working principle of AC motor is the rotating magnetic field (RMF) generated by the stator winding when an alternating current is passed through it. The rotor (having its own magnetic field) follows the RMF & starts rotation.

The AC motors are further classified into two types.

1. Synchronous Motor
2. Asynchronous or Induction Motor

**1. Synchronous Motor:**

AC motor has a constant speed called synchronous speed that only depends on the frequency of the supply current. The speed of such electric motors only varies with variation in supply frequency & remains constant upon varying loads. It is used for constant speed application & precision control.

A synchronous motor has the same stator design as asynchronous motor & it generates a rotating magnetic field when supplied with input alternating current. While the rotor design may vary i.e., it uses a separate DC excitation to generate its own magnetic field.

2. **Asynchronous Motor:**

The type of AC motor that never runs at synchronous speed is called asynchronous speed. Its rotor speed is always less than the synchronous speed. It does not require separate rotor excitation. Induction motor is one of asynchronous motor

The induction motor is a type of AC asynchronous motor that works on the principle of electromagnetic induction between the stator & the rotor. The revolving magnetic flux induces a current in the rotor due to electromagnetic induction which produces torque in the rotor. It is the most used electrical motor in industries.

It is mainly divided into two types based on the construction of its rotor.

i. Squirrel Cage Induction Motor
ii. Slip ring or wound rotor induction motor

**i. Squirrel Cage Induction Motor:**

The rotor of such an induction motor resembles a squirrel cage. It is made from copper bars connected at both ends using a conductive ring to make a closed-loop circuit. There is no electrical connection to the rotor. The stator's varying magnetic field induces a current in the rotor's bars. The induced current generates its own magnetic field in the rotor which interacts with the stator's revolving magnetic field & tries to eliminate it by revolving with it in the same direction.

It has a simple design; inexpensive & it is more reliable. Since there are no electrical connection or commutator & brush assembly, it requires less maintenance.

**ii. Slip Ring or Wound Rotor Induction Motor:**

A slip ring or wound rotor induction motor is another type of induction motor where the rotor is made of windings that are connected with the slip rings. The slip rings are used to connect the windings to external resistors for controlling the rotor current & hence allowing the control of speed/torque characteristics.

It has the same operation principle as squirrel cage induction motor except for the induced current in the rotor can be controlled using the external resistors. The external resistance also helps to increase the rotor resistance during the startup of the motor to reduce the high inrush current. It also increases the starting torque to left high inertia loads.

The downside of slip rings is that it constantly slides with the brushes that require costly maintenance due to mechanical wear & tear. The construction is complex & it is more expensive than a squirrel cage motor.

**DC motors:**

A DC motor or direct current motor is an electrical machine that transforms electrical energy into mechanical energy by creating a magnetic field that is powered by direct current. When a DC motor is powered, a magnetic field is created in its stator. The field attracts and repels magnets on the rotor; this causes the rotor to rotate. To keep the rotor continually rotating, the commutator that is attached to brushes connected to the power source supply current to the motors wire windings.

One of the reasons DC motors are preferred over other types of motors is their ability to precision control their speed, which is a necessity for industrial machinery. DC motors are able to immediately start, stop, and reverse—an essential factor for controlling the operation of production equipment.

DC motors are divided in to two types

1. Separately Excited DC Motor
2. Self-Excited DC Motor

**1. Separately Excited DC Motor:**

In a separately excited DC motor, the motor has separate electrical supplies to the armature winding and field winding, which are electrically separate from each other. The operations of the armature current and field current do not interfere with each other 's actions, but the input power is their total sum.

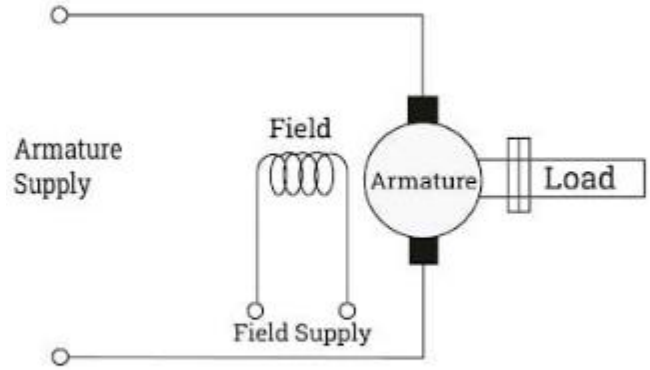



**Fig.4.3.** Separately excited DC motor

**2. Self-Excited DC Motor:**

In self excited DC motors, the field and armature windings are connected and have a single supply source. In case of self-excited DC motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding. Based on this, self-excited DC Motors can be classified as 3 types

i. Shunt wound DC motor
ii. Series wound DC motor
iii. Compound wound DC motor

**i. Shunt wound DC motor:**

In a shunt wound DC motor, the field and armature windings are connected parallel to each other; this exposes the field winding to terminal voltage. Though the supply is the same, the current for the field and armature windings is different. The speed of a shunt DC motor is constant and does not deviate with varying mechanical loads.

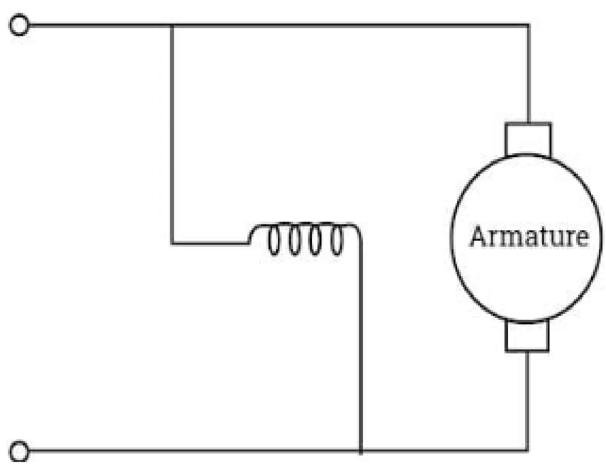



**Fig.4.4.**Shunt wound DC motor

**ii. Series wound DC motor:**

The field and armature winding on a series DC motor are connected to the power supply in a series. The same current flows in the field and armature windings. A series-wound motor can work with AC and DC voltage supply, which makes it a universal motor. Series motors always rotate in the same direction regardless of the voltage source. Their speed varies with the mechanical load.

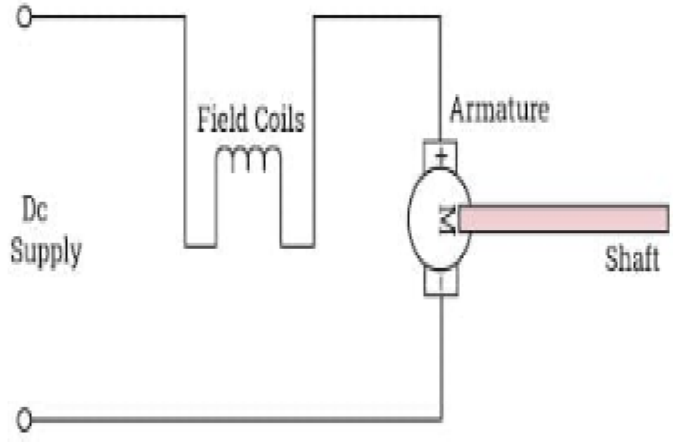



**Fig.4.5.** Series wound DC motor

**iii. Compound wound DC motor:**

A compound DC motor uses the features of the series and shunt field windings. The winding for the armature is connected in a series while the winding for the field is a shunt or parallel connection. Compound DC motors are further divided into cumulative and differential. With cumulative DC motors, the flux of the shunt field helps the flux in the series field. They both move in the same direction while the flux of a differential compound DC motor, for the series and shunt fields, moves in the opposite direction. Cumulative and differential compound DC motors can have long or short shunts; this is based on the shunting of the shunt field winding.

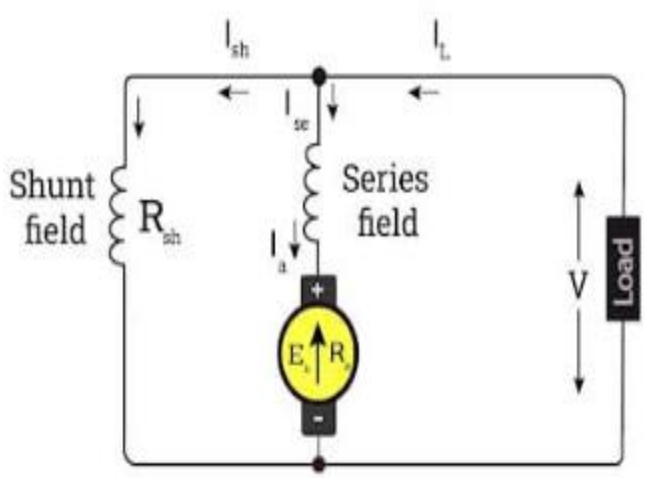



**Fig.4.6.** Compound wound DC motor

**STARTING OF MOTORS:**

**AC Motors:**

**Starting methods of Induction motors:**

From the torque slip characteristic of induction motor, it is clear that the slip equals to one we have some positive starting torque hence we can say that the three-phase induction motor is self-starting machine, then why there is a need of starters for three phase induction motor? The answer is very simple.

If we look at the equivalent circuit of the three-phase induction motor at the time of starting, we can see the motor behaves like an electrical transformer with short circuited secondary winding, because at the time of starting, the rotor is stationary and the back emf due to the rotation is not developed yet hence the motor draws the high starting current. So, we use starters in order to limit the high starting current. We use different types of starters for starting of induction motor, they are

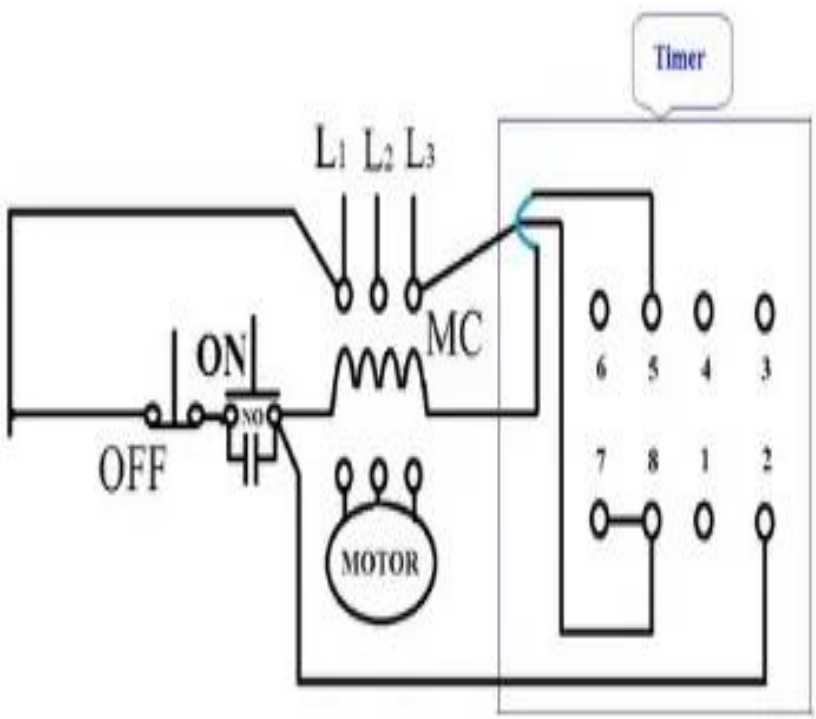
1. Direct on-line starting
2. Star-delta starting
3. Auto transformer starting

**1. Direct on-line starting:**

The DOL starter connects the motor directly to the main supply line, the motor draws a very high inrush current compared to the full load current of the motor (up to 5-8 times higher). The value of these large current decreases as the motor reaches its rated speed.These starters are using between 0.5-10 H.P (small) capacity motors.

Current on starting = 5 to 8 rated Current.

The average starting torque is: T on starting = 0.5 to 1.5 of rated T



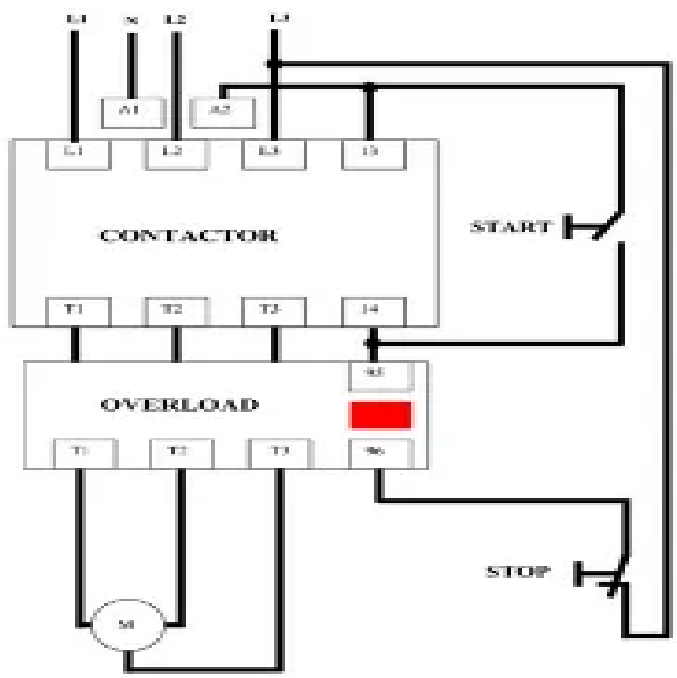



**Fig.4.7.** DOL starter

**DOL Starter Working Principle:**

The working principle of a DOL starter begins with the connection to the 3-phase main with the motor. The control circuit is connected to any two phases and energized from them only.When we press the start button, the current flows through the contactor coil (magnetizing coil) and control circuit also.

The current energizes the contactor coil and leads to close the contacts, and hence 3-phase supply becomes available to the motor.If we press the stop button, the current through the contact becomes discontinued, hence supply to the motor will not be available, and the similar thing will happen when the overload relay operates. Since the supply of motor breaks, the machine will come to rest.

**Advantages:**

- Simple and most economical starter.
- More comfortable to design, operate and control.
- Provides nearly full starting torque at starting.
- Easy to understand and troubleshoot.
- DOL starter connects the supply to the delta winding of the motor.

**Disadvantages:**

- High starting current (5-8 times of full load current).
- DOL Starter causes a significant dip in voltage, hence suitable only for small motors.
- DOL Starter reduces the lifespan of the machine.
- Mechanically tough.
- Unnecessary high starting torque

**Applications:**

The applications of DOL starters are primarily motors where a high inrush current does not cause excessive voltage drop in the supply circuit (or where this high voltage drop is acceptable).Direct on line starters are commonly used to start small water pumps, conveyor belts, fans, and compressors.

In the case of an asynchronous motor (such as the 3-phase squirrel-cage motor) the motor will draw a high starting current until it has run up to full speed.

**2. Star-delta starting:**

A star delta starter is the most commonly used method for the starting of a 3-phase induction motor. A star delta starter will start a motor with a star connected stator winding. When motor reaches about 80% of its full load speed, it will begin to run in a delta connected stator winding.

A star delta starter is a type of reduced voltage starter. We use it to reduce the starting current of the motor without using any external device or apparatus. This is a big advantage of a star delta starter, as it typically has around 1/3 of the inrush current compared to a DOL starter.

The starter mainly consists of a TPDP switch which stands for Triple Pole Double Throw switch. This switch changes stator winding from star to delta. These starter are using between 10-50H.P (medium) capacity motors.There is a complexity in starter connections and maintenance.

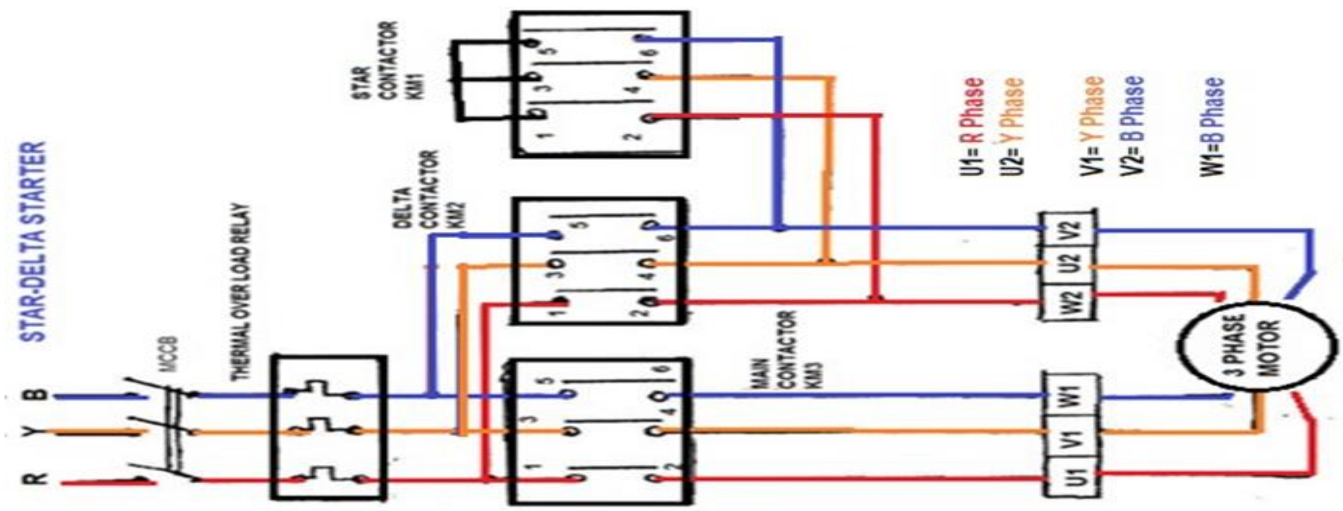



**Fig.4.8.** Star delta starter

**Advantages:**

- Inexpensive
- No heat is produced, or tap changing device needs to be used, hence efficiency increases.
- Starting current reduced to 1/3 of direct online starting current.
- Produce high torque per ampere of line current.

**Disadvantages:**

- Starting torque is reduced to 1/3 of full load torque.
- A particular set of motors required.

**Applications:**

As discussed in the above advantages and disadvantages, a **s**tar delta starter is most suited to applications where the required starting current is low and where the line current draw must be at a minimum value.Application for a star delta starter is a Centrifugal compressor.

**3. Auto transformer starting:**

The circuit diagram of an autotransformer starter for starting a 3-phase induction motor is shown in the below figure. The autotransformer starter can be used for starting both star and delta connected 3-phase induction motors. In this method, the starting current of the motor is limited by using a 3-phase autotransformer to decrease the initial applied voltage to the stator. The autotransformer is provided with a number of tapings to obtain the variable voltage.These starter are using above 50H.P (HIGH) capacity motors.There is a complexity in starter connections and maintenance

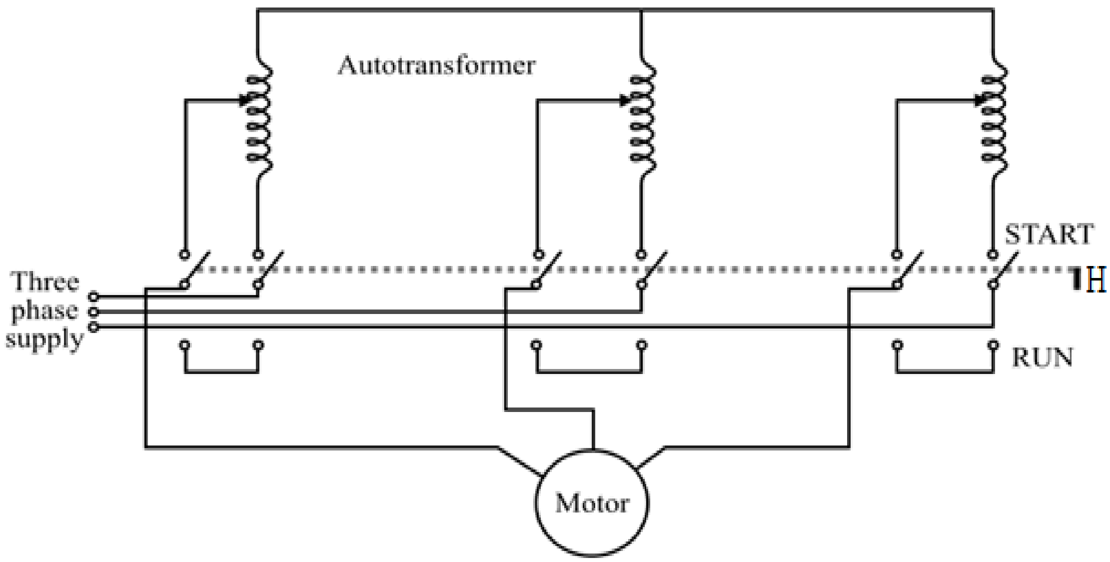



**Fig.4.9.** Auto transformer starter

In the autotransformer starting method, the starter is connected to a particular tapping of the autotransformer to obtain the most suitable starting voltage. A changeover switch S is used to connect the autotransformer in the circuit for starting the motor.

When the handle (H) of the switch S is at the START position, the primary winding of the autotransformer is connected to supply line and the induction motor is connected to the secondary winding of the autotransformer. When the motor picks up the speed (about 80 % of the rated speed), then the handle H is thrown to the RUN position. Consequently, the autotransformer is isolated from the circuit and the motor is now directly connected to the supply line and gets its rated voltage. The handle is held in the RUN position by the under-voltage relay. When the supply voltage falls below a certain value, then the handle is released and comes back to the OFF position. To provide the overload protection to the motor, a thermal overload relay is used in the motor circuit.

**Advantages:**

- The inrush current can be restricted by using this transformer
- The starting voltage adjustment can be done through the choice of an appropriate tap on the transformer.
- The supply current is less as compared to the motor current
- The usage of excitation current is less
- This motor is applicable for large motors, where the motor start through direct connection toward the network cannot be possible. The star-delta also cannot be used for large motors, particularly if they are activated through a significant load.
- This technique is appropriate for long starting phases.
- This transformer ratio ranges from 65% to 80%
- For each ampere of current supply, the highest torque will be there
- While designing this transformer, less copper is required.
- Its efficiency is high as compared to the conventional one.
- Voltage regulation is much better.

**Disadvantages:**

- Less power factor
- The circuit is fairly complex & involves a comparatively expensive autotransformer.
- Because of the big size of the device, the Korndorfer starter cannot be added to an accessible machine if the gap is limited.

**Applications**

- It is used to reduce voltage starter in induction motor
- Used like booster at the finish of long transmission line to pay off for line losses
- Used as starting device for particular kinds of fluorescent light fixtures
- Autotransformer is used in electrical devices within the testing labs
- Used to increase the incoming voltages
- Used in AC feeders like boosters to enhance the required voltage level.
- This transformer is used in induction & synchronous motors like a part for triggering purposes.
- Used to activate squirrel cage & slip-ring induction motors.
- Used to interconnect systems that operate in threshold voltages.

**Starting methods of synchronous motors:**

Synchronous motor is not self-starting since the net torque developed by the motor is zero. Now you get a question about, how to start a synchronous motor to reach synchronous speed? There are different starting methods of the synchronous motor are employed they are,

1. Pony motor starting method
2. DC machine starting method
3. Damper winding method
4. Slip ring Induction motor starting method

**1. Pony motor starting method:**

Pony motors are small motors mostly induction motors, which are used to run the rotor near to the synchronous speed. Once the rotor attains the synchronous speed, the DC excitation to the rotor is switched on. Pony motors are connected to the shaft of synchronous motor only up to it attains synchronous speed.Once the synchronism is established pony motor is decoupled. The motor then continues to rotate as synchronous motor. Note here, that the number of poles of the induction motor should be less than the synchronous motor else it will never be able to achieve the synchronous speed of the synchronous motor. This is because an induction motor always has a speed less than the synchronous speed and for it to become equal to the synchronous speed of the synchronous motor, its own speed has to be increased.

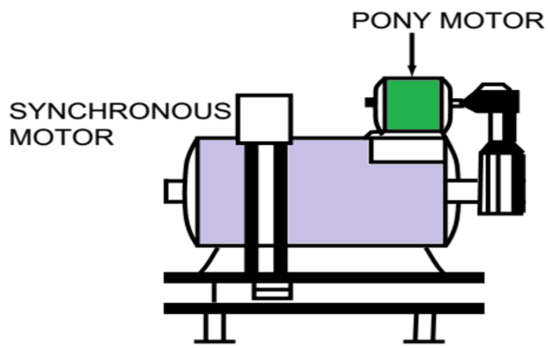



**Fig.4.10.**Pony motor starting

**2. DC machine starting method:**

This is also similar to pony motor method with some advantages. Mostly this method employed for large synchronous motors. For synchronous motor a dc machine will be connected. This dc machine is used as a DC motor to rotate the synchronous motor at a synchronous speed. Once motor starts running as a synchronous motor, the same DC machine acts as a DC generator to supply dc to the rotor of syn. motor. This have some advantages like low power usage and easy starting.This method offers easy starting and better efficiency.

**3. Damper winding method:**

In a synchronous motor, in addition to the normal field winding, the additional winding consisting of copper bars placed in the slots in the pole faces. The bars are short circuited with the help of end rings. Such an additional winding on the rotor is called damper winding. This winding as short circuited, acts as a squirrel cage rotor winding of an induction motor. The schematic representation of such damper winding is shown in the below Fig.

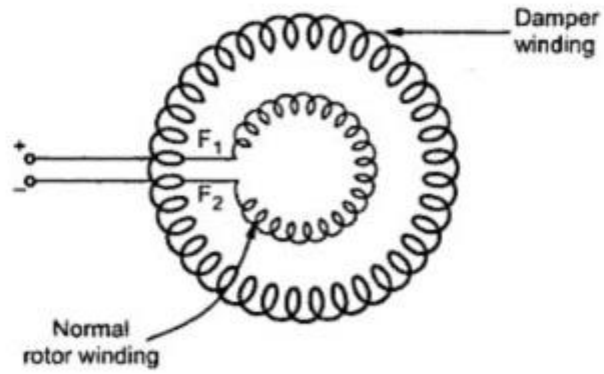



**Fig.4.11.**Damper winding

First synchronous motor runs as induction motor due to the damper winding at sub synchronous speed. Then DC supply is given to the field winding. At some instant motor gets pulled into synchronism and starts rotating at a synchronous speed. As rotor rotates at synchronous speed, the relative motion between damper winding and the rotating magnetic field is zero. Hence when motor is running as synchronous motor, there cannot be any induced EMF in the damper winding. So damper winding is active only at start, to run the motor as an induction motor at start.

**4. Slip ring induction motor starting method:**

The above method of starting synchronous motor as a squirrel cage induction motor does not provide high starting torque. So to achieve this, instead of shorting the damper winding, it is designed to a form a three phase star or delta connected winding. The three ends of this winding are brought out through slip rings. An external rheostat then can be introduced in series with the rotor circuit. So when stator is excited, the motor starts as a slip ring induction motor and due to resistance added in the rotor provides high starting torque. The resistance is then gradually cut off, as motor gathers speed.

When motor attains speed near synchronous. DC excitation is provided to the rotor, then motors gets pulled into synchronism and starts rotating at synchronous speed. The damper winding is shorted by shorting the slip rings. The initial resistance added in the rotor not only provides high starting torque but also limits high inrush of starting current. Hence it acts as a motor resistance starter.

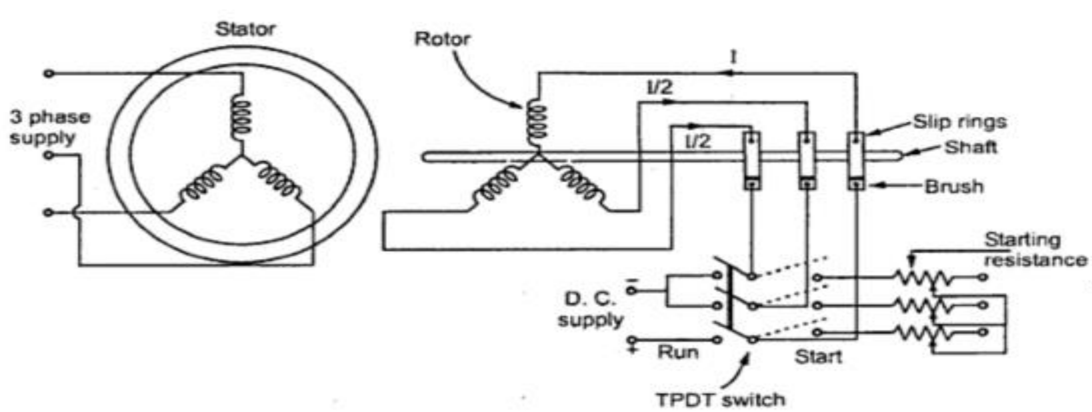



**Fig.4.12.**Starting as slip ring induction motor

**DC Motors:**

Starting methods of DC motors are given below

1. Three-point starter
2. Four-point starter

**1. Three-point starter:**

A three-point starter is an electrical device, used for starting as well as maintaining the DC shunt motor speed. The connection of resistance in this circuit is in series which decreases the initial high current and guards the equipment against any electrical failures. Here, the occurrence of back e.m.f plays an essential role in operating the motor. This emf extends when the armature of motor starts for rotating in the magnetic field by making the action as well as opposes the voltage supply.


**Fig.4.13.**Three Point starter device

**Construction of 3-point starter:**

The DC motor based 3-point starter mainly includes three terminals namely L, A, and F. Here, L (line terminal) is connected to the positive supply, A (armature terminal) is connected to the windings of an armature terminal, and F (field terminal) is connected to the winding of field terminal.

The construction of 3-point starter includes a resistance 'R' for controlling the initial current. The "H'-handle in the circuit kept in the OFF condition with a spring 'S'. The H-handle can be operated manually for motor operation. At the beginning of the motor position, the motor field winding gets the total supply voltage, & the armature current is restricted to the particular secure value by the resistance R.

**Working off a Three-Point Starter:**

The handle of the 3-point starter can be moved from one stud to another stud (contact positions), and this increases the speed of the motor till gets the RUN position. There are three main points are considered in this position which includes the following.

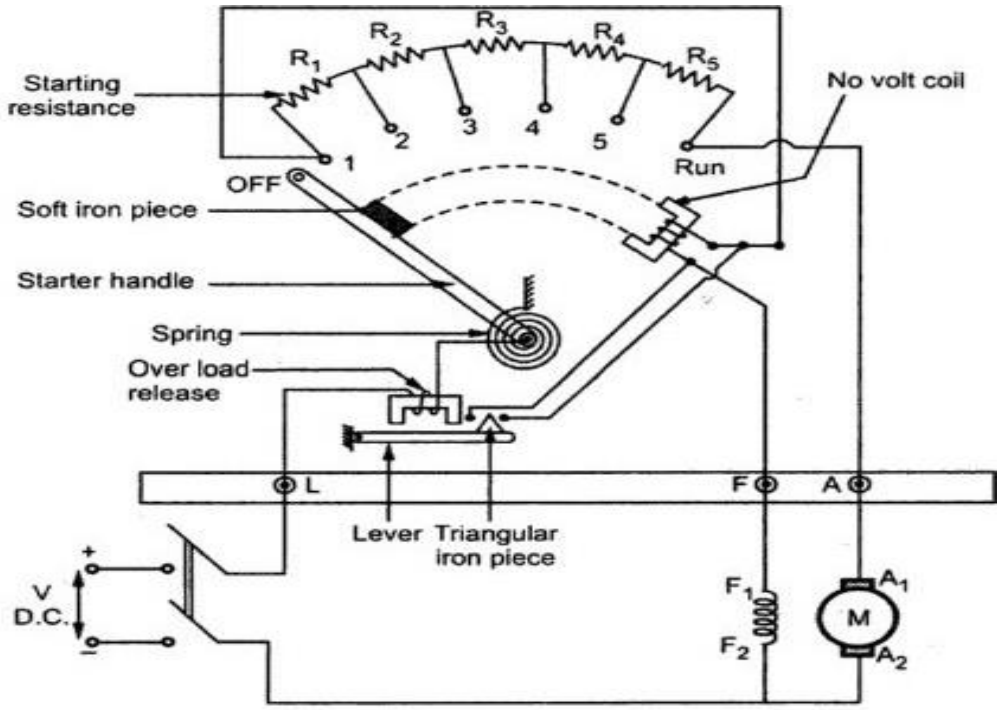



**Fig.4.14.** 3 Point starter circuit diagram

- The DC shunt motor gets the full speed
- The voltage supply in the circuit is straight across both the motor's windings.
- The R-resistance is totally cut-out.

The H-handle in the circuit is held in RUN condition with an electromagnet strengthened by an NVC (no volt trip coil). This NVC coil can be coupled in series with the motor field winding. In the incident turned OFF or dropped below a fixed value, then the NVC will get energized. By the act of S-spring, the handle-H is released as well as pulled back to the OFF condition.

At first when a DC supply is turned ON by H-handle in the OFF position, then the handle will move clock wise direction to the stud1. The winding of the shunt field is directly associated across the voltage supply as the total resistance, in the beginning, is included in series with the armature circuit.

If the voltage supply is unexpectedly disrupted, then the no-volt discharge coil is demagnetized as well as the H-handle goes back to the OFF location in the pull of the spring. If no-volt coil were not utilized, then there will be a supply failure. The H-handle would stay on the last stud. If the voltage supply is returned, then the DC motor will be openly allied across the supply, resulting in an extreme armature current.

If the DC motor is overloaded, it will draw extreme current from the current supply, then it amplifies the ampere rotates off the excess release coil as well as pull the armature, therefore no-volt coil will be short-circuited. This coil is demagnetized as well as the H-handle is pulled near the OFF location by the S-spring. Hence the electric motor is automatically detached from the current supply

**Drawbacks of a Three-Point Starter:**

- The main drawback of the 3-point starter is, it experiences from a major drawback of motors by a huge difference of speed with a modification of the field rheostat.
- To amplify the motor speed, the field resistance must be amplified. So, the flow of current throughout the shunt field is decreased.
- Whenever adding high resistance to get a high speed will make the field current very low.
- When NVC (no volt trip coil) is associated in series by shunt field, then the minute current will decrease the power of the electromagnet.
- This magnet may liberate the arm of the H-handle through the usual motor operation as well as detach it from the power supply.
- Therefore, the 4 Point Starter can be used, where no volt trip coil is allied in the parallel field.

**2. four-point starter:**

The functional characteristics of a 4-point starter are similar to a 3 point starter. Four-point starter works as a current controlling device in the deficiency of back EMF while starts running of the DC motor. A four-point starter also works as a protecting device. The main difference between 4-point starters compared to a 3-point starter is, the holding coil is detached from the shunt-field circuit. After this, Sit is connected in series with the current limiting resistance (R) across the line. The contact points of the circuit are called as studs that are denoted with 1,2,3,4,5 which are showed below in the 4 point starter circuit diagram


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**Fig.4.15.**four Point starter devices

**Construction and Working Principle:**

A 4-point starter includes four most important operational points.

- The line terminal (L) is connected to a positive supply
- The Armature terminal (A) is connected the winding of an armature.
- The field terminal (F) is connected to the field winding.
- In addition to 3-point starter, there is an extra operational point which is denoted with the letter N, and it is connected to the NVC (No Voltage Coil)

**Four Point Starter Circuit Diagram:**

The circuit diagram of a four-point starter is shown below, and its arrangement can form three parallel circuits.

- Armature, shunt field winding and starting resistance
- The shunt field winding & a variable resistance coil.
- The current limiting resistance and holding coil

From the above three circuit arrangements, there is no flow of current effect using the holding coil if there is some difference in speed of the motor. Currently, regular push-button starters are also utilized. In these starters, the ON-switch is pushed to link the current limiting beginning resistors in series through the armature circuit, and then the complete line voltage is obtainable to the circuit.

The beginning resistor is slowly detached with an automatic controlling plan. The armature circuit is detached once the OFF switch is pressed. The usual starter circuits have been designed with time delay relays and electromagnetic contactors. The main benefit of this starter is that it allows even the new operator to operate the motor easily.

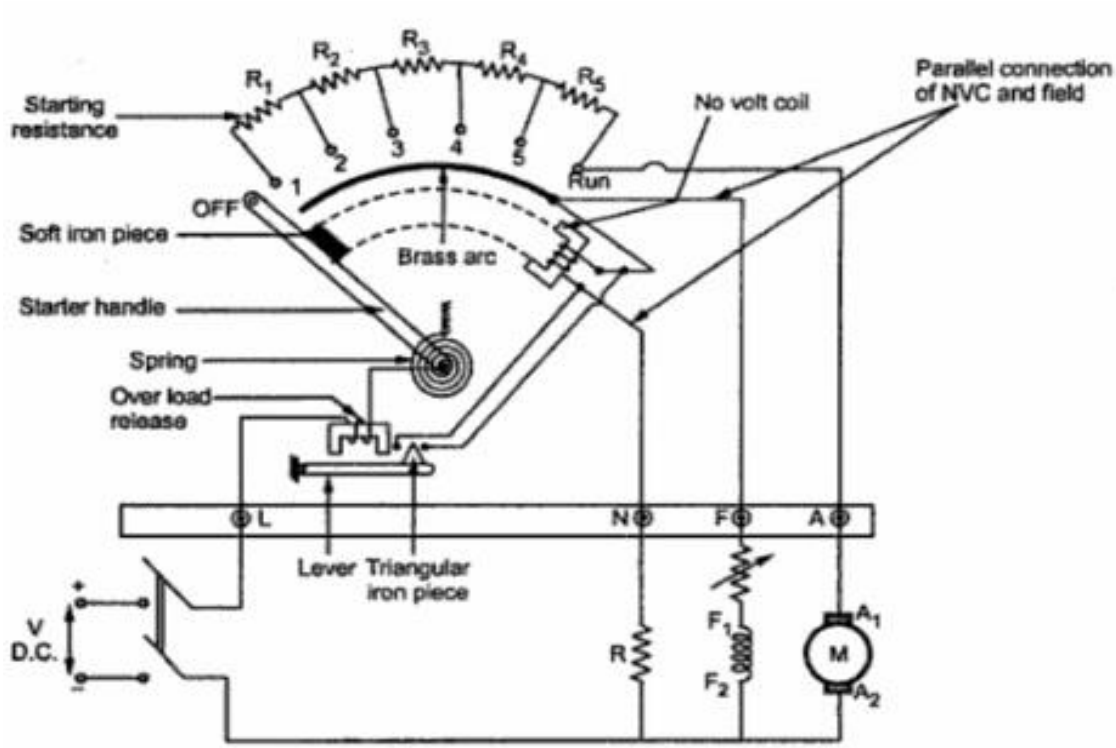


**Fig.4.16.** Four Point starter circuit diagram

**Drawbacks of 4 Point Starter:**

The only drawback or limitation of the four-point starter is that it cannot control the speed of the high current in the motor. When the motor winding is opened under the working condition then the field current usually decreases to zero. Although as a few of the remaining flux is still there in the DC motor, as well as we know that this flux is correlative to the motor's speed. Thus, the motor's speed enhances thoroughly, which is unsafe and therefore safety is not feasible. This unexpected rise in the motor's speed is known as "high-speed act of the motor".

**LIGHTNING PROTECTION:**

Lightning strikes can inject transient over voltages into an installation. Electrical equipment can be adversely affected by these surges, particularly sensitive electronics such as computers, adopters and televisions etc., and also it can damage the electrical equipment like transformers winding insulation, insulation of transmission towers, CT's and PT's in substation.

A Lighting Protection System (LPS) is the system that provides a means by which a lightning discharge may enter or leave earth without passing through and damaging personnel, electrical equipment, and non-conducting structures such as buildings.

So, A Lightning Protection System does not prevent lightning from striking; it provides a means for controlling it and prevents damage by providing a low resistance path for the discharge of the lightning energy.A reliable Lightning Protection System LPS must encompass both structural lighting protection and transient overvoltage (electronic systems) protection. Simply stated, a structural lightning protection system cannot and will not protect the electronic systems within a building from transient overvoltage damage.

To protect all the equipment's from the lightning we can go for lightning arresters

**Lightning arrester:**

A Lightning Arrester is a device used to protect a variety of electrical equipment and systems from the effects of lightning. The arrangement of these devices can be done on the towers, transmission poles and buildings to give a secure lane to the voltage & discharging current. Here these can be occurred during the strokes of lightning toward the ground to defend the system from the induced problems of lightning.

**Working Principle:**

Lightning arrestor working principle is, once the voltage surge travels throughout the conductor then it reaches the location of the arrestor where it is installed. So it will break down the insulation of the lightning arrestor for a moment, so voltage surge can be discharged toward the ground. Once the voltage of the system falls under the fixed value, then the insulation will be restored among the ground & conductor. Further, the current flow toward the ground will be stopped.

**Types of Lightning Arrester:**

Generally, lightning arresters are classified into different types. The construction of lightning arrestors is different based on its type but the working principle is the same. It provides a low resistance pathway to the surges in the direction of the ground. Let us discuss some types of lightning arresters. The choice of lightning arrester depends upon the following factors:

- Voltage
- Current
- Reliability
- Space available for installation, etc.

Heeding these above factors, there are different types of lightning arresters.

1. Rod Gap Arrester
2. Sphere Gap Arrester
3. Horn Gap Arrester
4. Multiple-Gap Arrester
5. Expulsion Type Lightning Arrester
6. Valve Type Lightning Arresters
7. Thyrite Lightning Arrester
8. Metal Oxide Lightning Arrester

**1. Rod gap arrester:**

It is the simplest type of lighting arrester. It consists two-rod electrodes, one of which is connected to the line and other to earth. The rods may be in the form of horn also. These are generally to use to protect the transformers. Under normal operating conditions, the gap remains non-conducting. When a high voltage surge occurs, the gap sparks over and surge current is drained to earth. Such arresters suffer from the following disadvantages:

- The operation is affected by climatic conditions.
- After the surge is over, due to ionization of air, the arc in the gap is maintained even at the normal supply voltage.
- Increased possibility of bird faults.

Due to the above disadvantages, the rod gap arresters are used only as a 'back-up' protection with main arrestors.

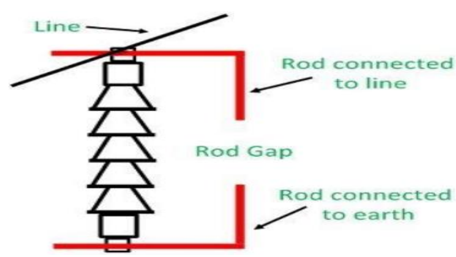


**Fig.4.17.** Rod gap arrester

**2. Sphere gap arrester:**

In such types of lightning arresters, an air gap is provided between two spheres. Here, one of the spheres is grounded, and another is connected to the line.

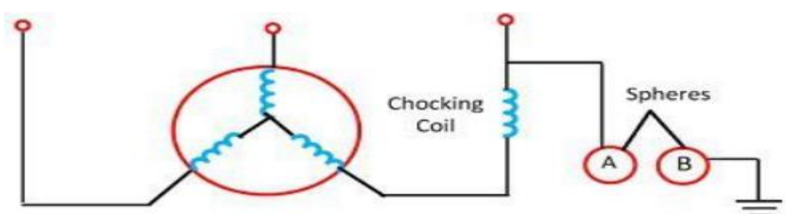


**Fig.4.18.** Sphere gap arrester

There is a choking coil between the transformer and the ground, which heats up when the voltage rises. The air between the spheres heats up and tries to escape. But the corona discharge mechanism ionizes the air and the fault current passes through it. Thus, it saves potential damage to the device.

**3. Horn gap arrester:**

This contains two horn-shaded pieces of metal. These two are separated by a small air gap and connected in a shunt between each conductor and earth. The distance between the two electrodes is optimum. This distance is filled with air that ionizes on fault current passage. Hence, the fault current is passed to the earth, and the inherent damage is stopped.

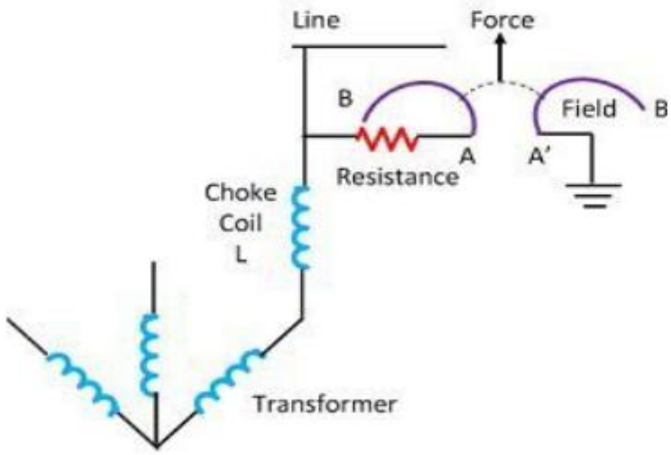


**Fig.4.19.** Horn gap arrester

**4. Multiple gap arrester:**

These types of arresters are designed with a sequence of metal cylinders that are insulated and divided through air gaps with each other. In the sequence of cylinders, the primary cylinder is connected toward the electrical line, whereas the remaining cylinders are connected to the ground by series resistance. Some of the gaps among the next cylinders contain a shunt resistance that grabs a surge when there is a surplus of voltage. The number of gaps required is depends on the line voltage.

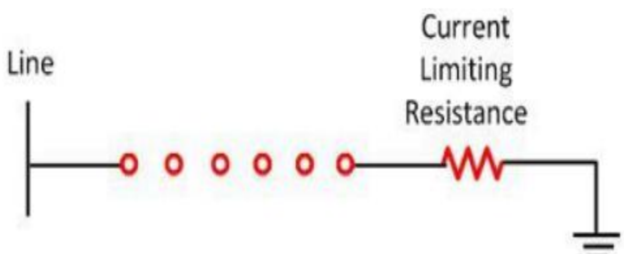


**Fig.4.20.** Multiple gap arrester

**5. Expulsion Type Lightning Arrester:**

Expulsion type arrester is an improvement over the rod gap in that it seals the flow of power frequency follows the current It consists of an arc extinguishing chamber in series with an air gap. The arc extinguishing chamber is in the form of fiber tube which interrupts the arc after discharging the surge by the generation of gasses.

When a voltage surge occurs that is sufficient to spark over the series gap and the gap in the fiber tube, discharge current flows to ground. The arc in the tube attacks some of the fiber of tube walls, releasing a large amount of a relatively cool, non-conducting gas.

The gas produced in fiber tube acts not only to extinguish the arc but also builds up high pressure and expelled through the lower electrode which is hollow. As the gas leaves the tube violently, it wipes out the ionized air around the arc. Due to this strong deionization effect, arc goes out at current zero instant and will not be re-established.

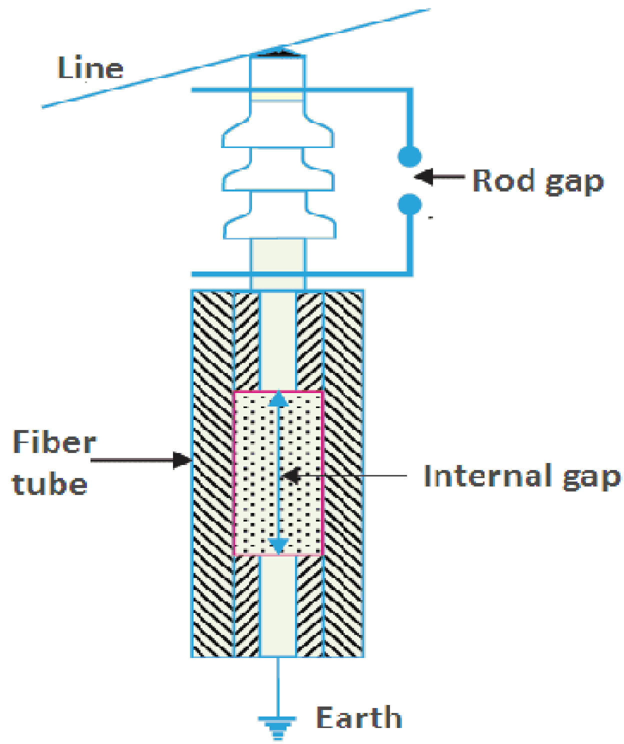


**Fig.4.21.** Expulsion type lightning arrester

An expulsion type lightning arrester has a current rating in addition to the voltage rating. The maximum current rating must be equal to the short-circuit current available at the point of installation. These are generally used on towers for the protection of transmission lines.

**6. Valve type lightning arrester:**

Such type of arrester is called nonlinear diverter It consists of an outer ceramic body containing a set of resistances (valves) and spark gaps in series. The resistances are made of a special silicon carbide ceramic. It possesses the characteristic of being substantially an insulator at one voltage and then changing to an excellent conductor at a higher voltage; the transition is due to voltage changes only, not to heat as in other valve materials.

High-voltage surges spark across the air gap and discharge current flows through the valve to ground. Since the valve has a low resistance under high voltage and a high resistance at a normal voltage so as soon as system voltage becomes normal current flow stops. The arc gets extinguished and the arrester regains its original state.

The valve type arrestors are extensively used for the protection of generating stations, sub-stations, overhead lines, cables and rotating machinery.

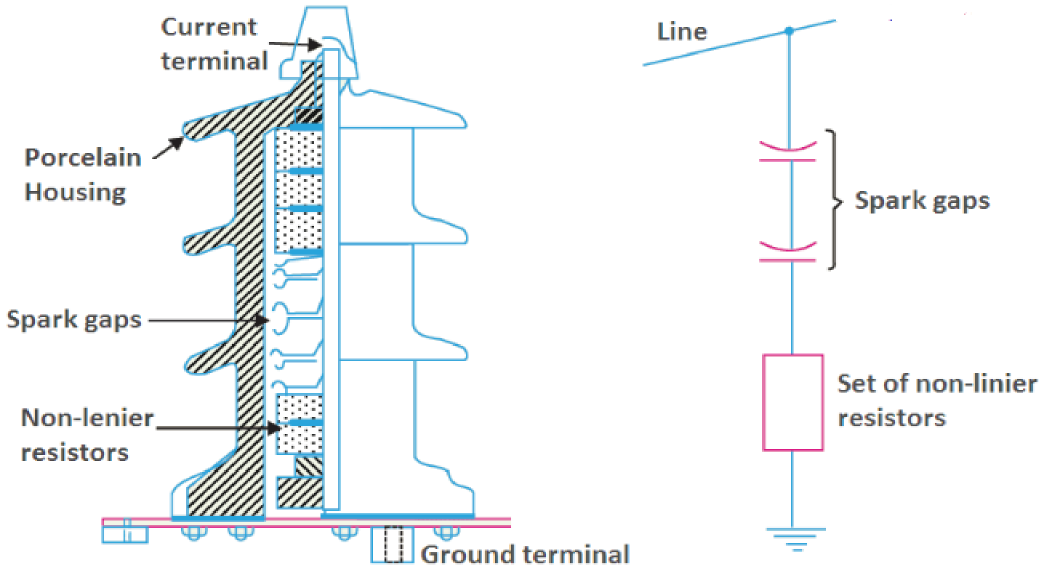


**Fig.4.22.** Valve type lightning arrester

They are rated for voltage only and are designated as 70%, 80%, and 100% arresters. The 80% arresters are suitable for solidly grounded systems. Whereas, 100% arresters are used on systems with isolated neutrals or those earthed through impedances.

The valve type arresters have been classified into the four types as under:

- Secondary Type
- Distribution Type
- Line Type
- Station Type

**Secondary type:** lighting arresters are used with medium voltage apparatus, where the equipment is installed in farms and other lightning-prone areas.

**Distribution type arresters:** are used on lines and substations up to 22 kV.

**Line type arresters:** are normally used for voltages up to 66 kV though they can be used for higher voltages also.

**Station type arresters:** provide the highest degree of protection and should be used where the cost of the protected equipment or the importance of service continuity justifies the extra investment on their account.

**7. Thyrite lightning arrester:**

This type of arrester is most commonly used for the protection against dangerous high voltage. It consists the thyrite which is an inorganic compound of ceramic material. The resistance of such material decreases rapidly from high value to low value and for current from a low value to high value it consisting a disc that's both the side is sprayed so as to give the electric contact between the consecutive disc. The disc is assembled inside the glazed porcelain container. It is used in conjunction with the container.

When the lightning takes place, the voltage is raised, and breakdowns of the gaps occur, the resistance falls to a very low value, and the wave is discharged to earth. After the surge has passed the thyrite again come back to its original position.

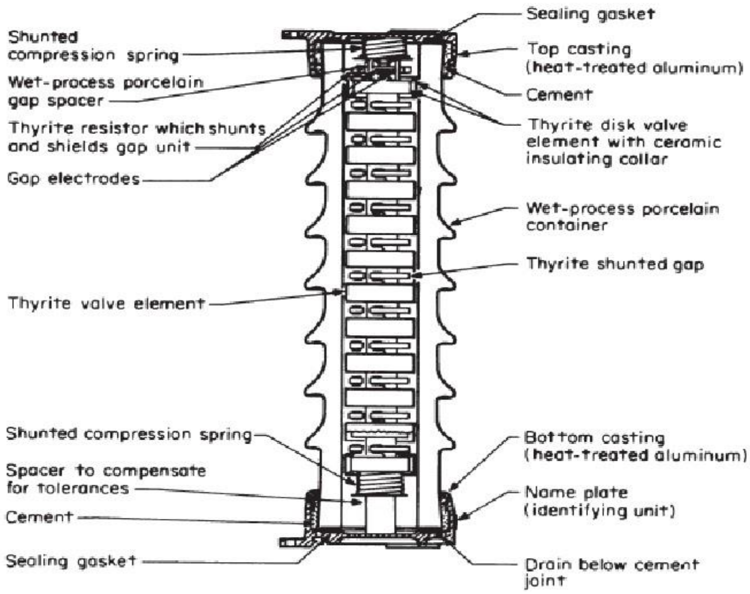


**Fig.4.23.** Thyrite lightning arrester

**8. Metal oxide lightning arrester:**

It is also called Zinc Oxide diverter. The schematic diagram of metal oxide lightning arrester is shown in below fig.

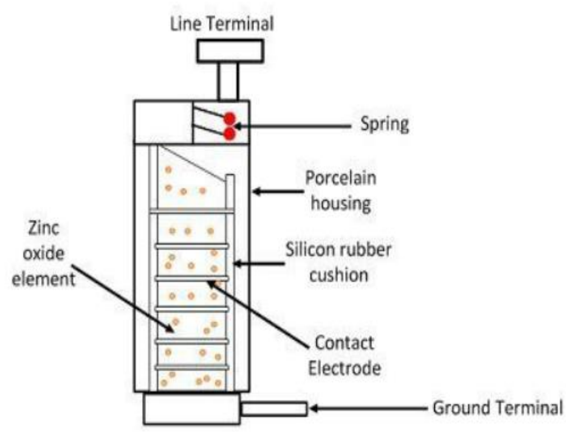


**Fig.4.24.** Metal oxide lightning arrester

These types of diverters are known as gapless surge diverters. The base material here is zinc, and the oxide manufactured is zinc oxide. It is a semiconducting material. This material is anesthetized by adding fine powders of insulating oxides.

This powder is treated and then stuffed into a disc-shaped structure. The disc is then enclosed in an earthenware housing filled with sulfur hexafluoride. Thus, the arrester consists of a potential obstacle at the edges of zinc oxide. This potential barrier constrains the river and pathways of the current. These MOV blocks acts like a voltage-controlled switch.

When the applied voltage across the arrester increases above the rated voltage of the arrester, the MOV starts conducting and excessive energy is drained to the ground. This process continues until the system attains the normal voltage. As soon as the system voltage becomes normal the conduction stops.

The MOV arrester is the one of the most commonly used arrester for the protection of modern power system. They don't have gaps. This "gap-less" design eliminates the generation of excessive heat during the operation of the arrester. They give best performance as the surge voltage conduction starts and stops very quickly at a precise voltage level. This reduces the failure of the arrester and improves system reliability and protection.

When a metal oxide arrester is disconnected from an energized line, it may have a small amount of static charge. Therefore, as a safety precaution, it should be discharged properly by connecting to a ground for a while.

**ELECTRICAL SYSTEMS FOR THE ELEVATORS:**

Due to the improved control structures, hardware and other automation systems in traction elevator systems, most of the manufacturers are producing energy-efficient elevators. Regenerative drive system in elevator is a remarkable advancement in these energy efficient elevators. For mid and high-rise buildings, traction or cable-driven type of elevators are perfectly suitable compared with the electromechanical relays.

**Types of elevators:**

An Elevator is a vertical transport system that carries people or goods between the floors of building safely and efficiently. There are different types of elevators:

1. Hydraulic Elevators
2. Pneumatic Elevators
3. Cable driven or traction Elevators

In an elevator, car is raised or lowered within several floors of a commercial and residential building. Depending on the load and the area of application, these elevators are installed with rated capacity. Hydraulic elevators are simple and effective in which the force required to move the car is low compared to the other elevators, but still their use is limited for certain stories high buildings such as 4 to 5 owing to the working ability of these elevators.

Compared to traditional elevators, pneumatic-vacuum elevators are environmentally friendly, easy to maintain, install and operate. And, compared to hydraulic elevators, pneumatic vacuum elevators require high pressure to move the car- and, in addition, their usage too is limited for a limited number of storied buildings. These elevators that run based on-air pressure are safe and popular over the past several years for two to three-storied buildings.

Nowadays buildings are constructed to greater heights and with the invention of traction electric elevators – they are commonly used in such buildings. Top speed, smooth ride quality and better elevation are the basic characteristics of these elevators. Let us see in brief about 'how an elevator works.

**Hydraulic elevators:**

The below figure shows the working of a hydraulic elevator wherein hydraulic fluid with a pumping system moves the elevator car up and down. In this type of elevator, a tank or fluid reservoir supplies hydraulic oil and the pump forces this oil through a least resistance path and returns it to the reservoir when the valve is opened. So, when the valve is closed, the pressurized oil created by the pump pushes the piston upside so that the car moves in the upward direction. And when the valve is opened, the fluid returns back to the tank, and hence the piston moves downwards.

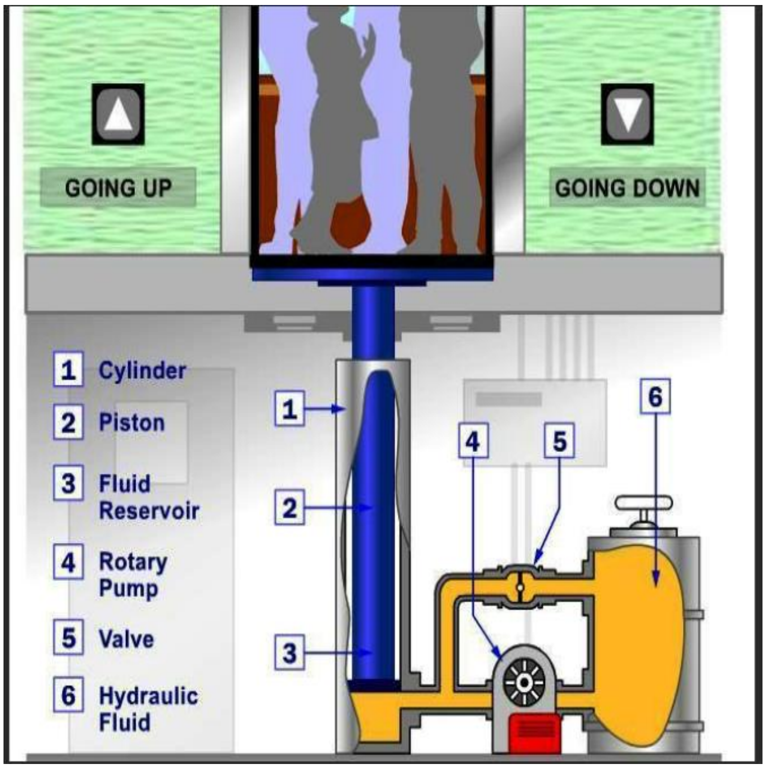


**Fig.4.25. Hydraulic elevators**

If the elevator reaches the correct floor, the elevator-control system sends the signals to a motor driver, which stops the motor, and then the pumping of fluid is halted at that position. While lowering, the car stays on exact floor by controlling the signals to the valve mechanism to open or close the valve. This is how the hydraulic system is operated for lifting and lowering the elevator car.

Due to a special type of fluid in this system, the force required to push the piston is very less. This is an advantage of it, but in order to elevate the car, the piston length required should be more. In other words, if the building height is more, the piston length required should also be longer. This requires an in-depth buried structure for high-storied buildings that’s why these are limited for high-storied buildings. Different types of hydraulic elevators are shown in the below figure.

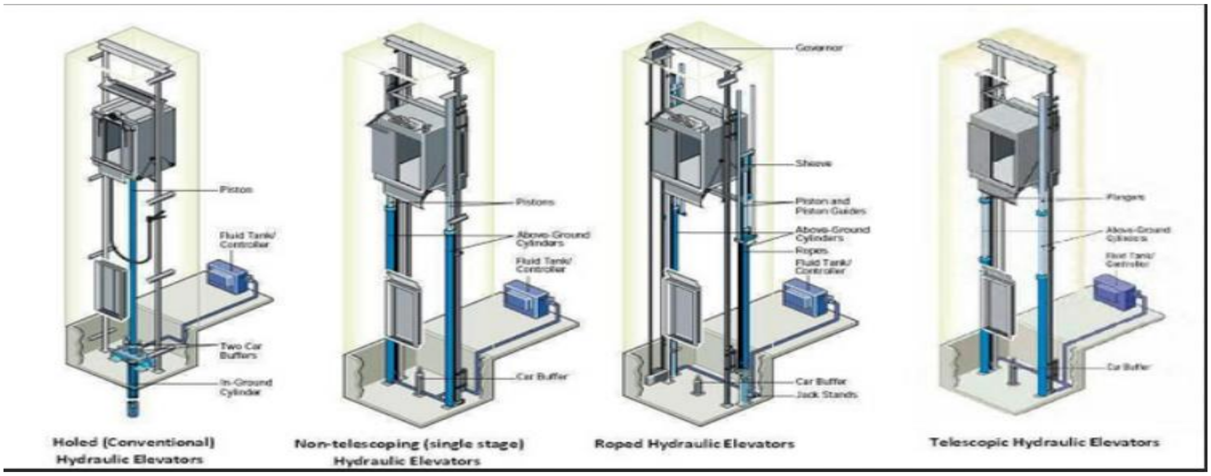


**Fig.4.26.**Different types of hydraulic elevators

**Pneumatic elevator:**

This type of elevator consists of exterior cylinder which is transparent self-supporting tube consisting of modular sections, which can be easily fitted into one another. The roof of this tube is made up of steel that ensures air-tight closures with suction inlets and valves. An elevator car runs inside this cylinder, and the head unit on the top cylinder contains turbines, valves and controllers to control the movements of this elevator.

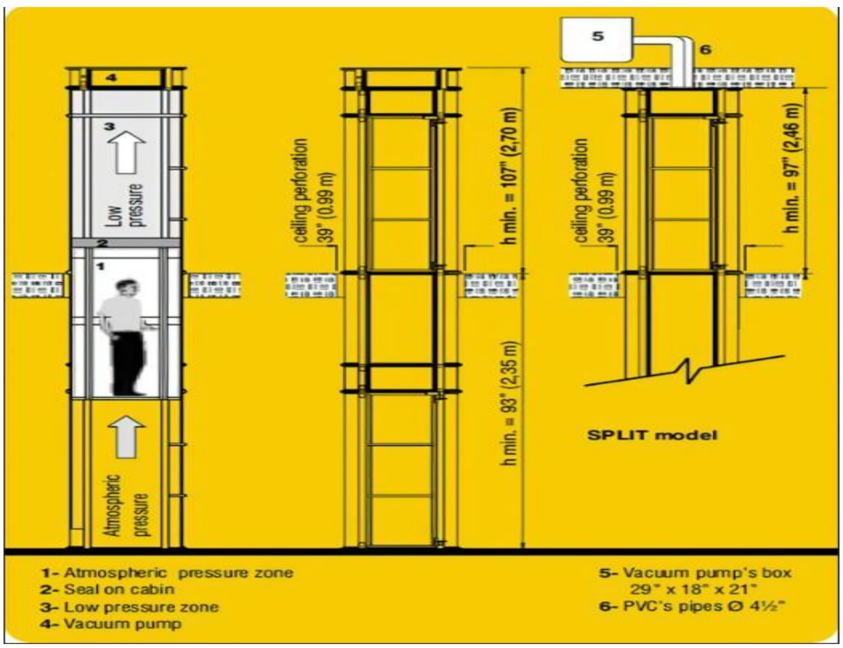


**Fig.4.27.**Pneumatic elevator

The vacuum pump of the elevator generates higher and lower atmospheric pressures above or below the elevator car, which cause to move the elevator upwards and downwards. As shown in the below figure, the car is lifted high by a higher atmospheric pressure below the car and a lowered air pressure above the car.

When the valves in the low-pressure chamber allow air into it – this causes to lower the car. These valves are also involved in controlling the speed of the car in a desired level. But, this type of elevator cannot build enough pressure to push the car to more than 3- 4 storied high building. That’s why these elevators find limited usage.

**Cable driven or traction elevator:**

This is a typical and most popular type of elevator consisting of a few numbers of hoisting ropes or steel cables which run over a pulley connected to an electric motor. This elevator can be a geared or gearless-traction elevator. In this type of elevator, five to eight wire cables or hoisting cables are attached to the top of the elevator car by wrapping around it on sheaves at one end, and the other end is attached to a counter weight that moves up and down on its guiderails. This counter weight is equal to the weight of the car plus half of the maximum passenger load in that car. This means, during the lifting operation, it needs power for the extra passengers in the car, and, the rest of the weight is balanced by the counter weight.

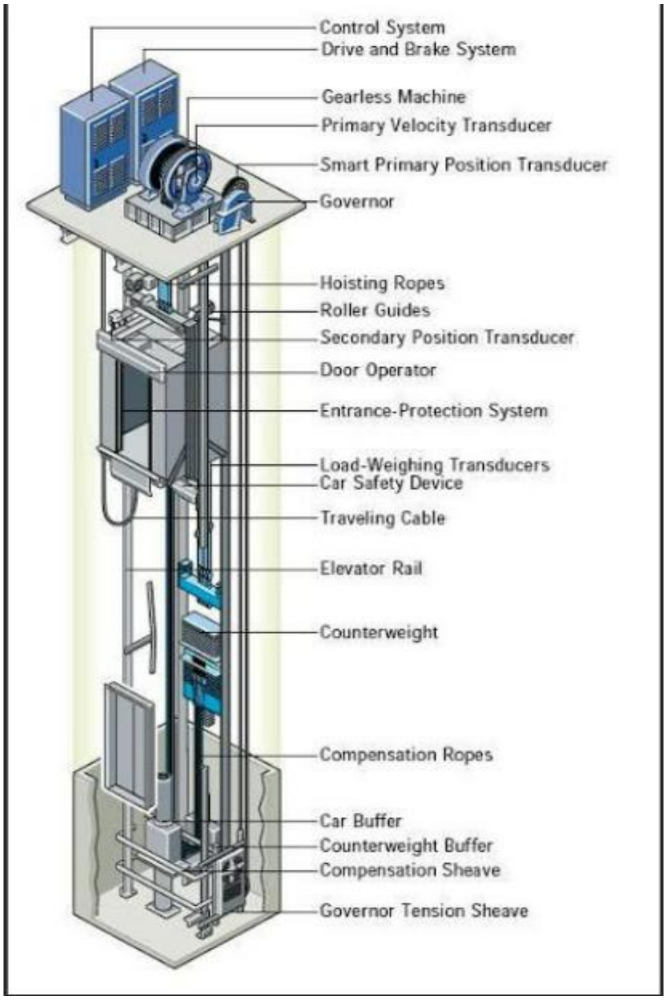


**Fig.4.28.**Traction elevator

Whenever the control system attached to the elevator drives the motor in the forward direction, the sheaves also turn around causing to move the car elevator upwards, and then stopping in the desired floor wherein the car is balanced by the counter weight. For the downward movement of the car, reverse happens through a rotating motor via a control mechanism. Some of the elevators use motors with four-quadrant operation to save the energy in regenerative mode. Due to high speeds and high-rise capabilities, these types of elevators are found in many of the applications of lifts and escalators.

**BATTERY BANKS:**

A battery bank is group of batteries connected together using series or parallel wiring. This allows more power to be stored than using single battery. This battery banks stores energy in the form of electrochemical form.

**Fig.4.29. Battery banks**

Battery banks in small power systems normally have nominal voltages of either 12v or 24v however lead acid batteries are available from 4v up to 24v batteries can be combined in series so that their voltages are added together. Two 12v batteries in series will provide 24v. Although voltages are adding the same current will flow through each battery, so that two identical batteries 12v in series supplying 5A to a load each supply 5A therefore the Ah capacity of two identical batteries in series is the same as one battery on its ow. The total internal resistance of batteries in series will equal the internal resistances of the individual batteries added together.

**UPS SYSTEM:**

An uninterruptible power supply or uninterruptible power source (UPS) is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails. A UPS differs from an auxiliary or emergency power system or standby generator in that it will provide near-instantaneous protection from input power interruptions, by supplying energy stored in batteries, super capacitors, or flywheels.

The on-battery run-time of most uninterruptible power sources is relatively short (only a few minutes) but sufficient to start a standby power source or properly shut down the protected equipment. It is a type of continual power system. A UPS is typically used to protect hardware such as computers, data centers, telecommunication equipment or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss.

UPS units' range in size from ones designed to protect a single computer without a video monitor (around 200 volt-ampere rating) to large units powering entire data centers or buildings. The world's largest UPS, the 46-megawatt Battery Energy Storage System (BESS), in Fairbanks, Alaska, powers the entire city and nearby rural communities during outages.

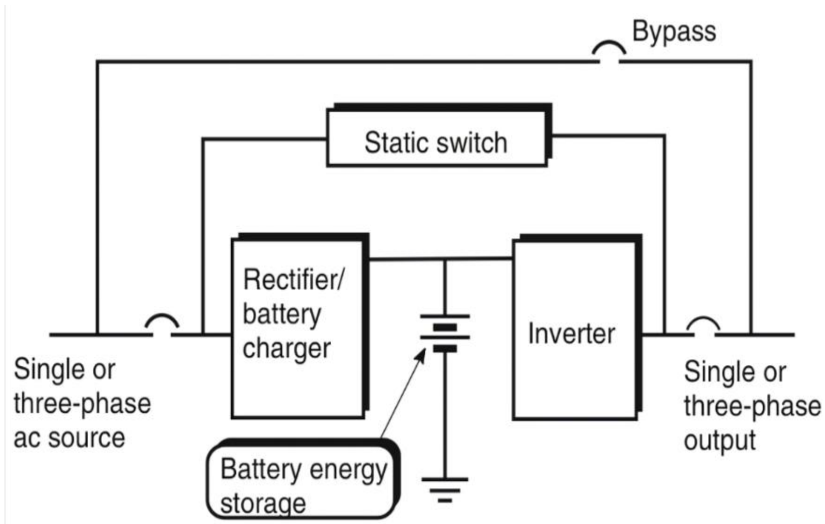


**Fig.4.30.**UPS System

The primary role of any UPS is to provide short-term power when the input power source fails. However, most UPS units are also capable in varying degrees of correcting common utility power problems:

1. Voltage spike or sustained overvoltage
2. Momentary or sustained reduction in input voltage
3. Voltage sag
4. Noise, defined as a high frequency transient or oscillation, usually injected into the line by nearby equipment
5. Instability of the mains frequency
6. Harmonic distortion, defined as a departure from the ideal sinusoidal waveform expected on the line

Some manufacturers of UPS units categorize their products in accordance with the number of power-related problems they address. A UPS unit may also introduce problems with electric power quality. To prevent this, a UPS should be selected not only by capacity, but also by the quality of power that is required by the equipment that is being supplied.

**Types of UPS systems:**

UPS systems have three different topologies or categories based on what type of power protection you need they are

1. Standby or offline
2. Line – interactive
3. Double conversion or online

An on-line UPS uses a "double conversion" method of accepting AC input, rectifying to DC for passing through the rechargeable battery (or battery strings), then inverting back to 120 V/230 V AC for powering the protected equipment.

A line-interactive UPS maintains the inverter in line and redirects the battery's DC current path from the normal charging mode to supplying current when power is lost.

In a standby ("off-line") system the load is powered directly by the input power and the backup power circuitry is only invoked when the utility power fails.

Most UPS below one kilovolt-ampere (1 kVA) are of the line-interactive or standby variety which is usually less expensive. For large power units, dynamic uninterruptible power supplies (DUPS) are sometimes used. A synchronous motor/alternator is connected on the mains via a choke. Energy is stored in a flywheel. When the mains power fails, an eddy-current regulation maintains the power on the load as long as the flywheel's energy is not exhausted. DUPS are sometimes combined or integrated with a diesel generator that is turned on after a brief delay, forming a diesel rotary uninterruptible power supply (DRUPS).

A fuel cell UPS was developed by the company Hydrogenic using hydrogen and a fuel cell as a power source, potentially providing long run times in a small space

**SELECTION OF UPS AND BATTERY BANKS:**

While selecting an UPS for a requirement, different manufacturers have different specifications, which make the comparison confusing. The comparison and selection should be based on the below technical parameters and the relevance for the particular requirement.

The 3 main components of the UPS are rectifier, inverter and battery. The rectifier acts as a load to the electrical mains and the following characteristic of the rectifier will decide the type of upstream infrastructure required.

- Input current distortion (THDI) : Harmonics,
- Input power factor,
- Input start-up current,
- Number of wires (3ph or 3ph+Neutral),
- Efficiency (influences global efficiency),
- Maximum output power,

- Input voltage & frequency tolerances
- Generator compatibility

The inverter of the UPS System will be a source for the critical loads connected to the UPS and based on the need of the load the following parameters decides the quality & capacity of the UPS.

- Nominal apparent power (VA)
- Nominal active power (W)
- Capability to support load Power factor (low power factor and Leading mainly)
- Inverter efficiency (influences global efficiency)
- Output voltage distortion
- Max load current crest factor
- Overload, Inrush current and short-circuit capability,
- With or without galvanic isolation

The battery is the heart of the UPS system and the selection of battery is more important as it decides the duration of operation in the event of mains failure. The battery also plays an important role in deciding the Capex and Opex cost. The following points have to be evaluated to have the right battery configuration.

- KW considered for battery sizing
- End cell voltage
- Ageing factor
  (incase of low backup time)
- No of battery bank in parallel
- Design life of the selected battery
- Required of charging current and its compatibility with UPS

# UNIT - V

# ELECTRIC TRACTION

**Syllabus:** 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, Adhesive weight and coefficient of adhesion.

**TRACTION SYSTEM:**

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, dirt, 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 over loads.
- Interference to the communication lines should be eliminated while the locomotive running along the track.

**TYPES OF TRACTION SYSTEM:**

Traction system is normally classified into two types based on the type of energy given as input to drive the system and they are:

1. Non electric traction system
2. Electric traction system

**1. 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 non electric traction system.

Types of non electric traction system are

i. Direct steam engine drive
ii. Direct internal combustion engine drive.

**i. Direct steam engine drive:**

Steam engine drive is the most widely used traction system in almost all the under developed countries. Steam locomotive is still the most widely adopted means of propulsion for railway work. Invariably, the reciprocating engine is employed because of their advantages.

**Advantages:**

- Simplicity in design
- It does not interfere with telecommunication line
- Low capital cost, because track electrification is not required
- Speed control is simple
- Connection between its cylinders and the driving wheels is simple

**Disadvantages:**

- Poor thermal efficiency
- Noise in operation
- Due to unbalanced reciprocating part that is considerable wear and tear on the track
- Corrosion of steel structure due to smoke emitted by the engine
- It pollutes atmosphere
- Efficiency is low
- Not suitable for underground system
- Maintenance cost is very high
- It takes own time for starting
- Speed of locomotive is very low
- It has strictly limited overload capacity.

**ii. Direct internal combustion engine drive:**

It is suitable for road and light railway work. It is unsatisfactory for any railway work.

**Advantages:**

- Low initial cost
- Very compact and self contained unit
- Simple speed control mechanism

- Its efficiency is 25%
- Its breaking arrangements are simple

**Disadvantages:**

- Overload capacity is low
- The life of the vehicle is short
- Maintenance and running cost are high
- It produces air pollution
- It requires gear system for speed control

**2. 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 may be classified into two groups:

i. Self-contained locomotives. **Ex**: Battery-electric drive and Diesel electric drive etc.
ii. Electric vehicle fed from the distribution networks. **Ex:** System operating with DC supply. Ex: tramways, trolley buses, railways and System operating with AC supply. Ex: railways.

**Advantages and disadvantages of electric traction:**

**Advantages:**

- 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.
- The speed control of the electric motor is easy
- Well suited for underground railways.
- It has the advantages of rapid acceleration and retardation.
- The maintenance and running costs are comparatively low.
- 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.
- 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.

**Disadvantages:**

- 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.

**i. 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 Battery-electric drive and Diesel electric drive.

**Diesel electric drive:**

This system is used in Indian railways. In this system gear mechanism is eliminated. Diesel engine is 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.

**Advantages:**

- As these are no overhead distribution system hence initial cost is low.
- Easy speed control is possible
- The overall efficiency is 25% more than steam locomotive
- Power loss in speed control is very low.
- Time taken to bring the locomotive into service is less.
- In this system, high acceleration and braking retardation can be obtained compared to steam locomotives.
- Simple starting method
- Breaking arrangements are simple.
- Haulage capacity is higher as compared with steam locomotives.

**Disadvantages:**

- The overloading capability of the diesel engine is less.
- The running and maintenance costs are high.
- The regenerative braking cannot be employed for the diesel engine drives
- It has a shorter life span
- Cooling arrangements are needed for diesel engine as well as motor generator set

**Battery-electric drive:**

In this system vehicle carries batteries which run DC motors used for driving the vehicle. This system is not suitable for railways. 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. The batteries are connected in parallel for starting and running half of the maximum speed. The batteries are connected in series foe running at maximum speed.

**Advantages:**

- Low maintenance cost
- Convenient to use
- Pollution free

**Disadvantages:**

- The major disadvantage is limited capacities of the batteries and the problem of charging them frequently.

**iii. Electric vehicle fed from the distribution networks:**

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 two types.

**System 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 tramways, trolley buses

**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. Rheostatic braking and mechanical braking 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, rheostatic braking is employed, due to high adhesion between roads and rubber types. A DC compound motor is employed in trolley buses.

**Railways:**

In railways Electric trains can be run on AC & DC. In early days DC at 1,500v &1-φ AC at 11 to 15kv having frequency 25 c/s or 16 2/3 c/s were used .However DC was preferred as compared to AC because in case of AC an additional equipment is required to convert normal frequency 50 c/s to 25c/s or 16 2/3 c/s.

Later on AC has proved more advantages in terms of ohmic losses .Moreover in cases of AC higher voltages can be obtained by use of transformer which reduces the losses and thus increases the spacing between two substations thereby reducing the number of feeding substations .In case of 3-φa.c normal frequency i.e 50c/s is employed for traction thereby by eliminating low frequency difficulty.

**Overview 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 below Table.

| 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 |

**Table.5.1.** Track electrification systems

**SPECIAL FEATURES OF TRACTION MOTORS:**

The motors required for traction work must meet the following requirements they are,

1. Mechanical features.
2. Electrical features.

**1. Mechanical features:**

- In overall dimensions, the traction motor must have small diameter, to arrange easily beneath the motor coach.
- A traction motor must have minimum weight so the weight of locomotive will decrease. Hence, the load carrying capability of the motor will increase
- A traction motor must be mechanically strong and robust and it should be capable of withstanding severe mechanical vibrations.
- The traction motor should be completely enclosed type when placed beneath the locomotive to protect against dirt, dust, mud, etc.

Use of cast steel is preferred for magnetic circuit of traction motor in comparison of cast iron as it gives good mechanical strength.

**Electrical features:**

- 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
- 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.
- Traction motors should be able to provide easy simple rheostatic and regenerative braking subjected to higher voltages so that system must have the capability of withstanding voltage fluctuations.
- The traction motor should have the capability of withstanding high temperatures during transient conditions.
- The traction motor should have the capability of handling excessive overloads.
- In traction work, more number of motors needs 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.
- Traction motor should have the feature of better commutation, to avoid the sparking at the brushes and commutator segments.
- The speed of the motor should fall with the increase in the load which in turn prevents the excessive loading as power output =torque*speed
- Traction motors should be capable to withstanding temporary interruptions at the instant of crossing over the cross over and section insulators.

Most suitable motors which meet the all most all above requirements are DC series motors and compound in case of DC system where single phase AC series and three phase induction motor in case of AC system.

**SPEED-TIME 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 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.

**i. Speed–time curve for main line service:**

Typical speed–time curve of a train running on main line service is shown in below fig. It mainly consists of the following time periods

a. Constant accelerating period.
b. Acceleration on speed curve.
c. Free-running period.
d. Coasting period.
e. Braking period.

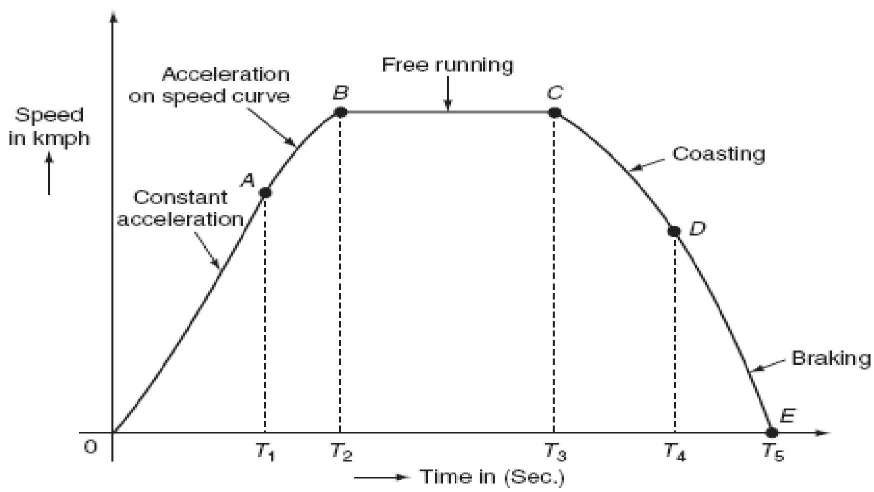


**Fig.5.1.** Speed–time curve for main line service

**a. Constant accelerating period:**

During this period, the traction motor accelerates 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'.

**b. 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'.

**c. 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.

**d. 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 '$\beta_c$'.

**e. 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.

**ii. 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 below Fig.

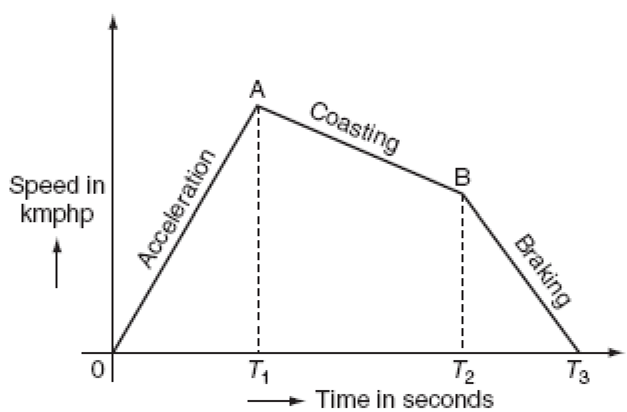


**Fig.5.2.** Speed–time curve for suburban service

The speed–time curve for urban service consists of three distinct periods. They are:

a. Acceleration.

b. Coasting.

c. 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.

**iii. 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 below Fig.

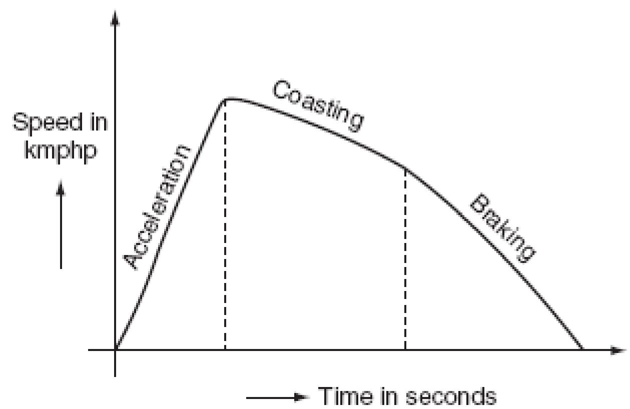


**Fig.5.3.** Speed–time curve for urban service

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 below Table.

| | *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 |

**Table.5.1.** Types of services

**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 form 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 is known as trapezoidal approximation, a simplified trapezoidal speed–time curve is shown in below Fig.

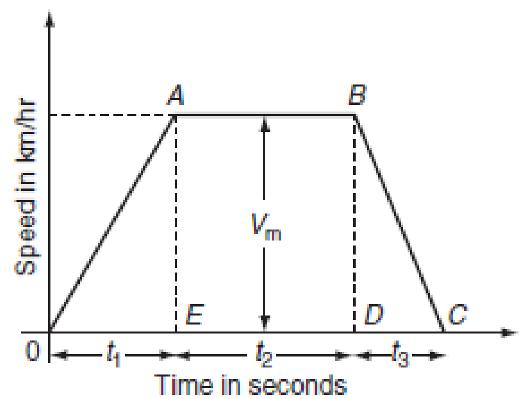


**Fig.5.4.** Trapezoidal speed–time curve

**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, Vm be the maximum or the crest speed of train in km/h, and Va be the average speed of train in km/h from the above Fig.

Actual running time of train, $T = t_1 + t_2 + t_3$.

Time for acceleration, $t_1 = \frac{V_m - 0}{\alpha} = \frac{V_m}{\alpha}$

Time for retardation, $t_3 = \frac{V_m - 0}{\beta} = \frac{V_m}{\beta}$

Time for free running period, $t_2 = T - (t_1 + t_3)$

$$= T - [\frac{V_m}{\alpha} + \frac{V_m}{\beta}]$$

$$= T - V_m [\frac{1}{\alpha} + \frac{1}{\beta}]$$

Area under the trapezoidal speed time curve gives, The total distance between the two 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 acceleration period × Time for acceleration

$$= \frac{0+V_m}{2} \times t_1 \text{ km/h} \times sec$$

$$= \frac{0+V_m}{2} \times \frac{t_1}{3600} \text{ km}$$

The distance travelled during free running period = Average speed × Time of free running

$$= V_m \times t_2 \text{ km/h} \times \text{sec}$$

$$= V_m \times \frac{t_2}{3600} \text{ km}$$

The distance travelled during retardation period = Average speed × Time for retardation

$$= \frac{\text{Vm}+0}{2} \times t_3 \text{ km/h} \times \text{sec}$$

$$= \frac{0+V_m}{2} \times \frac{t_3}{3600} \text{ km}$$

The distance between the two stops is:

$$D = \frac{V_m}{2} \times \frac{t_1}{3600} + V_m \times \frac{t_2}{3600} + \frac{V_m}{2} \times \frac{t_3}{3600}$$

Sub $T_2$ value in above equation

$$D = \frac{V_m t_1}{7200} + \frac{V_m}{3600}[T - (t_1+t_3)] + \frac{V_m t_3}{7200}$$

Now sub $t_1$ and $t_3$ values in above equation

$$D = \frac{V_m^2}{7200\alpha} + \frac{V_m}{3600}[T - V_m \left(\frac{1}{\alpha} + \frac{1}{\beta}\right)] + \frac{V_m^2}{7200\beta}$$

$$D = \frac{1}{3600}[\frac{V_m^2}{2\alpha} + V_m T - V_m^2 \frac{1}{\alpha} - V_m^2 \frac{1}{\beta} + \frac{V_m^2}{2\beta}]$$

$$D = \frac{1}{3600}[V_m^2\left(\frac{1}{2\alpha} - \frac{1}{\alpha}\right) + V_m T + V_m^2\left(\frac{1}{2\beta} - \frac{1}{\beta}\right)]$$

$$D = \frac{1}{3600}[V_m^2\left(\frac{1-2}{2\alpha}\right) + V_m T + V_m^2\left(\frac{1-2}{2\beta}\right)]$$

$$D = \frac{1}{3600}[\left(\frac{-V_m^2}{2\alpha}\right) + V_m T + \left(\frac{-V_m^2}{2\beta}\right)]$$

$$3600D = V_m T - V_m^2\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right)$$

$$3600D - V_m T + V_m^2\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right) = 0$$

Let $(\frac{1}{2\alpha}+\frac{1}{2\beta}) = X = \frac{\alpha+\beta}{2\alpha\beta}$ Sub this value in above equation

$$V_m^2 X - V_m T + 3600D = 0$$

By solving above quadratic equation we get

$$V_m = \frac{T + \sqrt{T^2 - 4X \times 3600D}}{2X}$$

$$V_m = \frac{T}{2X} \pm \sqrt{\frac{T^2}{4X^2} - \frac{3600D}{X}}$$

By considering positive sign, we will get high values of crest speed, which is practically not possible, so negative sign should be considered.

$$V_m = \frac{T}{2X} - \sqrt{\frac{T^2}{4X^2} - \frac{3600D}{X}}$$

$$V_m = \frac{\alpha\beta}{\alpha+\beta} T - \sqrt{(\frac{\alpha\beta}{\alpha+\beta})^2 T^2 - 7200(\frac{\alpha\beta}{\alpha+\beta}) D}$$

**Analysis of quadrilateral speed–time curve:**

Quadrilateral speed–time curve for urban and sub urban 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 below Fig.

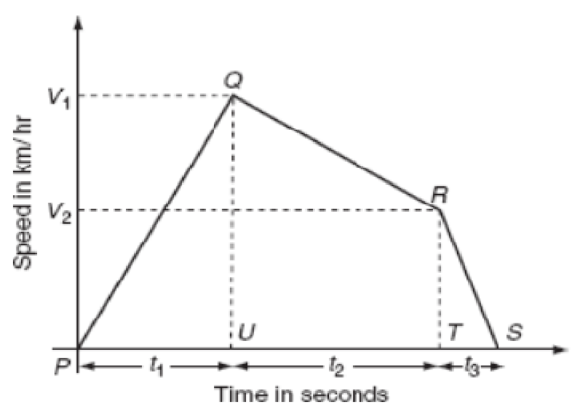


**Fig.5.4.**Quadrilateralspeed–timecurve

Let $V_1$ be the speed at the end of accelerating period in km/h, $V_2$ be the speed at the end of coasting retardation period in km/h, and $\beta_c$ 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, $t_2 = \frac{V_1 - V_2}{\beta_c}$

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 coasting retardation + the distance travelled during breaking retardation.

But the distance travelled during acceleration = average speed × time for acceleration

$$= \frac{0+V_1}{2} \times t_1 \text{ km/h} \times \text{sec}$$

$$= \frac{V_1}{2} \times \frac{t_1}{3600} \text{ km}$$

The distance travelled during coasting retardation = $\frac{V_2+V_1}{2} \times t_2$ km/h×sec

$$= \frac{V_2+V_1}{2} \times \frac{t_2}{3600} \text{ km}$$

The distance travelled during breaking retardation = average speed × time for breaking retardation

$$= \frac{0+V_2}{2} \times t_3 \text{ km/h} \times \text{sec}$$

$$= \frac{V_2}{2} \times \frac{t_3}{3600} \text{ km}$$

The total distance travelled D = $\frac{V_1}{2} \times \frac{t_1}{3600} + \frac{V_2+V_1}{2} \times \frac{t_2}{3600} + \frac{V_2}{2} \times \frac{t_3}{3600}$

$$=\frac{V_1 t_1}{7200} + \frac{(V_2+V_1)t_2}{7200} + \frac{V_2 t_3}{7200}$$

$$=\frac{V_1 t_1}{7200} + \frac{V_1 t_2}{7200} + \frac{V_2 t_2}{7200} + \frac{V_2 t_3}{7200}$$

$$=\frac{V_1}{7200}(t_1 + t_2)+\frac{V_2}{7200}(t_2 + t_3)$$

$$=\frac{V_1}{7200}(T - t_3)+\frac{V_2}{7200}(T - t_1)$$

$$=\frac{V_1}{7200}T - \frac{V_1}{7200}t_3+\frac{V_2}{7200}T - \frac{V_2}{7200}t_1$$

$$=\frac{(V_1+V_2)T}{7200}-\frac{V_1}{7200}t_3-\frac{V_2}{7200}t_1$$

$$=\frac{(V_1+V_2)T}{7200}-\frac{V_1 V_2}{7200\beta}-\frac{V_1 V_2}{7200\alpha}$$

$$=\frac{(V_1+V_2)T}{7200}-\frac{V_1 V_2}{7200\beta}-\frac{V_1 V_2}{7200\alpha}$$

$$D=\frac{(V_1+V_2)T}{7200}-\frac{V_1 V_2}{7200}(\frac{1}{\beta} + \frac{1}{\alpha})$$

$$3600D=\frac{(V_1+V_2)T}{2}-\frac{V_1 V_2}{2}(\frac{1}{\beta} + \frac{1}{\alpha})$$

$$3600D=\frac{(V_1+V_2)T}{2}-KV_1 V_2$$

$$3600D-\frac{(V_1+V_2)T}{2}+KV_1V_2=0$$

Where $k=\frac{1}{2}(\frac{1}{\beta}+\frac{1}{\alpha})=\frac{\alpha+\beta}{2\alpha\beta}$ and also $\beta_c=\frac{V_1-V_2}{t_2}$

$$\beta_c t_2 = V_1 - V_2$$

$$V_2 = V_1 - \beta_c t_2$$

$$V_2 = V_1 - \beta_c(\mathrm{T} - t_1 - t_3)$$

$$V_2 = V_1 - \beta_c(\mathrm{T} - \frac{V_1}{\alpha} - \frac{V_2}{\beta})$$

$$V_2 = V_1 - \beta_c(\mathrm{T} - \frac{V_1}{\alpha}) + \beta_c \frac{V_2}{\beta}$$

$$V_2\left(1 - \frac{\beta_c}{\beta}\right) = V_1 - \beta_c\left(\mathrm{T} - \frac{V_1}{\alpha}\right)$$

$$V_2 = \frac{V_1 - \beta_c\left(\mathrm{T} - \frac{V_1}{\alpha}\right)}{\left(1 - \frac{\beta_c}{\beta}\right)}$$

**Problems:**

1.The distance between two stops is 1.2km. A schedule speed of 40 kmph is required to cover that distance. The stop is of 18-s duration. The values of the acceleration and retardation are 2kmphp and 3kmphp, respectively. Then, determine the maximum speed over the run. Assume a simplified trapezoidal speed–time curve.

**Solution:**

Acceleration α=2.0kmphp.

Retardation β=3kmphp.

Schedule speed Vs=40kmph.

Distance of run, D=1.2km.

Schedule time, $T_s=\frac{D\times3600}{V_s}=\frac{1.2\times3600}{40}$

=108sec

Actual run time, $T=T_s$—stop duration

=108–18

=90s

Maximum speed $V_m=\frac{T}{2X}-\sqrt{\frac{T^2}{4X^2}-\frac{3600D}{X}}$

Where $X = (\frac{1}{2\alpha}+\frac{1}{2\beta})=(\frac{1}{2\times2}+\frac{1}{2\times3})=0.416$

$$V_m = \frac{90}{2\times0.416} - \sqrt{\frac{90^2}{4\times0.416^2} - \frac{3600\times1.2}{0.416}}$$

$= 108.173-\sqrt{11701.414 - 10384.61}$

= 71.88kmph

2. The speed—time curve of train carries of the following parameters:

(i) Free running for 12 min.

(ii) Uniform acceleration of 6.5 kmphp for 20s.

(iii) Uniform deceleration of 6.5 kmphp to stop the train.

(iv) A stop of 7min. Then, determine the distance between two stations, the average, and the schedule speeds

**Solution:**

Acceleration ($\alpha$) = 6.5 kmphps.

Acceleration period $t_1 = 20$ s.

Maximum speed $V_m = \alpha t_1$

$= 6.5 \times 20 = 130$ kmph.

Free-running time ($t_2$) $= 12 \times 60$

$= 720$ s.

$$\text{Time for retardation, } (t_3) = \frac{V_m}{\beta}$$

$$= \frac{130}{6.5} = 20 \text{ s}.$$

The distance travelled during the acceleration period:

$$D_1 = \frac{1}{2}\frac{V_m t_1}{3,600}$$

$$= \frac{1}{2} \times \frac{130 \times 20}{3,600}$$

$= 0.36$ km.

The distance travelled during the free-running period:

$$D_2 = \frac{V_m t_2}{3,600}$$

$$= \frac{130 \times 720}{3,600}$$

$= 26$ km.

$$\text{The distance travelled during the braking period } D_3 = \frac{V_m t_3}{7,200}$$

$$= \frac{130 \times 20}{7,200}$$

$= 0.362$ km.

The distance between the two stations:

$D = D_1 + D_2 + D_3$

$= 0.36 + 26 + 0.362$

$= 26.724$ km.

$$\text{Average distance } (V_{avg}) = \frac{D \times 3600}{T}$$

$$= \frac{26.724 \times 3600}{20 + 720 + 20}$$

$= 126.58$ kmph.

$$\text{Schedule speed } (V_s) = \frac{D \times 3600}{T + \text{stoptime}}$$

$$= \frac{26.724 \times 3,600}{20 + 720 + 20 + 70 \times 60}$$

$= 81.53$ kmph.

3. An electric train is to have the acceleration and braking retardation of 0.6km/hr/sec and 3km/hr/sec, respectively. If the ratio of the maximum speed to the average speed is 1.3 and time for stop is 25s. Then determine the schedule speed for a run of 1.6km. Assume the simplified trapezoidal speed–time curve.

**Solution:**

Acceleration $\alpha = 0.6$ km/hr/s.
Retardation $\beta = 3$ km/hr/s.
Distance of run $D = 1.6$ km.
Let the cultural time of run be $T$ s.

$$\text{Average speed } V_a = \frac{3,600D}{T} = \frac{3,600 \times 1.6}{T} = \frac{5,760}{T} \text{ kmph.}$$

$$\text{Maximum speed} = 1.3V_a = 1.3 \times \frac{5,760}{T}$$

$$= \frac{7,488}{T} \text{ km/hr}$$

$$V_m^2\left[\frac{1}{2\alpha} + \frac{1}{2\beta}\right] - V_m\, T + 3,600 = D$$

$$V_m^2 = \frac{V_m T - 3,600D}{\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right)}$$

$$= \frac{\frac{7,488}{T} \times T - 3,600 \times 1.6}{\left(\frac{1}{2 \times 0.6} + \frac{1}{2 \times 3}\right)}$$

$$= \frac{7,488 - 5,760}{0.833 + 0.166}$$

$$= 1,729.729$$

$$\therefore V_m = 41.59 \text{ km/hr.}$$

$$\text{Average speed, } (V_a) = \frac{V_m}{1.3} = \frac{41.59}{1.3}$$

$$(V_a) = 31.9923 \text{ kmph.}$$

$$\text{Actual time of run } T = \frac{3,600D}{V_a} = \frac{3,600 \times 1.6}{31.9923}$$

$$T = 180.0433 \text{ s.}$$

$$\text{Schedule time } T_s = \text{Actual time of run} + \text{time of stop}$$
$$= 180.0433 + 25$$
$$= 205.0433 \text{ s.}$$

$$\text{Schedule speed } V_s = \frac{D \times 3,600}{T_s} = \frac{1.6 \times 3,600}{205.0433}$$
$$= 28.0916 \text{ kmph.}$$

4. The distance between two stops is 5km. A train has schedule speed of 50kmph. The train accelerates at 2.5kmphps and retards 3.5kmphps and the duration of stop is 55s. Determine the crest speed over the run assuming trapezoidal speed–time curve.

**Solution:**

Acceleration (α) = 2.5kmphps.

Retardation (β) = 3.5kmphps

Distance of run $(D) = 5$ km.

Schedule speed $(V_s) = 50$ kmph.

$$\text{Schedule time, } T_s = \frac{D}{V_s} \times 3{,}600$$
$$= \frac{5}{50} \times 3{,}600$$
$$= 360 \text{ s.}$$

$$\text{Actual time of run } T = T_s - \text{Time of stop}$$
$$= 360 - 55$$
$$= 305 \text{ s.}$$

By using the equation:

$$V_m = \frac{T}{2X} - \sqrt{\frac{T^2}{4X2} - \frac{3{,}600D}{X}}$$

$$X = \frac{1}{2\alpha} + \frac{1}{2\beta}$$
$$= \frac{1}{2 \times 2.5} + \frac{1}{2 \times 3.5}$$
$$= 0.2 + 0.1428$$
$$= 0.3428.$$

$$\therefore V_m = \frac{305}{2 \times 0.3428} - \sqrt{\frac{(305)^2}{4 \times (0.3428)^2} - \frac{3600 \times 5}{0.3428}}$$
$$= 444.868 - \sqrt{197{,}905.5898 - 52{,}508.75146}$$
$$= 63.556 \text{ kmph.}$$

5. A train has schedule speed of 32kmph overall level track distance between $w_o$ stations being 2km. The duration of stop is 25s. Assuming the braking retardation of 3.2kmphps and the maximum speed is 20% greater than the average speed. Determine the acceleration required to run the service.

**Solution:**

Schedule speed Vs = 32 kmph.

Distance D = 2km.

Duration of stop = 25s.

Braking retardation = 3.2kmphps

$$\text{Schedule time } = \frac{D}{V_s}$$

$$= \frac{2}{32} \times 60 \times 60 = 225 \text{ s.}$$

Actual time of run $T = 225 - 25 = 200$ s.

$$\text{Average speed, } V_a = \frac{3,600 \times D}{T}$$

$$= \frac{3,600 \times 2}{200}$$

$$= 36 \text{ kmph.}$$

$$\text{Maximum speed, } (V_m) = 1.2\, V_a$$

$$= 1.2 \times 36$$

$$V_m = 43.2 \text{ kmph}$$

$$\therefore V_3^2 \left( \frac{1}{2\alpha} + \frac{1}{2\beta} \right) - V_m\, T + 3,600$$

$$\frac{1}{2\alpha} + \frac{1}{2\beta} = \frac{V_m T - 3,600 \times D}{V_m^2}$$

$$= \frac{43.2 \times 200 - 3,600 \times 2}{(43.2)^2}$$

$$\frac{1}{2\alpha} + \frac{1}{2\beta} = 0.7716$$

$$\frac{1}{2\alpha} = 0.716 - \frac{1}{2 \times 3.2}$$

$$\frac{1}{2\alpha} = 0.61535$$

$$\alpha = 0.893 \text{ kmphps.}$$

**Important Definitions:**

**Dead weight**:

It is the total weight of train to be propelled by the locomotive. It is denoted by W.

**Accelerating weight:**

It is the effective weight of train that has angular acceleration due to the rotational inertia including the dead weight of the train. It is denoted by $W_e$. This effective train is also known as accelerating weight. The effective weight of the train will be more than the dead weight. Normally, it is taken as 5–10% of more than the dead weight.

**Adhesive weight:**

The total weight to be carried out on the drive – in wheels of a locomotive is known as adhesive weight.

**Coefficient of adhesion:**

It is defined as the ratio of the tractive effort required to propel the wheel of a locomotive to its adhesive weight.

$$F_t \propto W$$

$$= \mu\, W$$

Where $f_t$ is the tractive effort and W is the adhesive weight

$$\mu = \frac{F_t}{W}$$