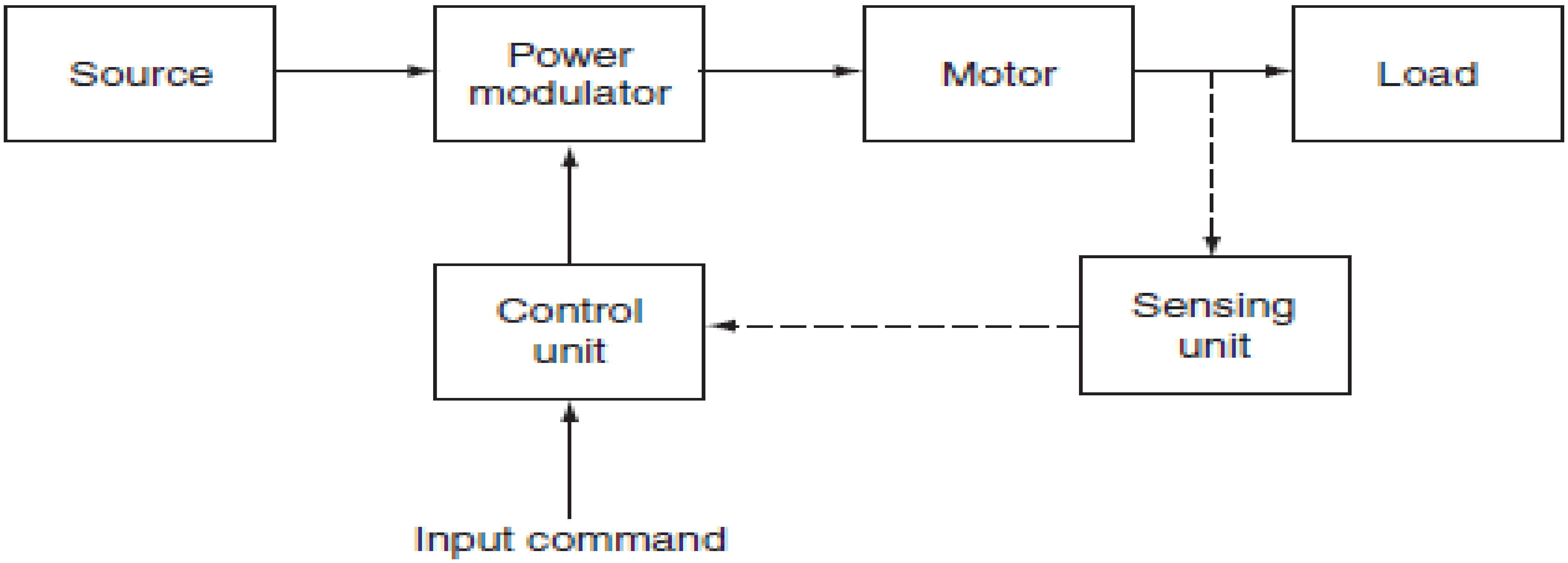
UTILIZATION OF ELECTRICAL ENERGY (UEE)

B.Tech IV-EEE-I-SEMISTER

UNIT-I : Electric Drives

BLOCK DIAGRAM OF ELECTRIC DRIVE



AC DRIVE	DC DRIVE
1. Used for AC motors	Used for DC motors
2. The power and control circuits are expensive and complex	The power and control circuits are inexpensive and simple
3. Require frequent maintenance	Require less maintenance
4. No commutation problem	Commutation problems
5. Speed and ratings values have no upper limits.	Speed and ratings values are limited.
6.Used in almost all the locations	Used in limited locations
7. Power to weight ratio is large	Power to weight ratio is considerably small
8. Produce less starting torque compared to dc drives	Produce high starting torque
9. Power consumption is less	Power consumption is More
10.Has good speed regulations	Poor speed regulations

1-φ and 3-φ, 50-Hz AC supplies are readily available in most locations. Very low power drives are generally fed from 1-φ source; however, the high-power drives are powered from 3-φsource; some of the drives are powered from a battery.

2.**Power modulator:-**

Power modulator performs the following functions:

- It modulates flow of power from the source to the motor is impart speed–torque characteristics required by the load.
- It regulates source and motor currents within permissible values, such as starting, braking, and speed reversal conditions.
- Selects the mode of operation of motor, i.e., motoring or braking.
- Converts source energy in the form suitable to the motor.

3.**Electrical motors:-**

Motors commonly used in electric drives are DC motors, induction motors, synchronous motors, blushless DC motors, stepper motors, and switched reluctance motors, etc. In olden days, induction and synchronous motors were employed mainly for const ant speed drives but not for variable speed drives, because of poor efficiency and are too expensive. But in nowadays, AC motors employed in variable speed drives due to the development of semiconductors employing SCRs, power transistors, IGBTs, and GTOs.

4.Load:-

- It is usually a machinery, such as fans, pumps, robots, and washing machines, designed to perform a given task, usually load requirements, can be specified in terms of speed and torque demands.

5.Control unit:-

- Control unit controls the function of power modulator. The nature of control unit for a particular drive depends on the type of power modulator used. When semiconductor converters are used, the control unit will consists of firing circuits. Microprocessors also used when sophisticated control is required.

6.Sensing unit :-

- Sensing unit consists of speed sensor or current sensor. The sensing of speed is required for the implementation of closed loop speed control schemes. Speed is usually sensed using tachometers coupled to the motor shaft. Current sensing is required for the implementation of current limit control.

3.Different characteristics of motors used for drives:-

- **DC MOTORS**

- The performance and selection of DC motor for a drive can be determined from it's characteristics. The important characteristics of different DC motors are….

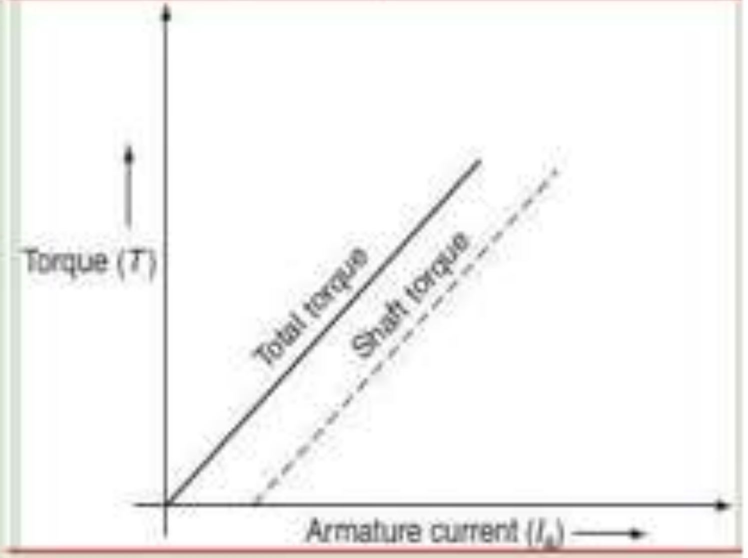
1.Starting characteristics.

a)Electric characteristics (T vs I_a)

b)Speed characteristics (N vs I_a)

c)Shaft torque characteristics (HP vs I_a)

2.Running characteristics (N vs T).

TYPE OF DC-MOTOR	RELAVENT EQUATIONS	TYPE OF CHARACTERISTICS
1. DC-Shunt Motor	$T \propto \phi \, Ia.$ $\therefore T \propto Ia.$	1. a) Electric characteristics (T vs Ia) 

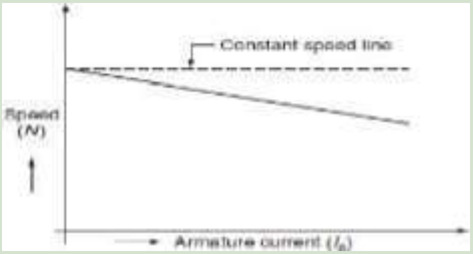
1. DC-Shunt Motor

$$N \propto \frac{E_b}{\emptyset}$$

$$E_b = (V - I_a R_a)$$

$$N \propto (V - I_a R_a)$$

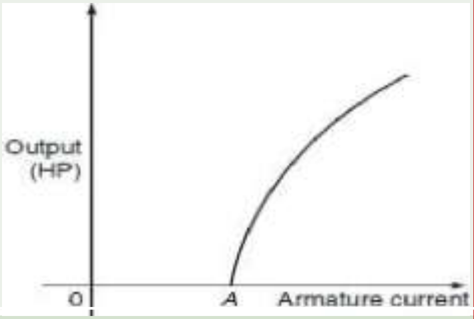
b) Speed characteristics (N vs Ia):-



1. DC-Shunt Motor

If the armature current increases, the output of the motor gradually increases.

c) Shaft torque characteristics (HP vs Ia):-



1. DC-Shunt Motor

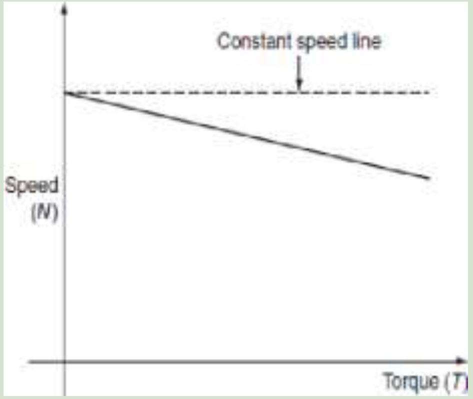
$$N \propto \frac{E_b}{\emptyset}$$

$$N = \frac{(V - I_a R_a)}{K\emptyset}$$

$$T = K\emptyset I_a$$

$$T = K_1 I_a$$

2. Running characteristics (N vs T):-

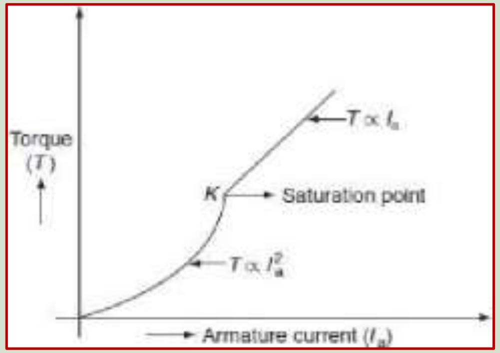


2 . DC-Series Motor

$$T = K\phi I_a.$$

$$T = K I_a^2$$

1. a) Electric characteristics (T vs Ia):-

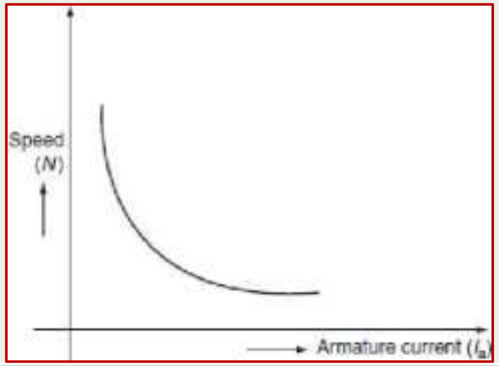


2 . DC-Series Motor

$$N \propto \frac{E_b}{\emptyset}$$

$$N \propto \frac{1}{\emptyset} \propto \frac{1}{I_a}$$

b) Speed characteristics (N vs Ia):-



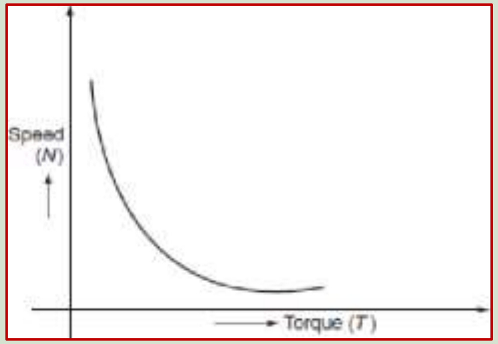
2 . DC-Series Motor

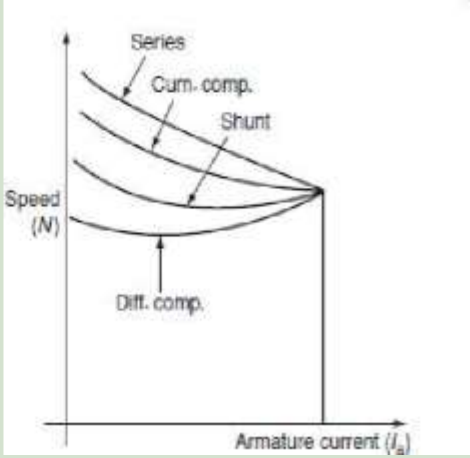
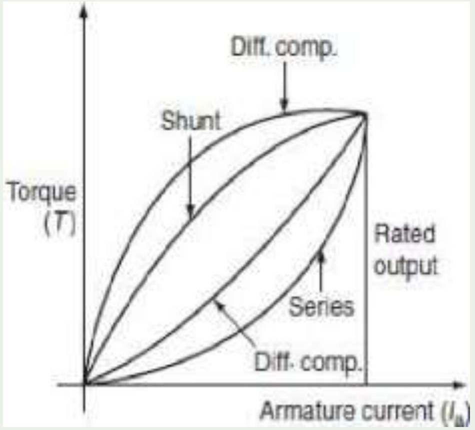
$$T = K I_a^2$$

$$N \propto \frac{1}{\emptyset} \propto \frac{1}{I_a}$$

$$N = \frac{1}{\sqrt{T}}$$

2. Running characteristics (N vs T):-



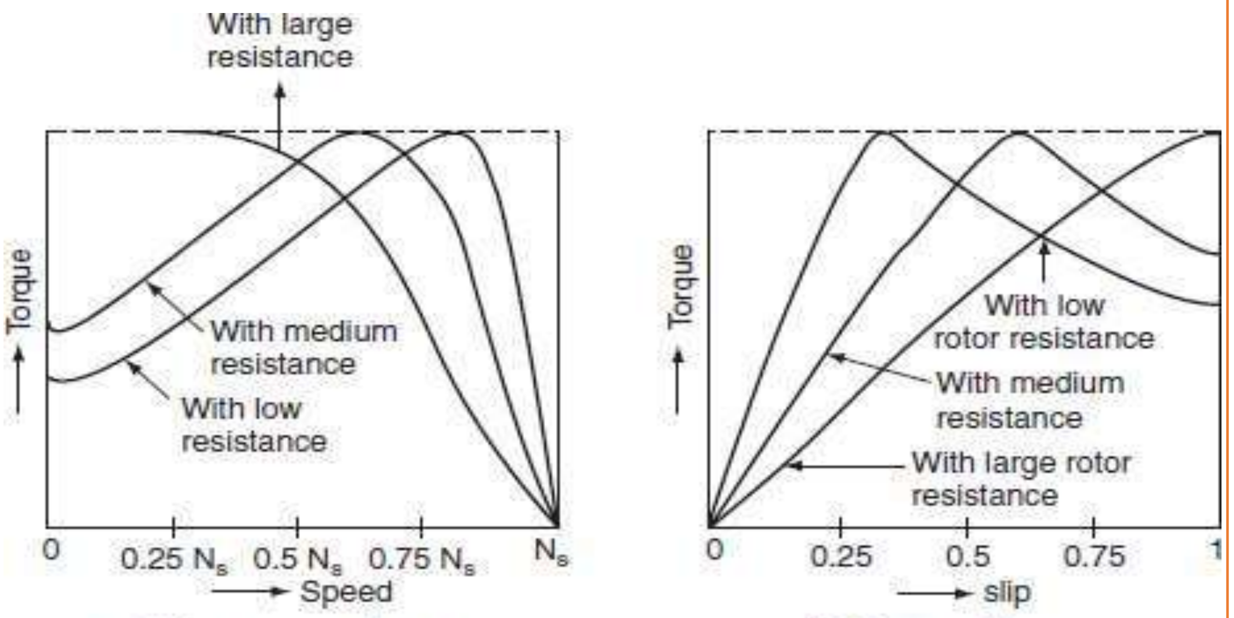
3. Characteristics of DC compound wound motors- a) Cumulative-compound motor:-	If the series field excitation aids with the shunt excitation, Hence net flux increases.	**Speed and armature current characteristics:-** 
b) Differential-compound motor:-	If the series field excitation opposes with the shunt excitation, Hence net flux decreases.	**Torque and armature current characteristics:-** 

THREE-PHASE INDUCTION MOTOR

$$T = \left(\frac{180}{2\pi N_S}\right) \times \frac{SE_2^2 R_2}{R_2^2 + (Sx_2^2)^2}$$

$$N_r = N_s(1 - s)$$

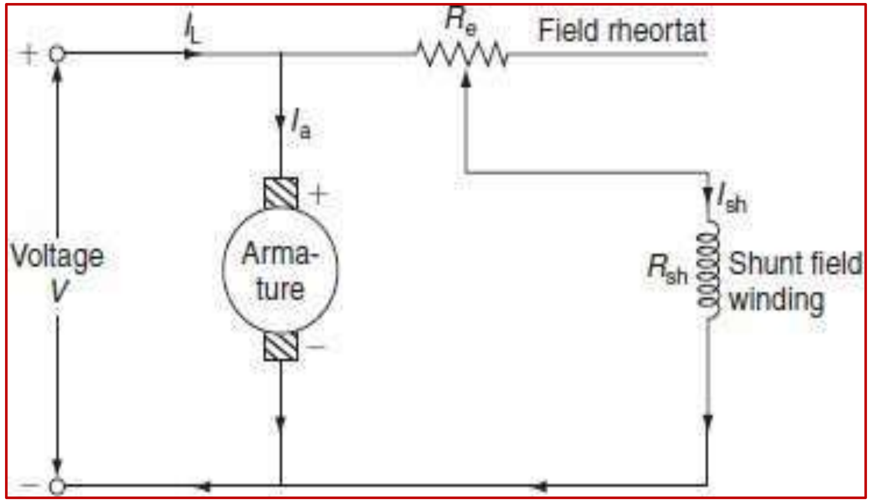
$$\rightarrow N_r = \frac{120f}{P}(1 - s)$$

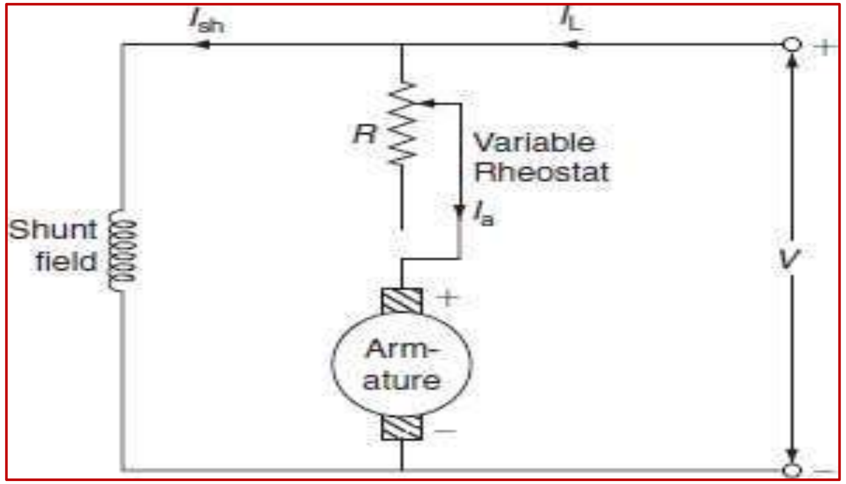


(a) Torque–speed curves (b) Torque–slip curves

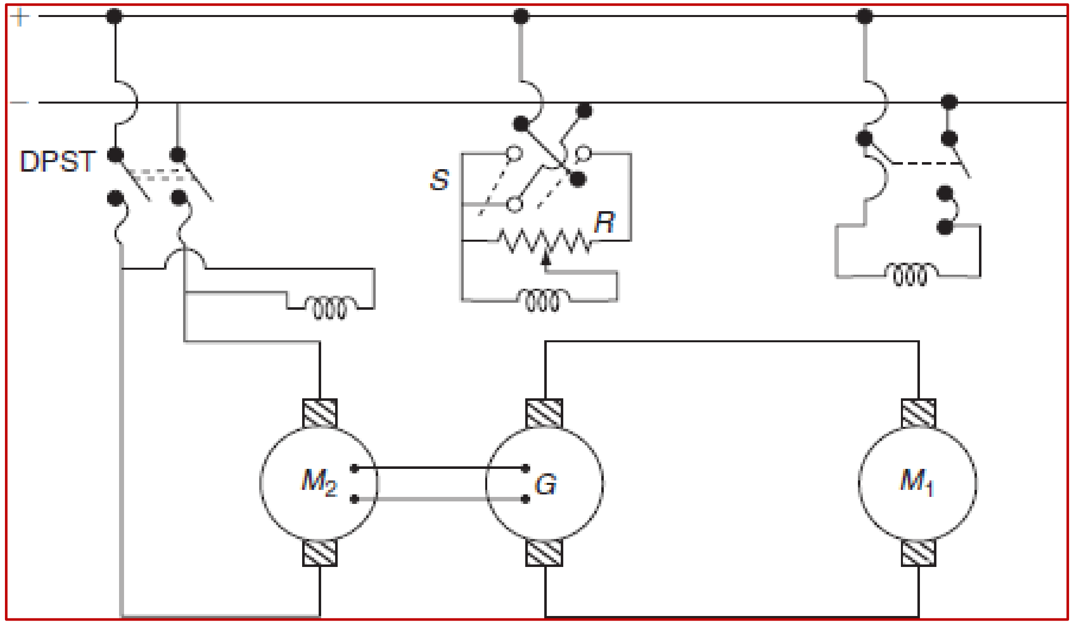
4. Speed control of different motors used for drives:

1. **Field control or flux control method**
2. **Armature control method**
3. **Applied voltage control:-**





I_{sh}
I_L
R
Variable
Rheostat
I_a
Shunt
field
V
Arm-
ature



DPST
S
R
M_2
G
M_1

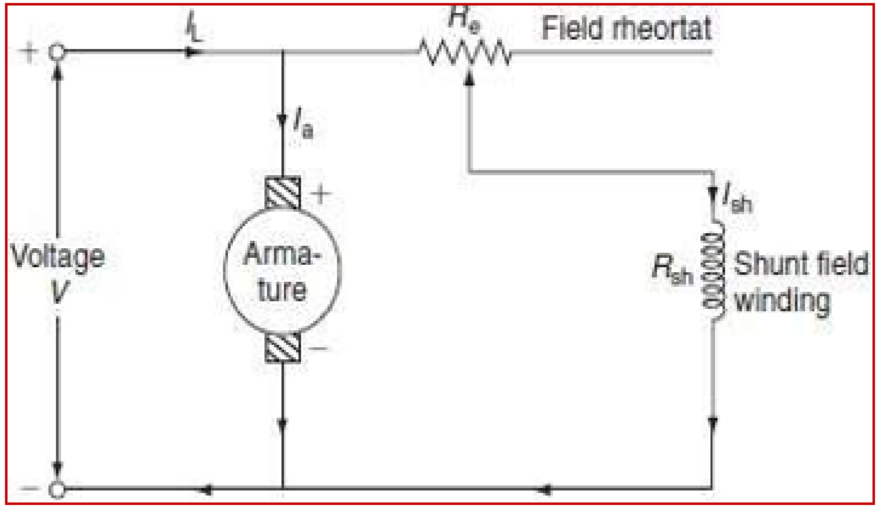
The natures of speed control required by different industrial drives are:

- Some drives require a continuously variable speed over the range from zero to full speed, such drives are known as ***variable-speed drives***.
- Some drives require only two to three fixed speeds over a region, such drives are known as ***multi-speed drives.***
- In some cases, speed is needed for adjusting or setting up the work on driven machine only for a few revolutions per minute. Such a speed is known as ***creeping speed.***

1. $N \propto \frac{E_b}{\emptyset}$ 2. $E_b = (V - I_a R_a)$ 3. $N \propto (V - I_a R_a)$

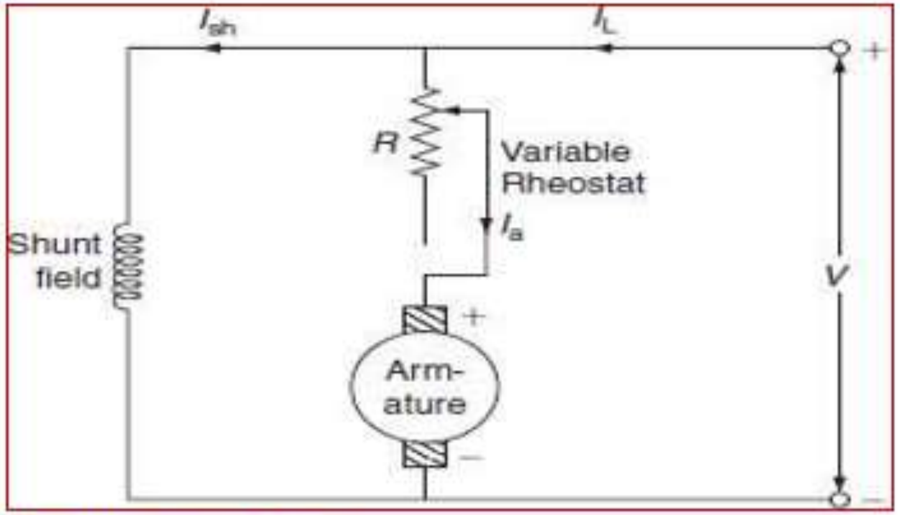
1. Field control or flux control method:-

In this method, speed control is obtained by controlling the field current or flux by means of a variable resistance inserted in series with the shunt filed winding. The external resistance (R_e) connected in series with the field winding is shown as shunt field regulator. The method of regulating the speed by varying the flux or field current in the shunt field winding is known as flux control method.



2. Armature control method:-

In armature or Rheostatic control method of speed, a variable Rheostatic or resistance connected in series with the armature is known as controller resistance. The speed is directly proportional to the voltage applied across the armature. Voltage across the armature can be controlled by changing resistance connected in series with it. As the controller resistance is increased, the potential difference across the armature is decreased thereby decreasing the armature speed.



3. Applied voltage control:-

This method requires a variable voltage for the field circuit; such a variable supply can be obtained by means of an adjustable Power electronic rectifier. Hence speed can be controlled.

- 1. $N \propto \frac{E_b}{\emptyset}$ 2. $E_b = (V - I_a R_a)$ 3. $N \propto (V - I_a R_a)$

Ward–Leonard method of speed control:-

The speed control of DC motor accomplished by means of an adjustable voltage generator is called the Ward–Leonard system. If it is desired to have wide and very sensitive speed control, then this system is more generally used.

In the figure shown -***R*** is the potential divider, ***M₁*** is the main motor whose speed is to be controlled, ***G*** is the separately excited generator that feeds the armature of the motor ***M₁***, ***M₂*** is the driving motor that drive generator and main motor, and ***S*** is a double-throw switch.

THREE-PHASE INDUCTION MOTOR

A 3-phase induction motor is a constant speed machine at a given load, but in most of the appliances like ….industrial and domestic need variable speeds , hence the speed of induction motor should able to control using different methods .

The speed of induction motor is given by ,

$$N_r = N_s(1-s) \qquad \rightarrow N_r = \frac{120f}{P}(1-s)$$

The torque produced by 3-phase induction motor is given by ,

$$T = \left(\frac{180}{2\pi N_S}\right) \times \frac{SE_2^2 R_2}{R_2^2 + (Sx_2^2)^2}$$

The methods employed for speed control of induction motors from both stator and rotor side are as follows:

The speed control of 3-phase induction motor from stator side are further classified as:

(a) V/f control or frequency control.

(b) Controlling supply voltage.

(c) Changing the number of stator poles.

(d) Adding rheostat in the stator circuit.

The speed controls of 3-phase induction motor from rotor side are further classified as:

(a) Adding external resistance on rotor side.

(b) Cascade control method.

(c) Injecting slip frequency EMF into rotor side.

Speed Control from Stator side

(a) V/f control or frequency control:-

1. Whenever 3-phase supply is given to three phase induction motor, rotating magnetic field(RMF) will produced, which rotates at synchronous speed given by,

$$N_S = \frac{120f}{P} \qquad N_r = N_s(1-s)$$

$$\rightarrow N_r = \frac{120f}{P}(1-s)$$

The a synchronous speed and, therefore, the speed of motor can be controlled by varying supply frequency.

2. But when frequency changes(decreases) , the flux in the core increases, Hence at a point the stator and rotor core gets saturated.

we have,

$$E_2 \propto V = 4.44kf\emptyset_m N$$

$$\emptyset_m = \frac{V}{4.44kfN}$$

To avoid core saturation and hence to maintain constant flux , it is recommended that vary voltage(V) in proportion to changes in frequency ,Hence it is also called as V/f –control.

(b) Controlling supply voltage:-

1. The torque under running condition of a 3-phase induction motor is given by,

$$T = \left(\frac{180}{2\pi N_S}\right) \times \frac{SE_2^2 R_2}{R_2^2 + (Sx_2^2)^2}$$

In low slip region 's' is very small . Due to this, the term $(sx_2)^2$ is small and hence negligible when compared to R_2 So torque becomes ,by keeping R_2 is constant,

$$T \propto \frac{SE_2^2}{R_2} \quad \rightarrow T \propto SE_2^2 \quad \rightarrow T \propto SV^2$$

2. From the above equation, it is clear that if we change supply voltage, torque will also change and hence speed. This method of speed control is rarely used because small change in speed requires large reduction in voltage, and hence the current drawn by motor increases, which cause over heating of induction motor.

(c) Changing the number of stator poles:-

1. In this method, the stator is provided with two separate windings which are wound for two different pole numbers. These two stator windings are electrically isolated from each other by Using switching arrangement, at a time, supply is given to one winding only and hence speed control is possible.

We have, $$N_r = N_s(1-s) \rightarrow N_r = \frac{120f}{P}(1-s)$$

2. A disadvantage of this method is that smooth speed control is not possible. This method is more costly and less efficient as two different stator windings are required. This method of speed control can only be applied for squirrel cage motor.

(d) Adding rheostat in the stator circuit :-

In this method of speed control of three phase induction motor, rheostat is added in the stator circuit due to which voltage gets dropped. In case of three phase induction motor torque produced is given by,

$$\rightarrow T \propto SV^2$$

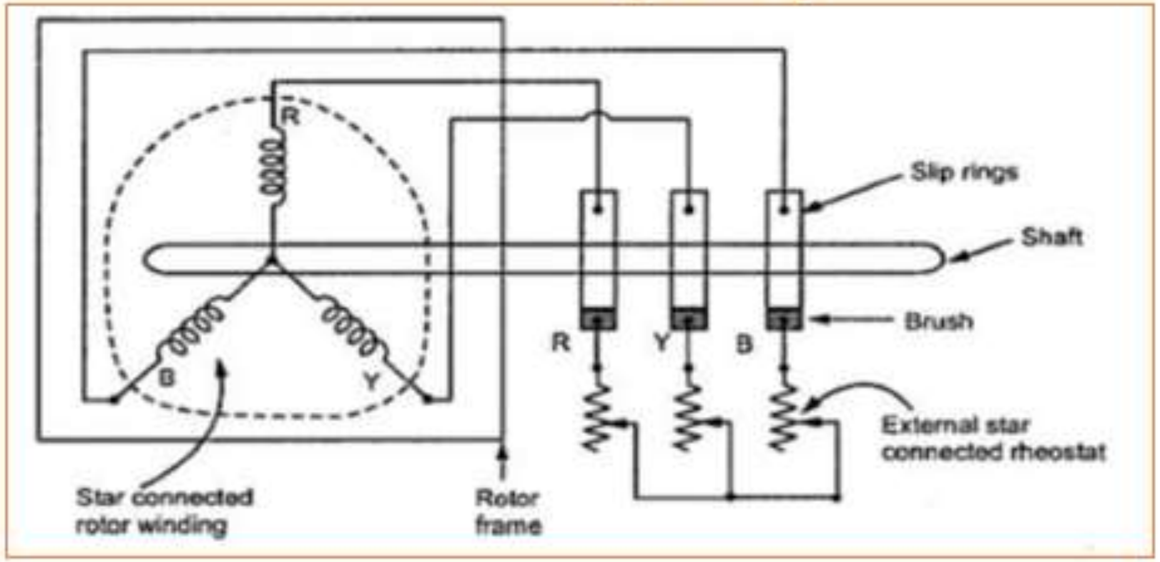
If we decrease supply voltage(V), torque will also decrease. But for supplying the same load, the torque must remain the same and it is only possible if we increase the slip and if the slip increase , motor will run with reduced speed.

Speed Control from Rotor side

(a) Adding external resistance on rotor side:-

1. In this method of speed control of 3-phase induction motor as shown in figure, the motor speed is reduced by introducing external resistance in the rotor circuit. We have,

$$T = \left(\frac{180}{2\pi N_S}\right) \times \frac{SE_2^2 R_2}{R_2^2 + (Sx_2^2)^2}$$



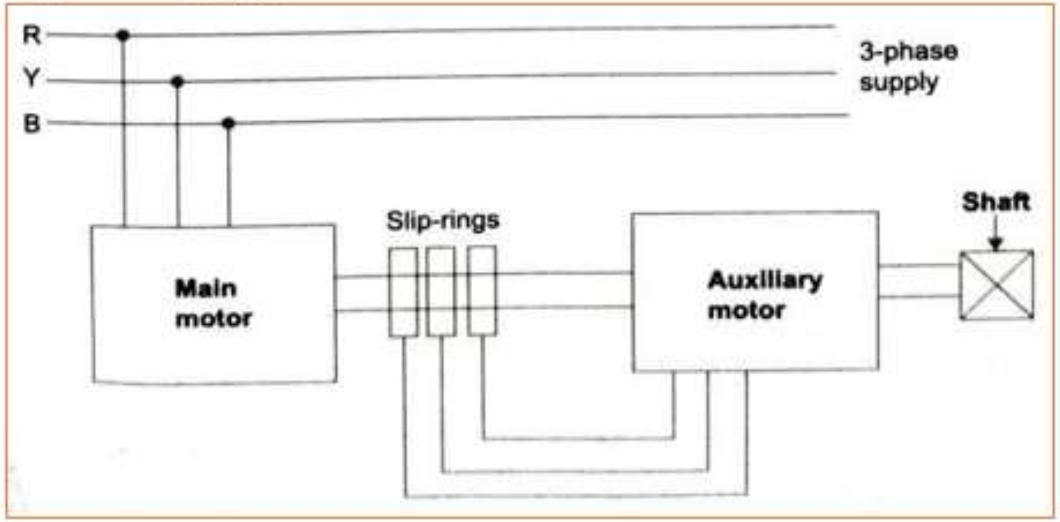
2. The 3-phase induction motor generally operates in low slip region. In low slip region, the term $(sx_2)^2$ becomes very small when compared to R_2. So, it can be neglected and also E_2 is constant. So the equation of torque after simplification becomes,

$$T_f \propto \frac{S}{R_2}$$

3. Now, if we increase rotor resistance **R2** ,torque decreases but to supply the same load, torque must remain constant. So we increase slip, which will further result in decrease in rotor speed. Thus, by adding additional resistance in rotor circuit we can decrease the speed of three phase induction motor.

(b). Cascade control method :-

1. In this method of speed control, the two 3-phase induction motors are connected on a common shaft and hence called cascaded method of control. One motor is called the main motor which should be slip ring type and another motor is called the auxiliary motor which can be slip ring type or squirrel cage type.



2. Let, Under no-load , the resultant speed of cascaded motor(N_R) is almost equal to synchronous (N_S)…..is given by

$$N_R = \frac{120f}{P_A + P_M}$$

where, P_M =poles of main motor , P_A=poles of Aux.motor

In this method , if the torque produced by the main and auxiliary motors act in same direction, then resulting in number of poles **(P_A+P_M).** Such type of cascading is called cumulative cascading. There is one more type of cascading in which the torque produced by the main motor is in opposite direction to that of auxiliary motor. Such type of cascading is called differential cascading; resulting in speed corresponds to number of poles **(P_A - P_M).**

3. In this method of speed control of 3-phase induction motor, four different speeds can be obtained as fallows,

- When only main induction motor works, having speed corresponds to .....$N_r = \frac{120f}{P_M}$
- When only auxiliary induction motor works, having speed Ns corresponds to .... $N_r = \frac{120f}{P_A}$
- When cumulative cascading is done, then the complete set runs at a speed of

$$N_R = \frac{120f}{P_A + P_M}$$

- When differential cascading is done, then the complete set runs at a speed of

$$N_R = \frac{120f}{P_A - P_M}$$

(c) Injecting 'slip frequency EMF' into rotor side:-

1. When the speed control of 3-phase induction motor is done by adding resistance in rotor circuit, some part of the power,

called the **slip power**, is lost as **I^2R** losses. This slip power be recovered and loss can supplied back in order to improve the overall efficiency of 3-phase induction motor and this scheme of recovering the power is called **slip power recovery scheme.**

2. The basic principle of slip power recovery scheme is to connect **an external source of Emf of slip frequency** to the rotor circuit. The injected Emf can either **oppose** the rotor induced Emf(**E_2**) or **aids** rotor induced Emf.

3. If it **opposes** the rotor induced Emf and hence speed decreases and if the injected Emf **aids** the main rotor Emf , hence speed increases. Therefore by injecting induced Emf in rotor circuit the speed can be easily controlled.

5. Temperature rise:-

The size of the motor and its rating which are used for selection for a drive mainly dependent upon the raise in temperature. The temperature raise in turn depends upon the type of insulation used.

The increase in temperature is mainly dependent on the following two factors:

6. Types of industrial loads :-

While selecting a motor, in addition to the information of load–speed–torque characteristics, the variation of load torque, losses, and temperature raise with time is also needed.

In case the load and torque verses time variation is periodic and repetitive, such one cycle of variation of load with time is known as **load or *duty cycle***. The various types of loads that occur in industrial practice can be classified depending upon their **variation with time** and **duty cycle**.

A) Classification of loads with respect to time.

B) Classification of loads with respect to duty cycle.

C) Classification of loads with respect to time:-

The loads are classified with respect to time as follows:

1. Continuous and constant loads:-

The loads on the motor operate for a long time under the same conditions.

Ex: fan, compressors, conveyors, centrifugal pumps, etc.

2. Continuous and variable loads:-

The load on the motor operates repetitively for a longer duration but varies continuously over a period.

Ex: metal cutting lathes, hoist winches, conveyors, etc.

3. Pulsating loads:-

The load on the motor which can be viewed as constant torque superimposed by pulsations in short duration..

Ex: Tile looms, reciprocating pumps, certain type of loads with crankshaft, frame saws, etc.

3. Impact loads:-

The load on the motor having regular and repetitive load peaks or pulses, i.e., load increases to a maximum level suddenly.

Ex: rolling mills, shearing machines, etc.

4. Short-time intermittent loads:-

The load on the motor occurs periodically in identically duty cycle, each duty cycle having a period of application of load and rest.

Ex: Roller trains, cranes, hoisting mechanisms, etc.

5. Short-time loads:-

The load on the motor occurs periodically remains constant for short time and then remains idle or off for longer time.

Ex: servomotors, motor–generator sets, used for charging batteries, drilling machines, etc.

B) Classification of loads with respect to duty cycle:-

There are three basic classifications of duties of an electric motor. ….They are:

1. Continuous duty cycle.
2. Short-time duty cycle.
3. Intermittent duty cycle.

1. Continuous duty :-

Continuous duty is the duty when the on-period is so long that the motor attains a steady-state temperature raise. The motor so selected should be able to withstand momentary overload capacity.

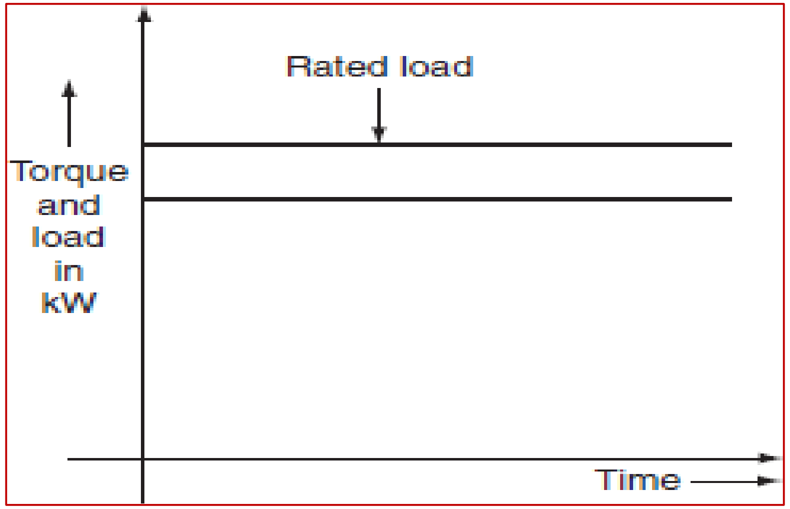
This type of motors will have high efficiency because they will be operating almost at its full load and also have good power factor.

There are mainly two types of continuous duty cycle. They are:

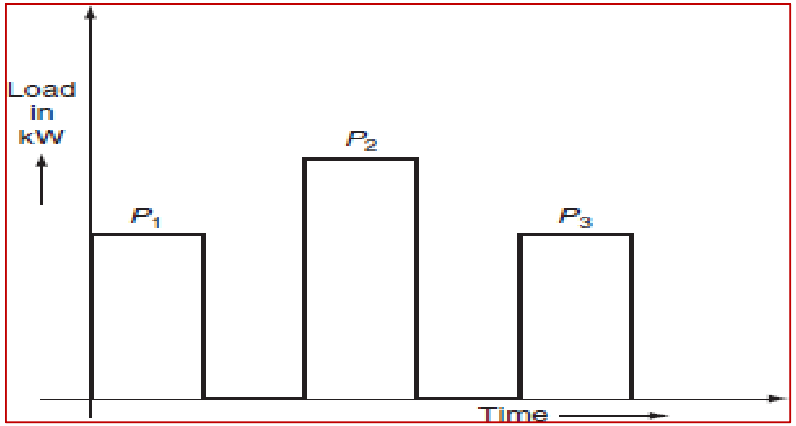
a) Continuous duty at constant load cycle.

b) Continuous duty at variable load cycle.

In continuous duty with **constant load cycle**, the load torque remains constant for a sufficiently longer period. The variation of torque against time for continuous duty is shown in



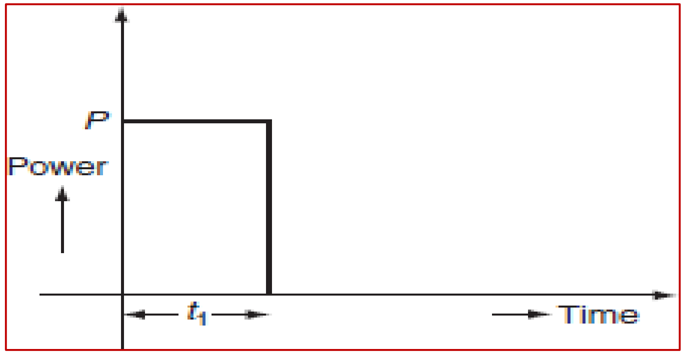
In continuous duty with **variable load cycle**, the load on the motor is not constant, but it has several phases in one cycle. The variation of load against time for variable load cycle is shown in Figure.



The selection of motor for this type of duty involves thermal calculation, which is a difficult task. The motors operating for such type of duties will have poor efficiency and also poor power factor.

2. Short-time duty :-

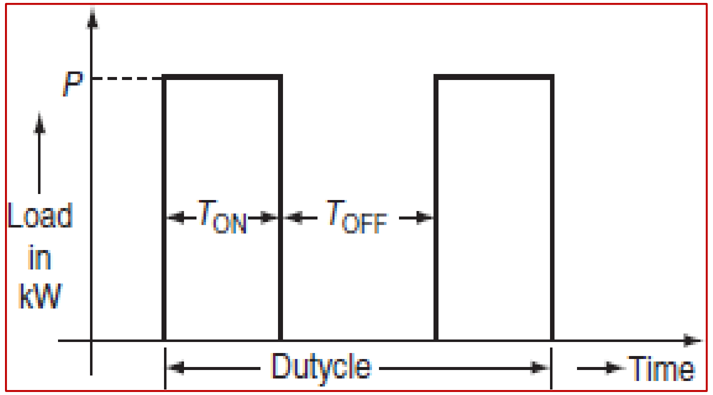
In this type of duty, the load occurs on the motor during a small interval and the remains idle for long time to re-establish the equality of temperature with the cooling medium. The variation of the load against time for short-time duty is shown in Fig.



Usually, such type of short-time duty occurs in bridges, lock gates, and some other household appliances such as mixies.

3. Intermittent duty :-

The duty in which load on the motor varies periodically in a sequence of identical cycles shown in Figure in which motor is loaded for sometimes **'ton'** and shut off for a period of **'toff'**.



Motor heats during 'on' period 'ton' and cools down during 'off' period 'toff'. The ratio of 'ton' to (ton + toff) is known as ***duty ratio.***

$$duty\,ratio = \frac{t_{on}}{t_{on} + t_{off}}$$

UNIT-II: Electric Heating & Electric Welding

1. Electric Heating.
2. Methods of Electric Heating.
3. Resistance Heating.
4. Induction Heating.
5. Dielectric Heating.
6. Electric welding.
7. Resistance welding.
8. Electric Arc welding.
9. Comparison between Resistance and Arc Welding.
10. Comparison between A.C. and D.C. Welding

Heat plays a major role in everyday life. All heating requirements in domestic purposes such as cooking, room heater, immersion water heaters, and electric toasters and also in industrial purposes such as welding, melting of metals, tempering, hardening, and drying can be met easily by electric heating, over the other forms of conventional heating.

Heat and electricity are interchangeable. Heat also can be produced by passing the current through material to be heated. This is called electric heating; there are various methods of heating a material but electric heating is considered far superior compared to the heat produced by coal, oil, and natural gas.

Advantages of Electric Heating

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

1.Economical:

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

2.Cleanliness:

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

3. 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.

4. Ease of control:

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

5. Uniform heating:

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

6. 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.

7. Automatic protection:

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

8. 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

9. Better working conditions:

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

10. Less floor area:

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

11. High temperature:

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

12. Safety:

The electric heating is quite safe.

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.

1. Conduction:-

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.

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

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 convection of heat depends mainly on the difference in the fluid density at different temperatures.

Ex: Immersion water heater.

3. Radiation:-

In this mode, the heat transfers from source to the substance to be heated without heating the medium in between. It is dependent on surface.

Ex: Solar heaters.

Essential Requirements of Good Heating Element

The **materials used** for heating element should have the following properties:

- ✓ High-melting point.
- ✓ Low temperature coefficient of resistance.
- ✓ Free from oxidation.
- ✓ High-mechanical strength.
- ✓ Non-corrosive.
- ✓ Economical.
- ✓ High-specific resistance.

Causes of Failure of Heating Elements

Heating element may fail due to any one of the following reasons.

1. Formation of hot spots.
2. Oxidation of the element and intermittency of operation.
3. Embrittlement caused by gain growth.
4. Contamination and corrosion.

Material for Heating Elements

S. No.	Type of alloy	Composition	Commercial name	Max. operating temperature	Resistivity at 20°C	Specific gravity
1	Nickel chromium (Ni–Cr)	80% Ni 20% Cr	Nichrome	1,150°C	1.03 μΩ-m	8.35
2	Nickel chromium iron (Ni–Cr–Fe)	60% Ni 16% Cr 24% Fe	—	950°C	1.06 μΩ-m	8.27
3	Nickel Copper (Ni–Cu)	45% Ni 55% Cu	Eureka or constantan	400°C	0.49 μΩ-m	8.88
4	Iron chromium aluminum (Fe–Cr–Al)	70% Fe 25% Cr 5% Al	Kanthal	1,200°C	1.4 μΩ-m	7.20

2. 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.

2.1. Resistance Heating

When the electric current is made to pass through a high-resistive element, a power loss($P_L = I^2R$) takes place in it, which results in the form of heat energy.

Applications: This method of heating has wide applications such as drying, baking of potteries, commercial and domestic cooking, and the heat treatment of metals such as annealing and hardening. In oven where wire resistances are employed for heating, temperature up to about 1,000°C can be obtained.

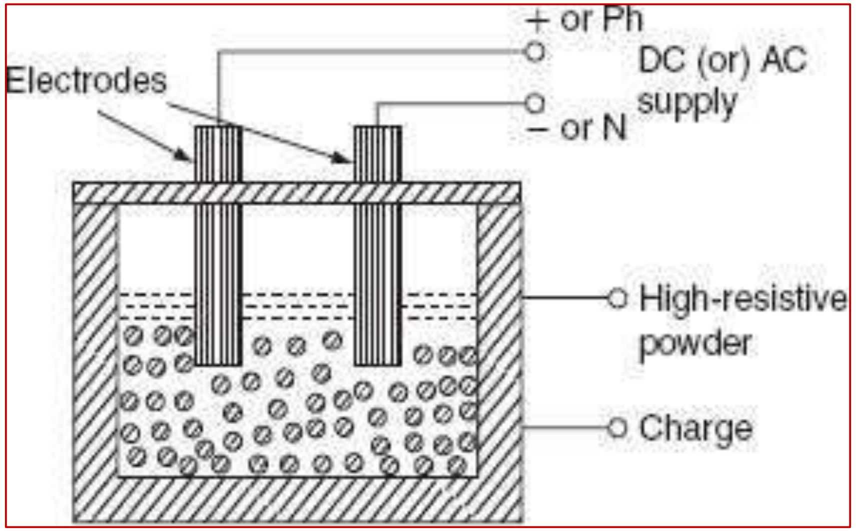
The resistance heating is further classified as:

1. Direct Resistance heating.
2. Indirect Resistance heating.
3. Infrared (or) Radiant heating.

1. Direct Resistance heating:-

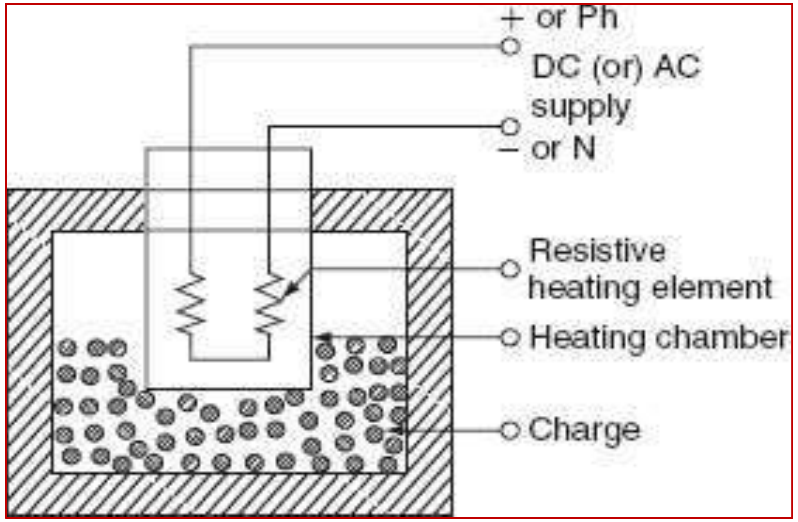
In this method, electrodes are immersed in a material or charge to be heated. The charge may be in the form of powder, pieces, or liquid. The electrodes are connected to AC or DC supply as shown in Figure. In case of DC or 1-φ AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3-φsupply.

The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency. As the current in this case is not variable, so that automatic temperature control is not possible. This method of heating is employed in salt bath furnace and electrode boiler for heating water. **(Q=I^2.R.t)**



2. Indirect Resistance heating:-

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 Figure. 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.



This arrangement provides uniform temperature and automatic temperature control. Generally, this method of heating is used in immersion water heaters, room heaters, and the resistance ovens used in domestic and commercial cooling and salt bath furnace.

3. Infrared (or) Radiant heating:-

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

In the radiant heating, the heating element consists of tungsten filament lamps together with reflector and to direct all the heat on the charge. Tungsten filament lamps are operating at 2,300°C instead of 3,000°C to give greater portion of infrared radiation and a longer life. The 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.

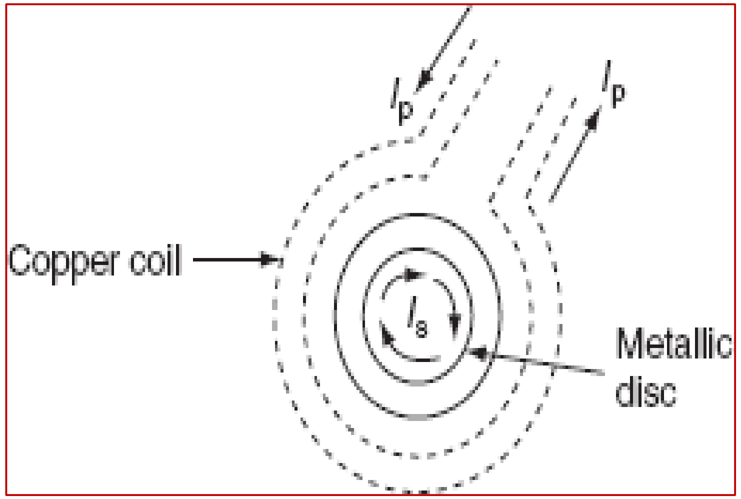
The radiant heating is mainly used for drying enamel or painted surfaces. The main advantage of the radiant heating is that the heat absorption remains approximately constant whatever the charge temperature.

2.2. 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

$$\text{(Power drawn} = \frac{V^2}{R}\text{)},$$

which is possible only with the metals, 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.



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.

There are basically two types of **induction furnaces** and they are:

1. Core type (or) Low-frequency induction furnace.

2. Coreless type (or) High-frequency induction furnace.

1. Core type Induction furnace:-

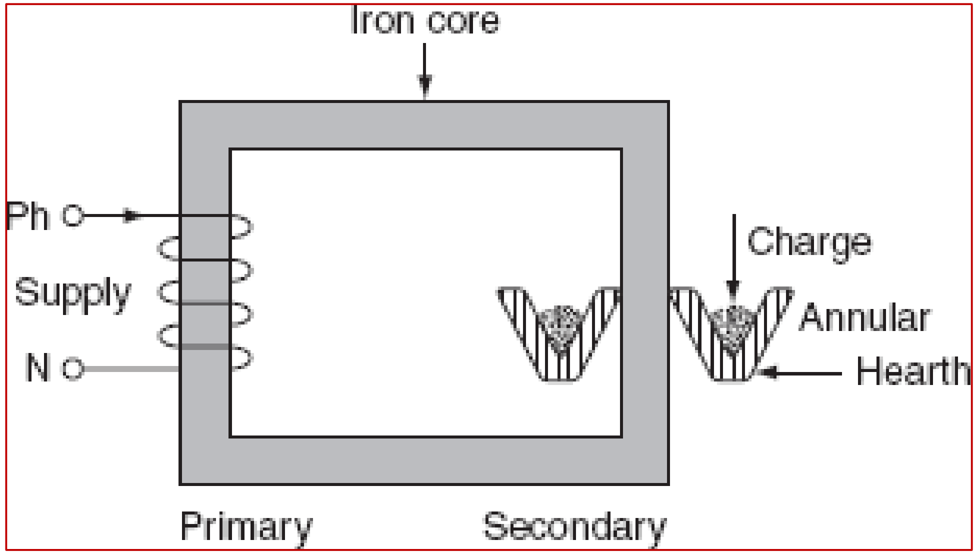
The operating principle of the core type furnace is the electromagnetic induction. This furnace is operating just like a transformer. It is further classified as:

a) Direct core type.

b) Vertical core type.

c) Indirect core type.

a). Direct core type:



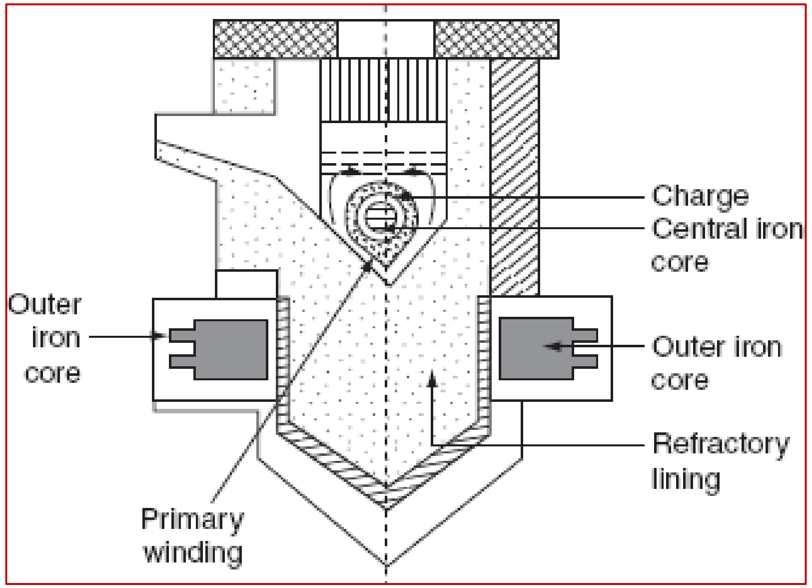
The core type furnace is essentially a core type transformer in which the charge to be heated forms single- turn secondary circuit and is magnetically coupled to the primary by an iron core as shown in Figure. The furnace consists of a circular hearth in which the charge to be melted in the form of an annular ring. Main Draw back is ***pinch effect.***

b). Vertical core type:

It is an improvement(from Pinch effect) over the direct core type furnace, This type of furnace consists of a vertical core(shell type) instead of horizontal core as shown in Figure. It is also known as ***Ajax–Wyatt induction furnace.***

The Primary winding is connected to 600V,50Hz, AC supply, then flux will generate in the V-shaped core, hence current will pass in secondary winding(molten metal) where charge is melted. Here heat transfer is done by Convection method.

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.

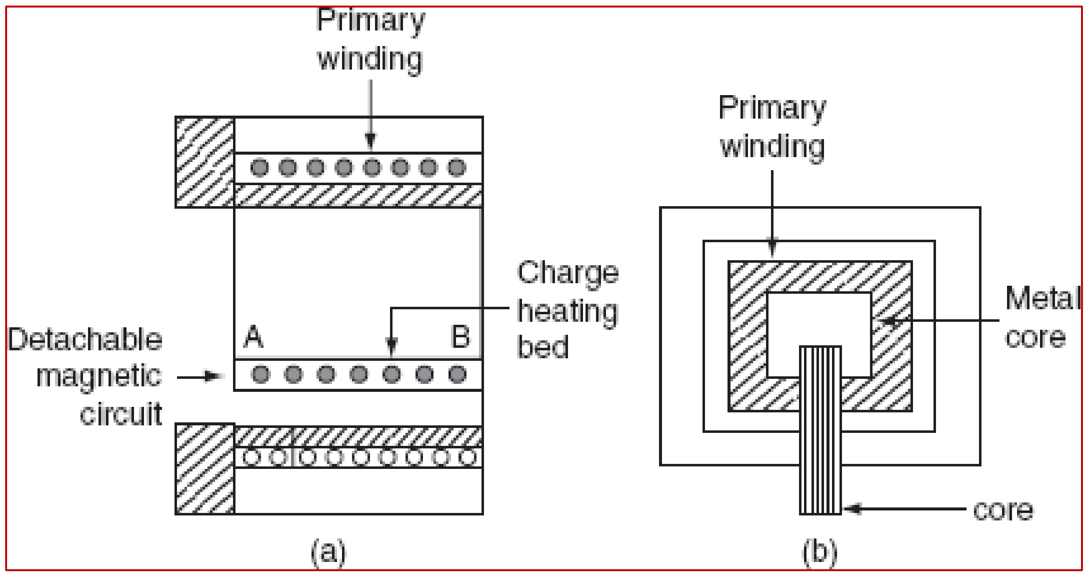


c). Indirect core type:

This type of furnace is used for providing heat treatment to metals.The secondary winding itself forms the walls of the container or furnace and an iron core links both primary and secondary windings.

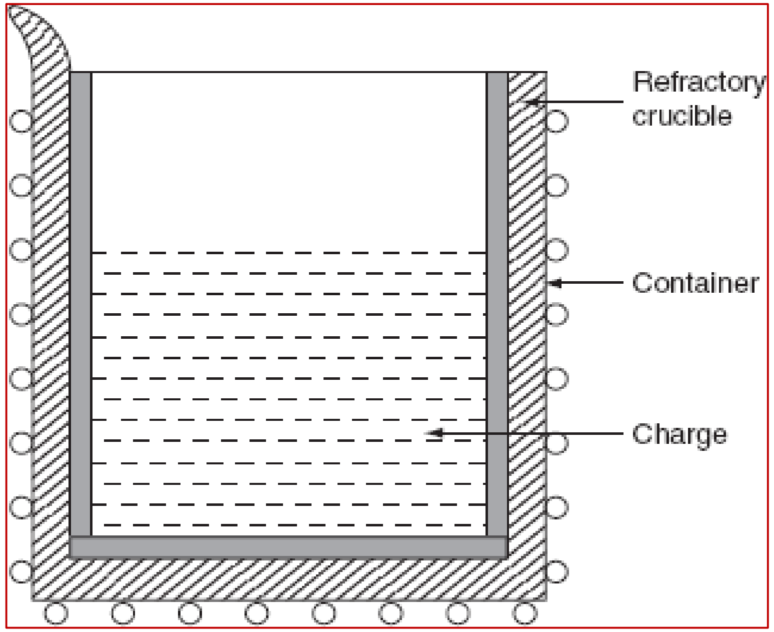
When primary is connected to AC supply currents are induced in the metal made furnace, and heat is transferred to charge to be heated by Radiation. The main advantage of such furnace is wide variation of temperature control is possible .?

When the furnace reaches to critical temperature, the reluctance of the magnetic circuit increases many times and the inductive effect decreases thereby cutting off the supply heat. Thus, the temperature of the furnace can be effectively controlled.



2. Core Less type Induction furnace:-

It is a simple furnace with the absence core is shown in Figure. In this furnace, heat developed in the charge due to eddy currents flowing through it. The furnace consists of a refractory crucible cylindrical in shape enclosed within a coil that forms primary of the transformer. The furnace also contains a conducting or non- conducting container(charge to be placed) that acts as secondary.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. The eddy currents developed in any magnetic circuit gives ***Eddy current loss*** causes ***Heating of charge[H](metal)*** given by :



$$W_e \propto B_m^2 f^2 \quad \& \quad H=[(w \times S \times \Delta T)+(w \times l)]$$

w=weight of charge, **S**=Specific heat , ***l***=Latent Heat required

where ***Bm*** is the maximum flux density (tesla), ***f*** is the frequency in (Hz), and ***We*** is the eddy current loss (watts). The selection of a suitable frequency of the primary current can be given by penetration formula. According to this:

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

Where d=depth of charge, ρ=resistivity of the material. μ= the permeability of the material

Following are the advantages of coreless furnace over the other furnaces:

- ✓ Ease of control.
- ✓ Oxidation is reduced, as the time taken to reach the melting temperature is less.
- ✓ The 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.

2.3. Dielectric Heating

When non-metallic materials i.e., insulators such as wood, plastics, and China glass are subjected to high-voltage alternating electric field, the atoms get stresses, and due to interatomic friction caused by the repeated deformation and the rotation of atomic structure **(polarization),** heat is produced. This is known as dielectric loss, causes dielectric heating.

Dielectric loss is ...... $P_L = V.\,I.\,Cos\emptyset = VI_R$

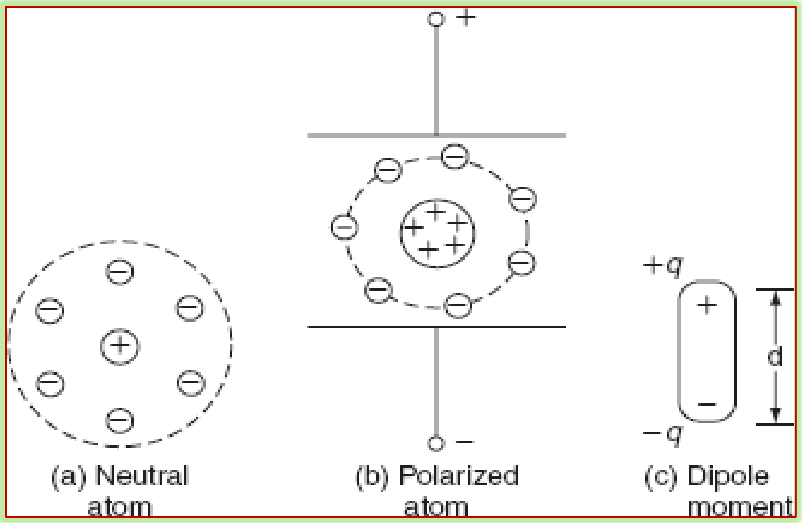
We have .... $Tan\delta = \frac{I_R}{I_C}$

$$P_L = V.I_R = V.I_C.Tan\delta$$

$$P_L = V.\left(\frac{V}{X_C}\right).Tan\delta$$

$$P_L = V^2.wc.Tan\delta$$

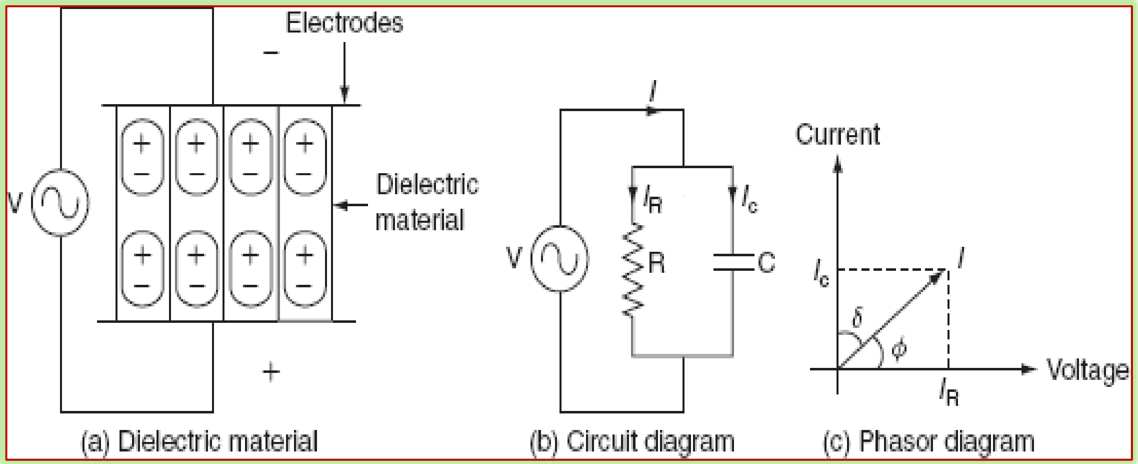
$$P_L = V^2.(2\pi f).\left(\frac{\epsilon_0.\epsilon_R.A}{d}\right).Tan\delta$$



(a) Neutral atom (b) Polarized atom (c) Dipole moment

From the above Eq……

$P_L \propto V^2$ & $P_L \propto f$



(a) Dielectric material (b) Circuit diagram (c) Phasor diagram

3. Electric welding

Electric Welding 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.

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 workpiece.
- ✓ Skilled welding is necessary to produce good welding.

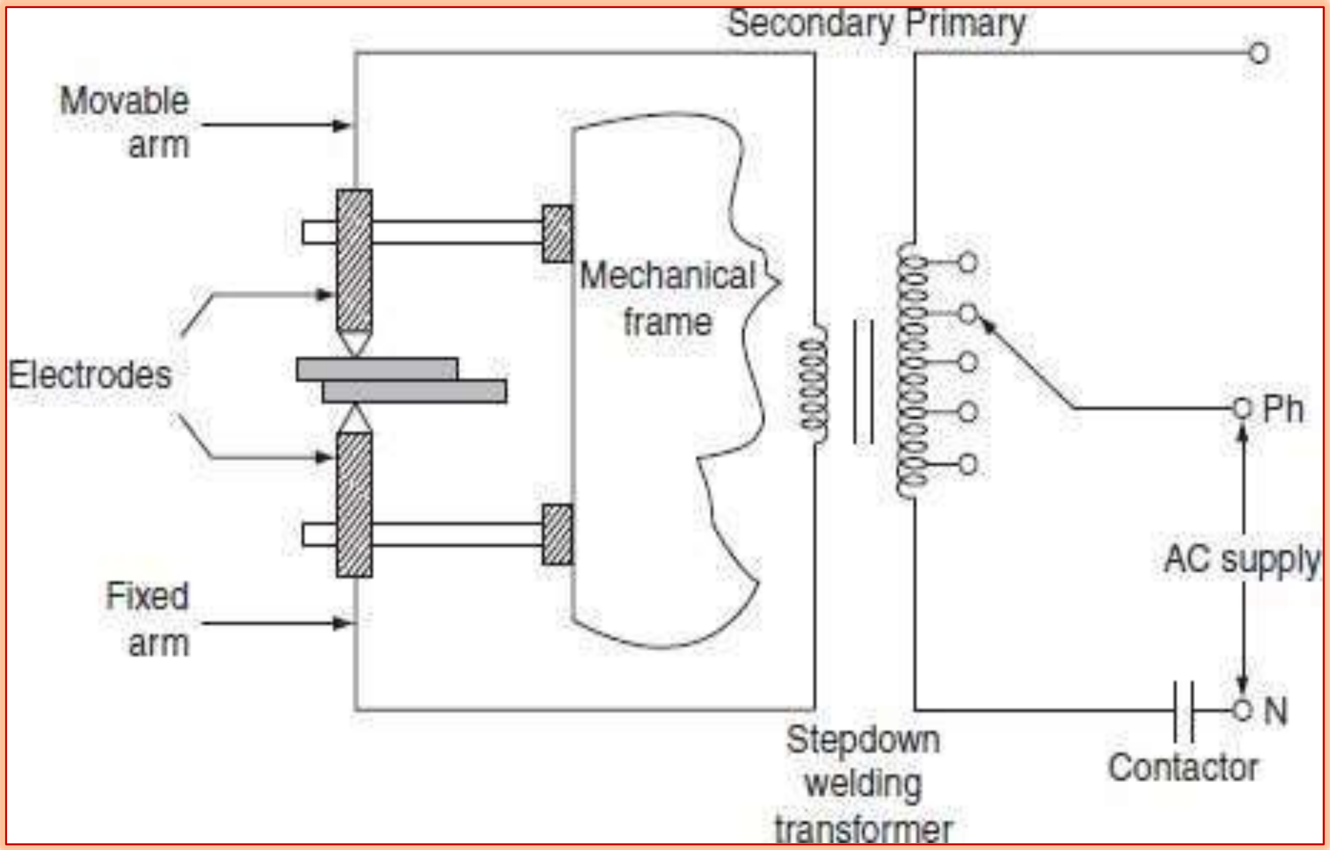
1. **Resistance welding.**
2. **Arc welding.**

3.1. 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:

$$H = I^2 . R . t$$

where I is the current through the electrodes, ***R* is the contact resistance of the interface,** and ***t*** is the time for which current flows.



Advantages:

- Welding process is rapid and simple.
- No need of using filler metal. E.g.:(tin, lead, silver, lead- free, cadmium-free, copper, aluminium, nickel, and gold.)
- Both similar and dissimilar metals can be welded.
- Comparatively lesser skill is required.
- It can be employed for mass production.

drawbacks:

- ✓ Initial cost is very high.
- ✓ High maintenance cost.
- ✓ The workpiece with heavier thickness cannot be welded, since it requires high input current.

Applications:

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

Types of Resistance Welding

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

3.1. Spot welding.

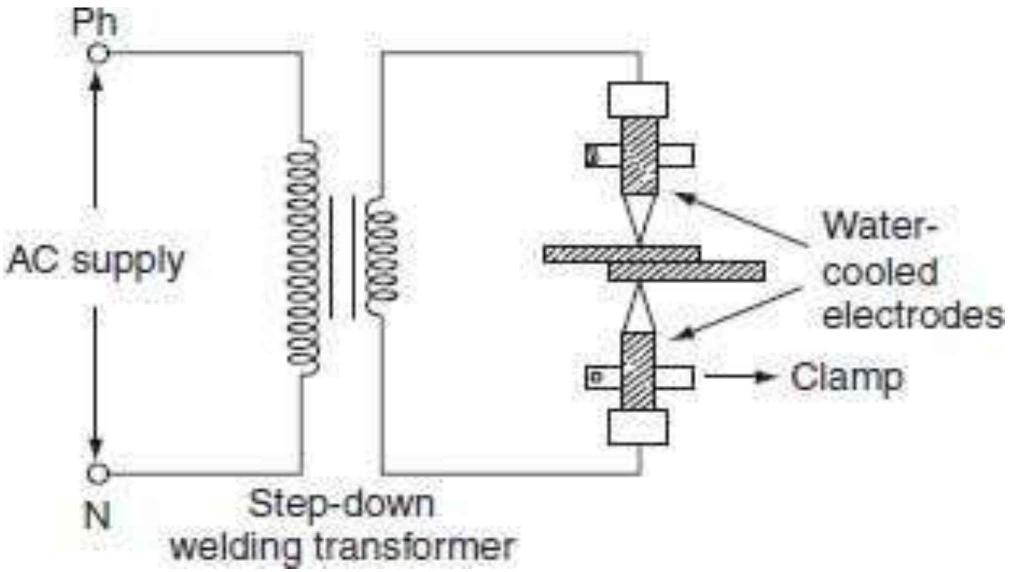
3.3 Projection welding.

3.2. Seam welding.

3.4. Butt welding.

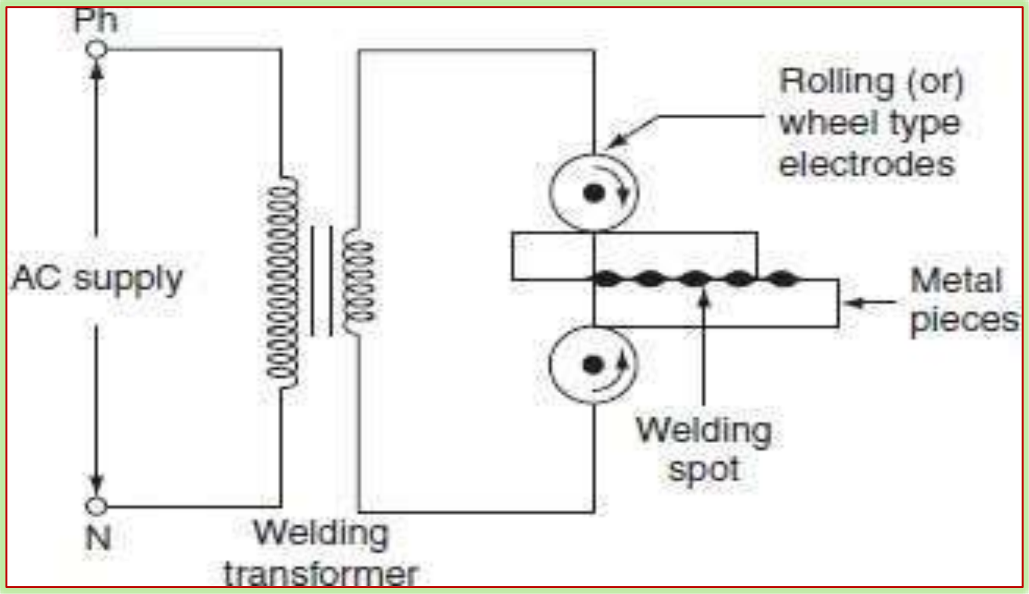
1. Spot welding:

- Spot welding means the joining of two metal sheets and fusing(blend) them together between copper electrode tips at suitably spaced intervals by means of heavy electric current passed through the electrodes as shown in Figure.
- The electrodes are made up of copper or copper alloy and are water cooled. The welding current varies widely depending upon the thickness and composition of the plates. It varies from 1,000 to 10,000 A, and voltage between the electrodes is usually less than 2 V.
- 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.



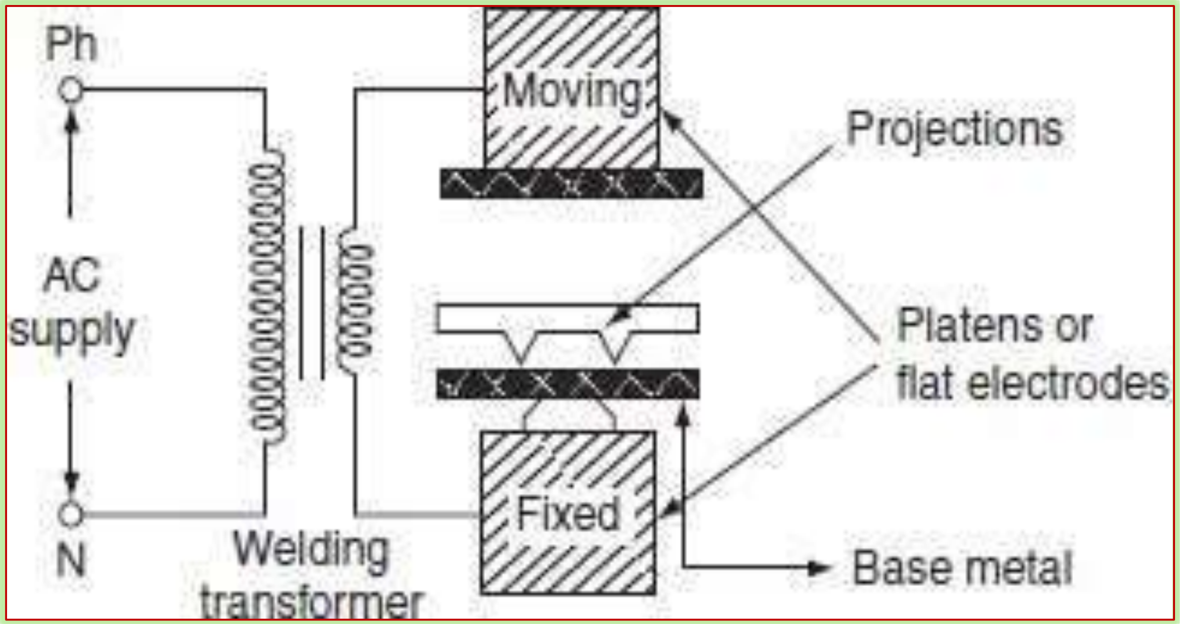
3.2. Seam welding:

- 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 Figure. 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.



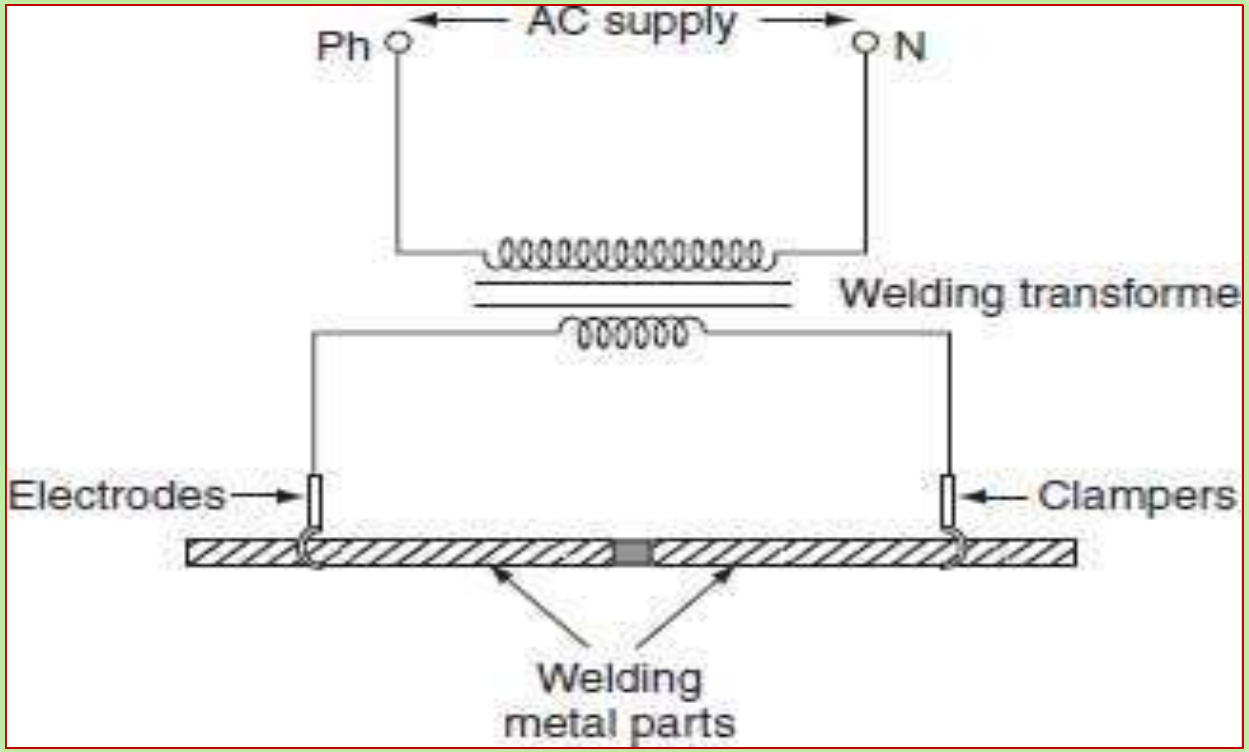
3.3. Projection welding:

- ✓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 metals to be weld are held together in between the two platens, one is movable and the other is fixed, as shown in Figure.



4. Butt welding:

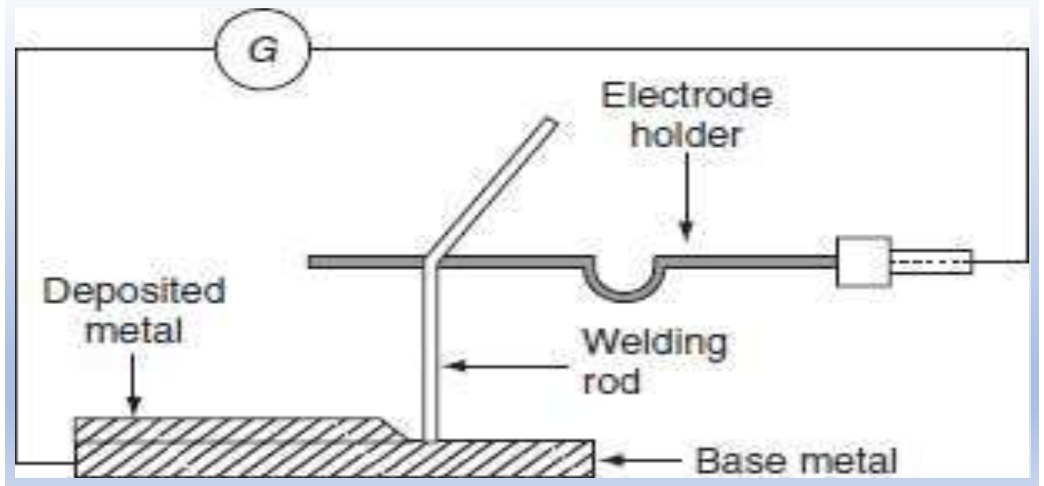
Butt welding is similar to the spot welding; however, the only difference is, in butt welding, instead of electrodes the metal parts that are to be joined or butted together are connected to the supply.



3.2. Electric Arc welding:

Electric arc welding is the process of joining two metallic pieces or melting of metal is obtained due to the heat developed by an arc struck between an electrode and the metal to be welded or between the two electrodes as shown in Figure. The heat so developed is utilized to melt the part of workpiece and filler metal and thus forms the weld. In this method of welding, no mechanical pressure is employed; therefore, this type of welding is also known as **"Non-Pressure welding".**

For the arc welding, the temperature of the arc should be 3,500°C. At this temperature, mechanical pressure for melting is not required. Both AC and DC can be used in the arc welding. Usually 70–100 V on AC supply and 50–60 V on DC supply system is sufficient to struck the arc in the air gap between the electrodes. Once the arc is struck, 20–30 V is only required to maintain it.

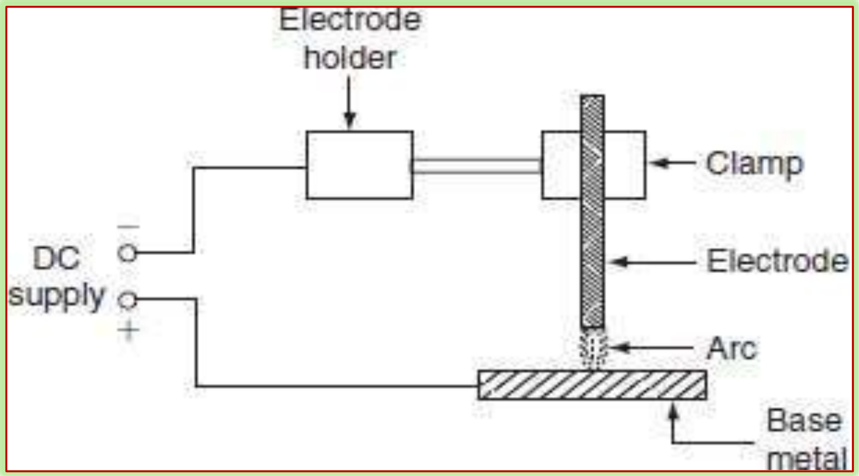


Various types of electric arc welding are:

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

3.2.1. 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 Figure.



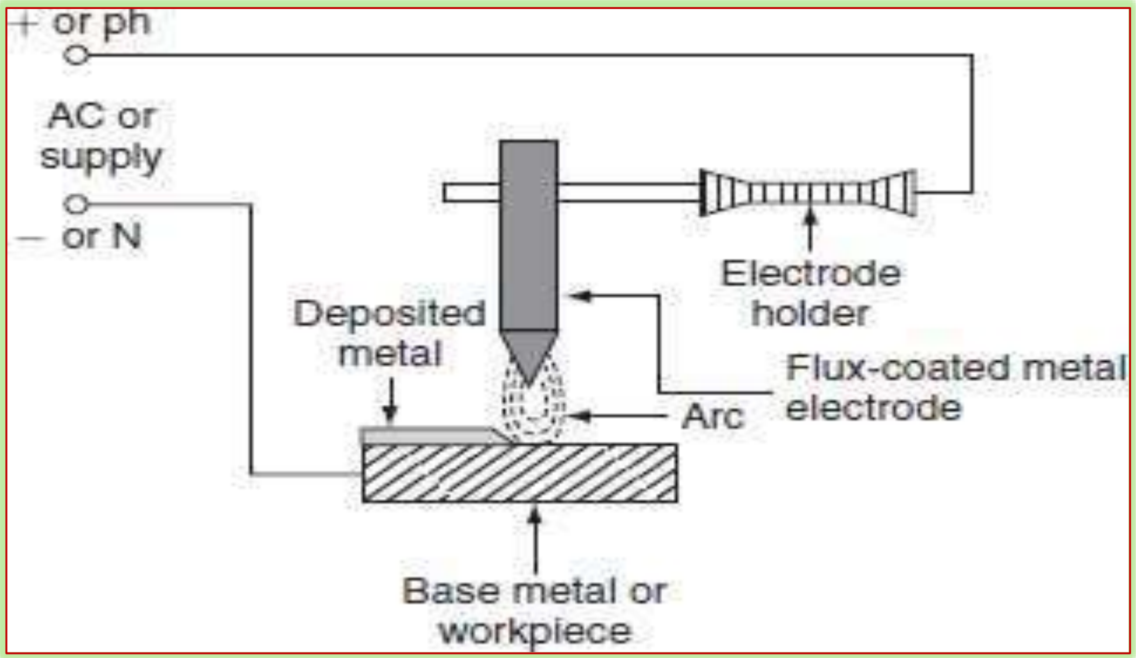
In this process of welding, the electrodes are placed in an electrode holder used as negative electrode and the base metal being welded as positive. DC is preferred for carbon arc welding since there is no fixed polarity maintained in case of AC.

3.2.2. Metal arc welding:

In metal arc welding, the electrodes used must be of the same metal(Flus coated with chemical) 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 workpieces to be welded and withdrawn apart. The circuit diagram for the metal arc welding is shown in Figure. The arc produced between the workpiece and the electrode results high temperature of the order of about 2,400°C at negative metal electrode and 2,600°C at positive base metal or workpiece.

This high temperature of the arc melts the metal as well as the tip of the electrode, then the electrode melts and deposited over the surface of the workpiece, forms complete weld.

Both AC and DC can be used for the metal arc welding. The voltage required for the DC metal arc welding is about 50–60 V and for the AC metal arc welding is about 80–90 V.



3.2.3. Atomic hydrogen arc welding:

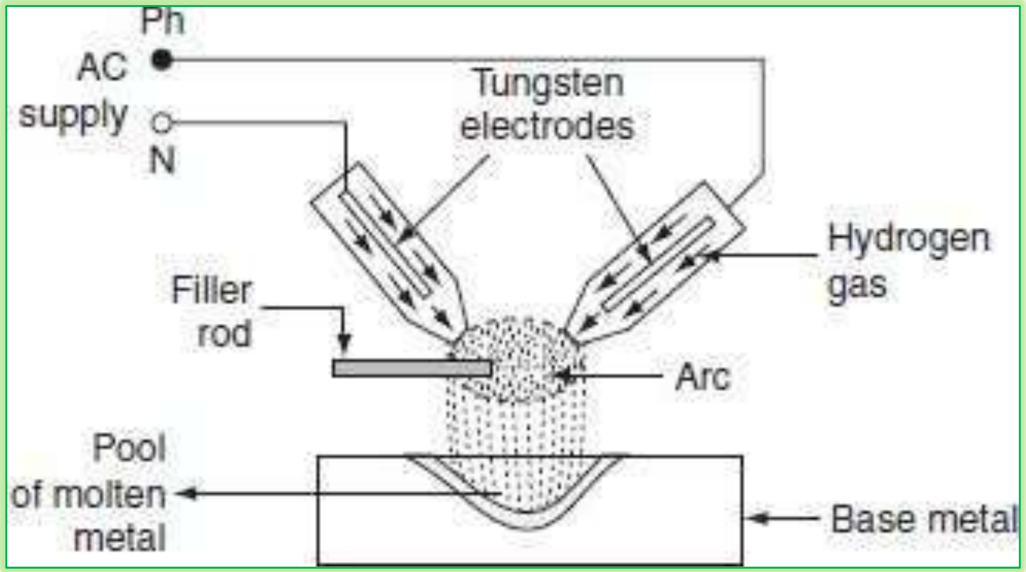
In atomic hydrogen arc welding, shown in Figure, the heat for the welding process is produced from an electric arc struck between **two tungsten electrodes in an atmosphere of hydrogen.**

Here, hydrogen serves mainly two functions;

--- Firstly, acts as a protective screen for the arc and

--- Secondly, it acts as a cooling agent for the glowing tungsten electrode tips.

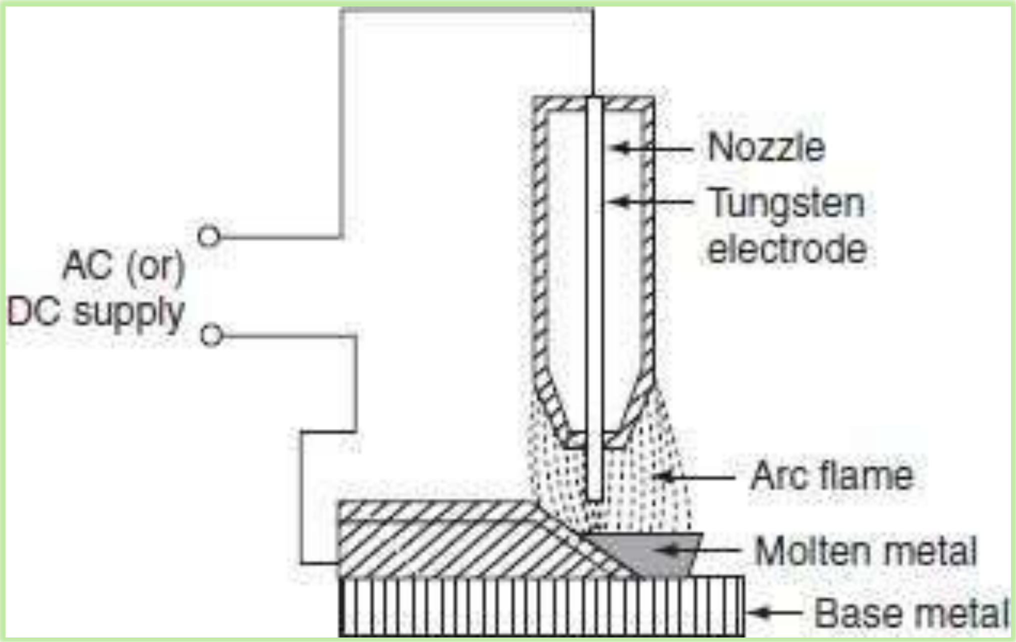
As the hydrogen gas passes through the arc, the hydrogen molecules are broken up into atoms, absorbs heat from the glowing tungsten electrodes so that these are cooled.



3.2.4. Inert gas metal arc welding:

It is a gas-shielded metal arc welding, in which an electric arc is stuck **between tungsten electrode** and workpiece to be welded. 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 Figure.

As both beryllium and argon are chemically inert, so the molten metal is protected from taking part in to chemical reaction. 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.



3.2.5. Submerged arc welding:

In Submerged Arc Welding, the arc is established between above metal electrode and the workpiece. Electric arc and molten pool are **shielded by blanket of granular flux** on the workpiece. The flux may be made of silica, metal oxides, and other compounds fused together and then crushed to proper size.

Initially to start an arc, **short circuit path** is provided by introducing steel wool(?).. between the welding electrode and the workpiece. This is due to the coated flux material, when cold it is non-conductor of the electricity but in molten state, it is highly conductive.

Welding zone is shielded by a blanket of flux, so that the **arc is not visible.** Hence, it is known as ***'submerged arc welding'.*** As the arc in progress, the melted electrode metal forms globules and mix up with the molten base metal, so that the weld is completed.

4. Comparison between Resistance and Arc Welding:

Resistance welding	Arc welding
1. The source of supply is AC only.	The source of supply is either AC (1-φ or 3-φ) or DC.
2. The heat developed is mainly due to the flow of contact Resistance.	The heat developed is mainly due to the striking of arc between electrodes or an electrode and the workpiece.
3.The temperature attained by the workpiece is not so high.	The temperature of the arc is so high, so proper care should be taken during the welding.
4. External pressure is required.	No external pressure is required hence the welding equipment is simpler and easier to control.
5. Filler metal is not required to join two metal pieces.	Suitable filler electrodes are necessary to get proper welding strength.
6. It cannot be used for repair work; it is suitable for mass production.	It is not suitable for mass production. It is most suitable for repair works and where more metal is to be deposited.

5. Comparison between A.C. and D.C. Welding:

AC welding	DC welding
1. Motor -Generator set or Rectifier is required in case of the availability of AC supply.	Only Transformer is required.(For momentarily Transient current).
2. The cost of the equipment is high.	The cost of the equipment is cheap.
3. Arc stability is more.	Arc stability is less.
4. The heat produced is uniform.	The heat produced is not uniform.
5. Both bare and coated electrodes can be used.	Only coated electrodes should be used.

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UNIT – III : ILLUMINATION

1) Introduction.
2) Terms used in illumination.
3) Laws of illumination.
4) Polar curves.
5) Photometry.
6) Various illumination Methods.
7) Comparison betweentungsten filament Lamps and fluorescent tubes.
8) Basic principles of light control.
9) Types and design of lighting Schemes.
10) Flood lighting.

1) 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.

Nowadays, 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.

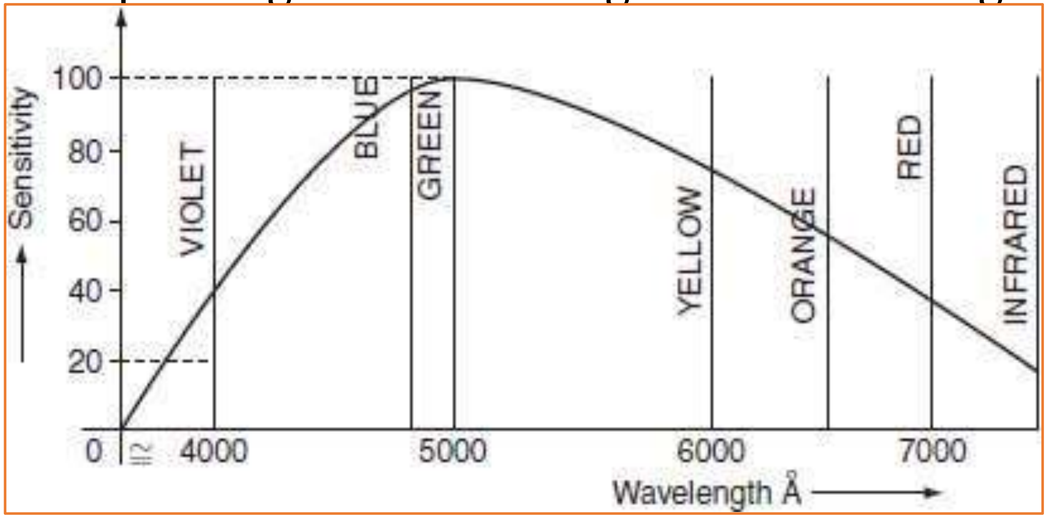
Light is a form of electromagnetic energy radiated from a body and human eye is capable of receiving it. Light is a prime factor in the human life as all activities of human being ultimately depend upon the light.

2) Terms used in illumination:

The following terms are generally used in illumination.

The energy radiation of the heated body is **monochromatic,** i.e. the radiation of only one wavelength emits specific color. The wavelength of visible light lies between

4,000 and 7,500 Å. The color of the radiation corresponding to the wavelength is shown in Figure.



2. Relative sensitivity:

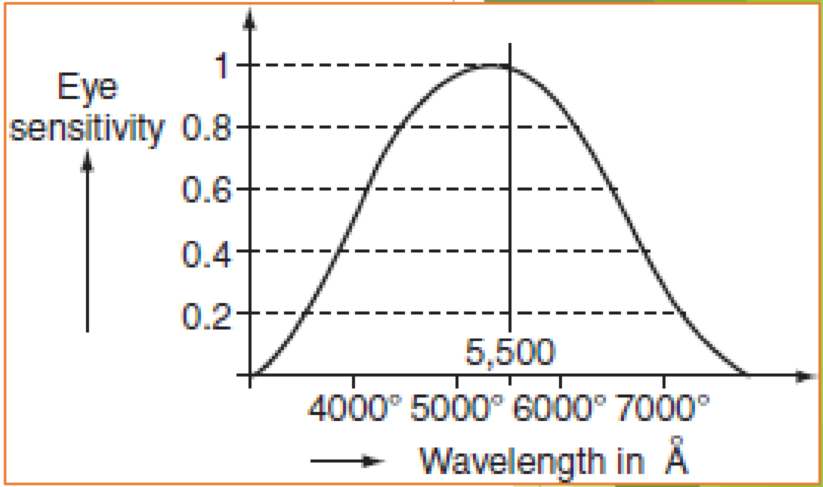
The reacting power of the human eye to the light waves of different wavelengths varies from person to person, and also varies with age. The average relative sensitivity is shown in the Figure. The eye is most sensitive for a wavelength of 5,500 Å. So that, the relative sensitivity according to this wavelength is taken as **unity.**

Blue and violet corresponding to the short wavelengths and red to the long wavelengths, orange, yellow, and green being in the middle of the visible region of wavelength.

The color corresponding to 5,500 Å is not suitable for most of the applications since yellowish green. The relative sensitivity at any particular wavelength (λ) is known as relative luminous factor **($K\lambda$).**

3. Light: (*Q*)

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*'.**



4. Luminous flux: (φ)

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

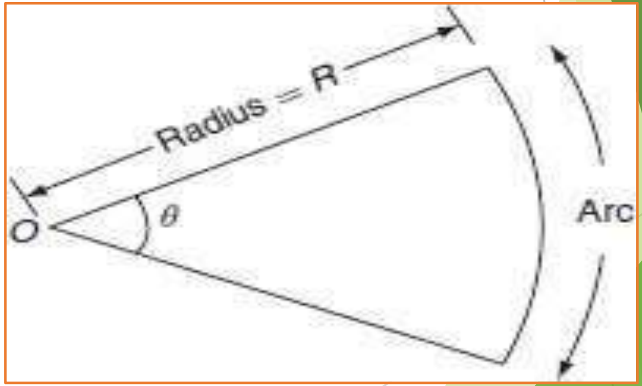
5. Radiant efficiency:

When an electric current is passed through a conductor, some heat is produced to I^2R loss, which increases its temperature of the conductor. At low temperature, conductor radiates energy in the form of heat waves, but at very high temperatures, radiated energy will be in the form of light as well as heat waves.

'Radiant efficiency' is defined as the ratio of energy radiated in the form of light, produces sensation of vision to the total energy radiated out by the luminous body'.

6. Plane angle:(θ)

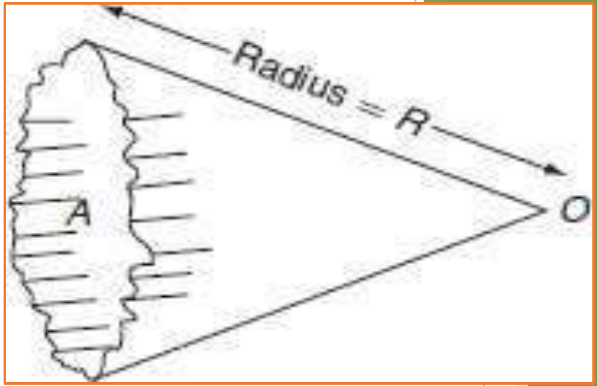
A plane angle is the angle subtended at a point in a plane by two converging lines as shown in Figure.. It is denoted by the letter **'θ' (theta)** and is usually measured in degrees or radians.



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

7. Solid angle:(ω)

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. It is usually denoted by symbol 'ω' and is measured in steradian.($\boldsymbol{\omega}$= **4π** : is maximum for sphere)



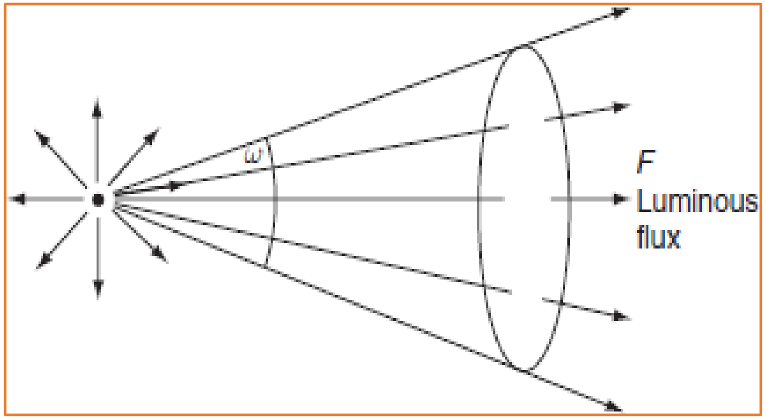
$$Solid\ angle(\omega) = \frac{Area}{(radius)^2}$$)

The Relationship between plane angle and solid angle is

$$\boldsymbol{Solid\ angle(\omega) = 2\pi \times [1 - \cos\theta]}$$

8. Luminous intensity:(I)

Luminous intensity in a given direction is defined as the **luminous flux emitted by the source per unit solid angle** as shown in the figure.It is denoted by the symbol ' *I* ' and is usually measured in **'candela'.** The figure shows Luminous flux emitting from the source.



9. Lumen:

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

Lumen = candle power of source × solid angle.

Lumen = CP × ω

Total(max) flux emitted by a source of one candle power is **'4π' lumens.**

10. Candle power (CP):

The CP of a source is defined as the total luminous flux lines emitted by that source per unit solid angle, is measured in lumen/steradian or **candela.**

$$CP = \frac{Lumen}{\omega}$$

11. Illumination: (E)

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 candle (or) foot candle.

$$Illumination, E = \frac{Luminous\ flux}{area}$$

$$E = \frac{\varphi}{A} = \frac{CP \times \omega}{A}$$

12. Lux (or) meter candle:

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

13. 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 $= \frac{1 Lumen}{(ft)^2}$

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

1 foot candle = 10.76 *lux (or) m − candle*

14. Brightness:(L)

Brightness of any surface is defined as the **luminous intensity pen unit surface area** of the projected surface in the given direction. It is usually denoted by symbol **'L'.**

If the luminous intensity of source be 'I' candela on an area A, then the projected area is Acosθ.

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

15. Relation between I, E, and L :

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

$$\text{we have Brightness}, \mathbf{L} = \frac{\mathbf{I}}{\mathbf{A}} = \frac{\mathbf{I}}{\pi r^2}$$

$$\text{Illumination}, \mathbf{E} = \frac{\varphi}{\mathbf{A}} = \frac{\mathbf{I} \times \omega}{\mathbf{A}}$$

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

$$\text{we have}, \mathbf{E} = \frac{\mathbf{I}}{r^2} = \frac{\mathbf{I} \times \pi}{r^2 \times \pi} = \pi \mathbf{L}$$

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

16. Mean horizontal candle power (MHCP):

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

17. Mean spherical candle power (MSCP):

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

18. Mean hemispherical candle power (MHSCP):

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

19. 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.

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

20. Lamp efficiency:

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

$$Lamp\ efficiency = \frac{Luminous\ flux}{power\ input}$$

21. Specific consumption:

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

22. Space to height ratio:(SHR)

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

$$SHR = \frac{\text{horizontal disance betwen two adjacent lamps}}{\text{mounting height of lamps above the working plane}}$$

23. 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

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

24. Maintenance factor:

It is defined as the ratio of illumination under normal working conditions to the illumination when everything is clean.

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

25. Depreciation factor:

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

26. 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.

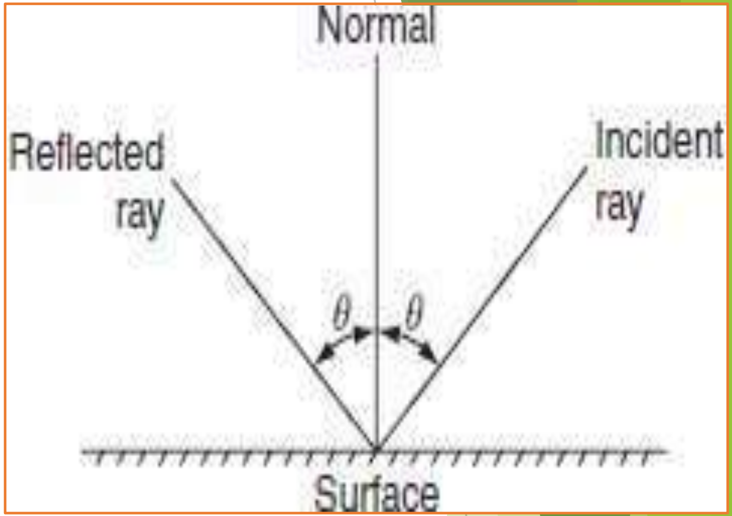
27. Absorption factor:

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.

28. Reflection factor or coefficient of reflection:

When light rays hit on a surface, it is reflected from the surface at an angle of incidence shown in Figure. 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.



29. 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 varying 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.

3). Laws of illumination:

Mainly there are two laws of illumination.

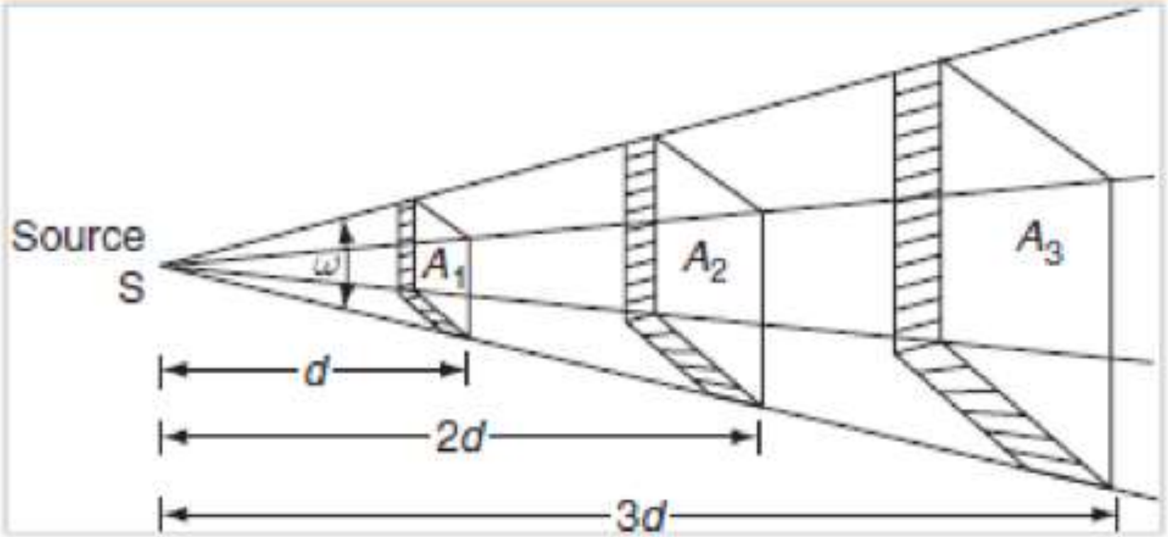
1. Inverse square law.
2. Lambert's cosine law.

1. Inverse square law:

Statement:

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

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 and $'\omega'$ be the solid angle as shown in Figure.



for Area, A_1 : **Solid angle,** $\omega = \frac{A_1}{d^2}$

Luminous flux reaching the area A1 is:

$\boldsymbol{\varphi}$ = luminous intensity × solid angle

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

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

$$E_1 = \frac{\varphi}{A} = \frac{IA_1}{d^2} \times \frac{1}{A_1}$$

$$\therefore\ E_1 = \frac{I}{d^2}$$

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

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

And, illumination '*E3*' on the surface *area A3* is:

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

From the above equations E1, E2, E3 we can write,

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

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

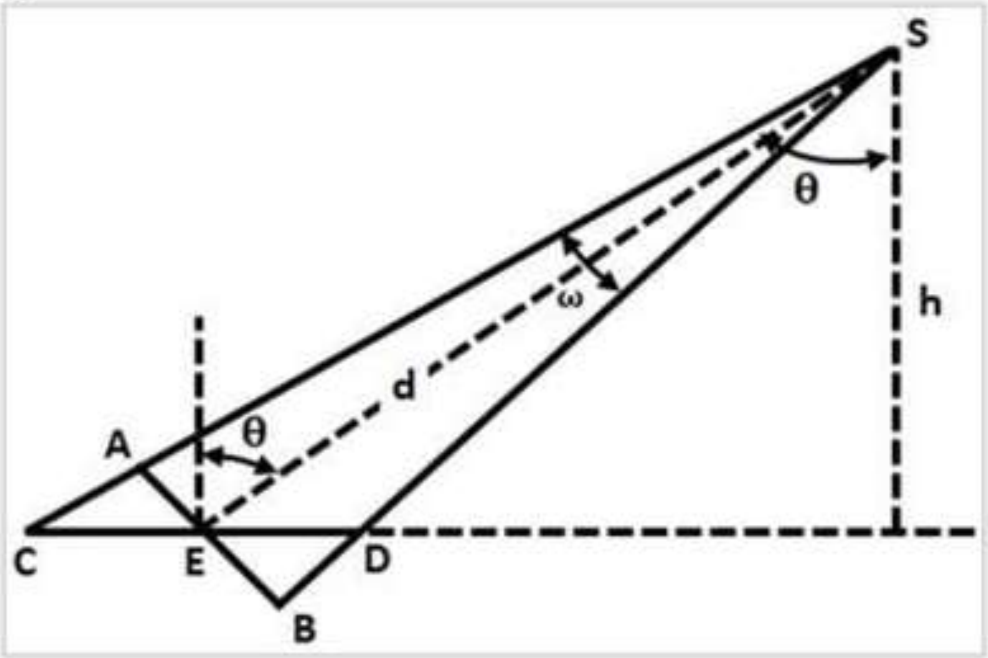
2. Lambert's cosine / cosine cube law:

Statement:

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:

Consider a point source **'S'** at a height **'h'** from the surface CD. Assume that surface CD subtends solid angle **'ω'** at point source 'S' as shown below. Let AB be the inclined surface area normal to the light flux with E as the center point of the surface.



From the above figure,

$$AB = CD \times \cos\theta$$

Illumination on surface AB is,

$$E_{AB} = \frac{\varphi}{A} = \frac{I \times \omega}{area\ of\ AB}$$

Illumination on surface CD is,

$$E_{CD} = \frac{\varphi}{A} = \frac{I \times \omega}{area\ of\ CD} = \frac{I \times \omega}{\left(\frac{area\ of\ AB}{\cos\theta}\right)}$$

$$E_{CD} = \frac{I \times \omega}{area\ of\ AB} \times \cos\theta$$

$$E_{CD} = E_{AB} \cos\theta$$

From the figure, the height of the point source from the surface is,

$$h = d \times \cos\theta$$

Now illumination on CD is given as,

$$E_{CD} = \frac{I \times \omega}{area\ of\ AB} \times \cos\theta$$

$$E_{CD} = \frac{I}{\left(\frac{area\ of\ AB}{\omega}\right)} \times \cos\theta$$

From inverse square law,

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

$$E_{CD} = \frac{I}{\left(\frac{h^2}{\cos^2\theta}\right)} \times \cos\theta$$

$$E_{CD} = \frac{I}{h^2} \times \cos^3\theta$$

The above equation is known as **Cosine Cube Law.**

Limitations of Laws of Illumination :

1. The inverse square law is used to measure the illuminance only on the **horizontal surfaces** i.e., the inverse square law is only applicable if the surface is normal to the light flux.

2. The source is considered as the **point source** in inverse square law. But, in practice, the point source does not exist. Hence, a lot of errors are introduced in the calculation of illuminance using inverse square law.

3. Lambert's cosine law of illuminance is used to measure the illuminance only **on inclined surfaces.**

4). Polar Curves:-

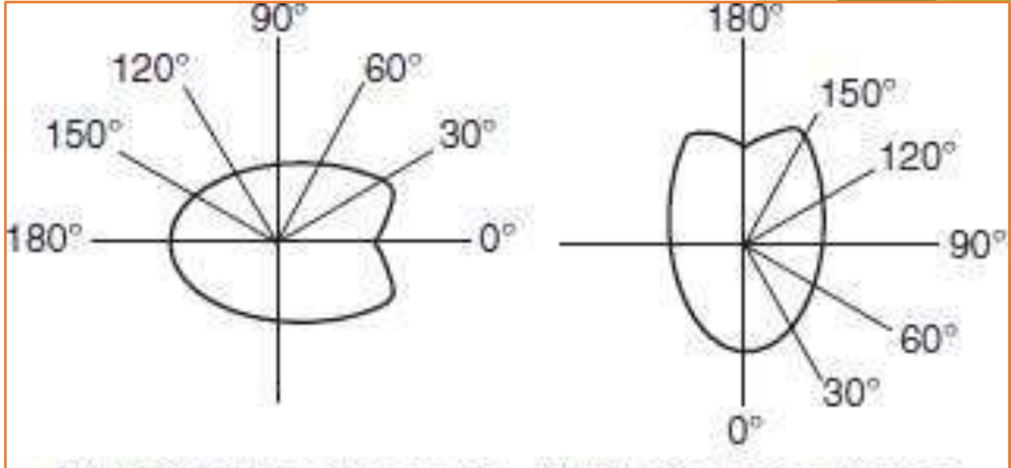
1. The luminous flux or luminous intensity emitted by a source can be determined using the intensity **distributed uniformly** over the surrounding surface.

2. But in some cases its **surface not uniform** in all directions, under this, luminous intensity or the distribution of the light can be represented with the help of the **polar curves.**

3. The polar curves are drawn by taking luminous intensities in various directions at an equal angular displacement in the sphere. A radial ordinate pointing in any particular direction on a polar curve represents the luminous intensity of the source when it is viewed from that direction. Accordingly, there are two different types of polar curves and they are:

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

Figure shows the typical polar curves for an ordinary lamp.



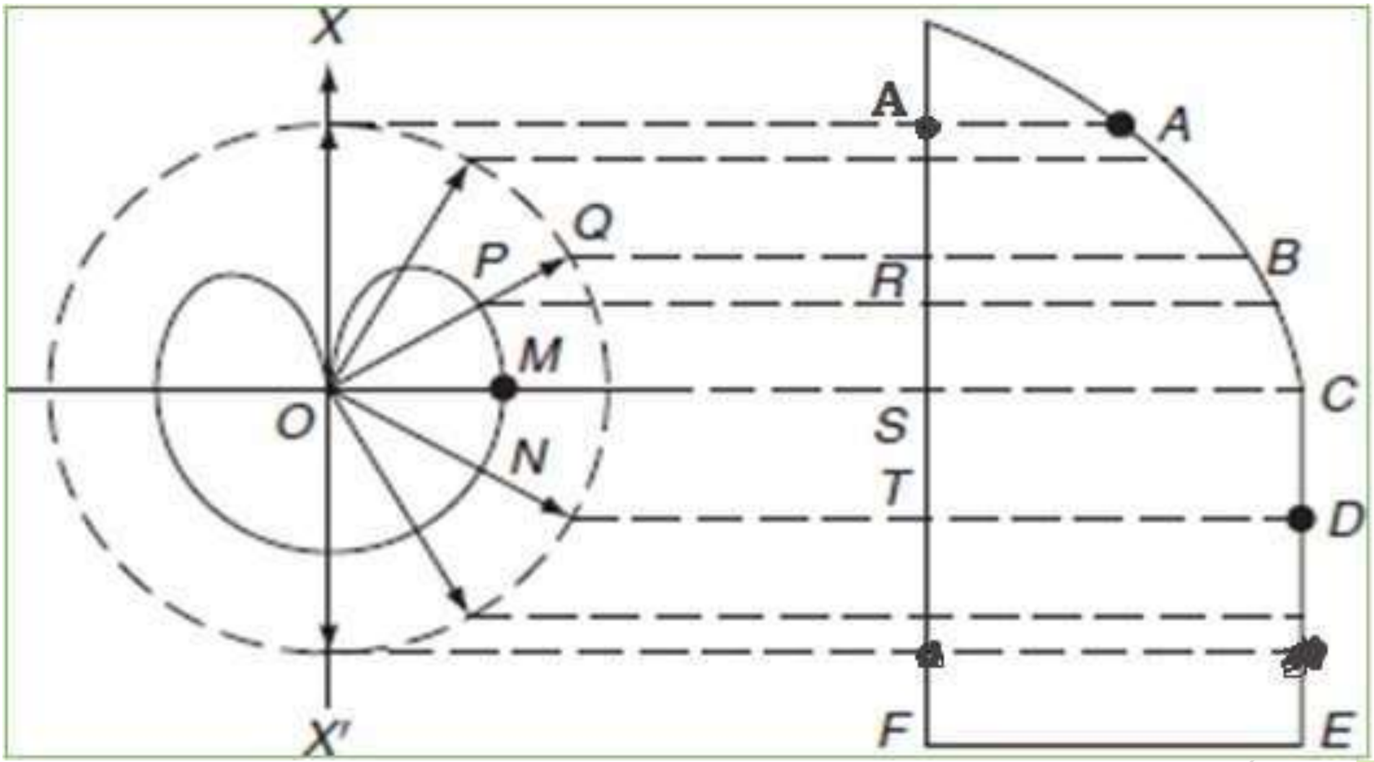
(a) Horizontal polar curves (b) Vertical polar curves

4. **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.

5. 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).**

Rousseau's construction

Let us consider a vertical polar curve is in the form of two lobes symmetrical about *XOX*1 axis. A simple Rousseau's curve is shown in Figure.



Rules for constructing the Rousseau's curve :

1. Draw a circle with any convenient radius and with ‘O’ as center.
2. Draw a line 'AF’ parallel to the axis XOX1 and is equal to the diameter of the circle.
3. Draw any line ‘OPQ' in such a way that the line meeting the circle at point ‘Q’. Now let the projection be ‘R’ onto the parallel line 'AF’.
4. Erect an ordinate at ‘R’ as, RB = OP.
   Now from this line 'AF' ordinate equals to the corresponding radius on the polar curve are setup such as SC = OM, TD = ON, and so on.
6. The curve ABCDEFA so obtained by joining these ordinates is known as Rousseau's curve.

The mean ordinate of this curve gives the

$$\textbf{Mean ordinate of the curve} = \frac{\textbf{area of ABCDEFA}}{\textbf{length of AF}}$$

5). Photometry:

Photometry involves the measurement of candle power or **luminous intensity** of a given source. The candle power of a given source in a particular direction can be measured by the comparison with a **standard 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.**

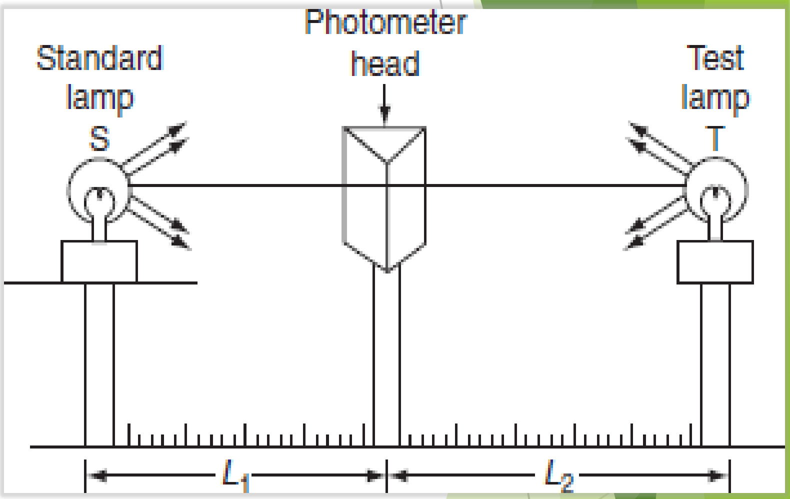
Principle of simple photometer:

"The principle methods of measurement are based upon the inverse square law".

The photometer bench essentially consists of **two steel rods** with 2- to 3-m long. This bench carries **stands** 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, When **photometer head** and sources moving and the photometer head acts as **screen** for the comparison of the illumination of the standard lamp and the test lamp.

Let photometer bench has 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.**



If the distances of the standard source '*S*' and the test source '*T*' from the photometer head are ***L1* and *L2*,** respectively, then, according to the **inverse square law,**

$$\text{The CP of standard source}(S) \ \alpha \ L_1^2$$

$$\text{The CP of Test source}(T) \ \alpha \ L_2^2$$

$$\frac{\text{CP of Standard source}}{\text{CP of Test source}} = \frac{L_1^2}{L_2^2}$$

$$\mathbf{CP\ of\ Test\ source = CP\ of\ standard\ source} \times \frac{L_2^2}{L_1^2}$$

In order to obtain the **accurate Intensity(I)** of test source, the **distance of the sources** from the **photometer head** should be **measured accurately.**

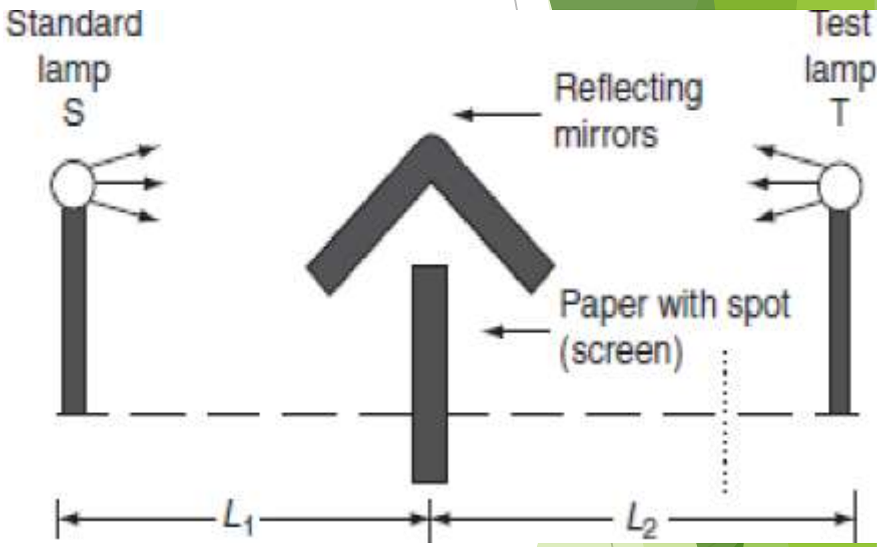
Photometer heads:

The photometer heads that are most common in use are:

1. Bunsen-grease spot photometer.
2. Lumer–Brodhun photometer.
3. Flicker photometer.

The first two are best suited for , if the two sources to be compared give the light of same or approximately similar colors. For differ in color, a flicker photometer is best suited.

1. Bunsen-grease spot photometer:



1. Bunsen photometer consists of a tissue paper, with **a spot of grease** or wax at its center. It held vertically in a carrier between the two light sources to be compared.

2. The central spot will appear dark on the side, having illumination in excess when seen from the other side. Then, the observer will adjust the position of photometer head in such a way that the grease spot is

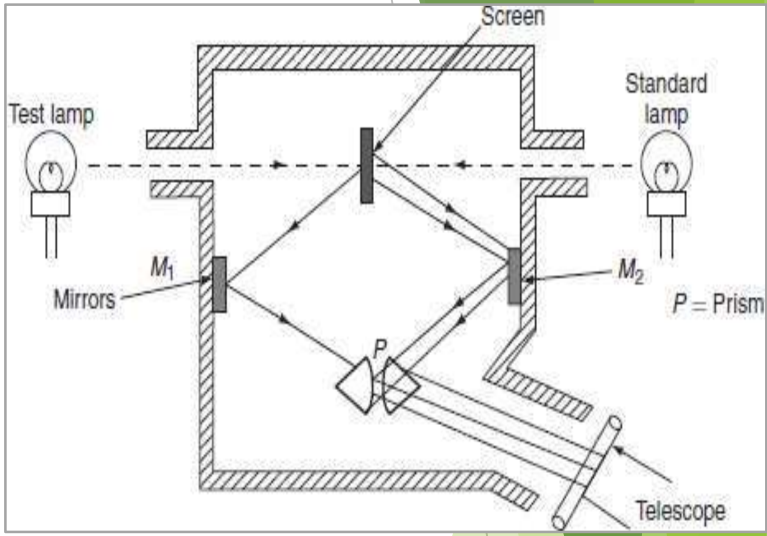
2. Lummer–Brodhun photometer:

There are two types of Lummer–Brodhun photometer heads.

I) Equality of brightness type.

II) Contrast type.

The Contrast type is more accurate and therefore, extensively used in the photometric measurements.



I) Equality of brightness type:

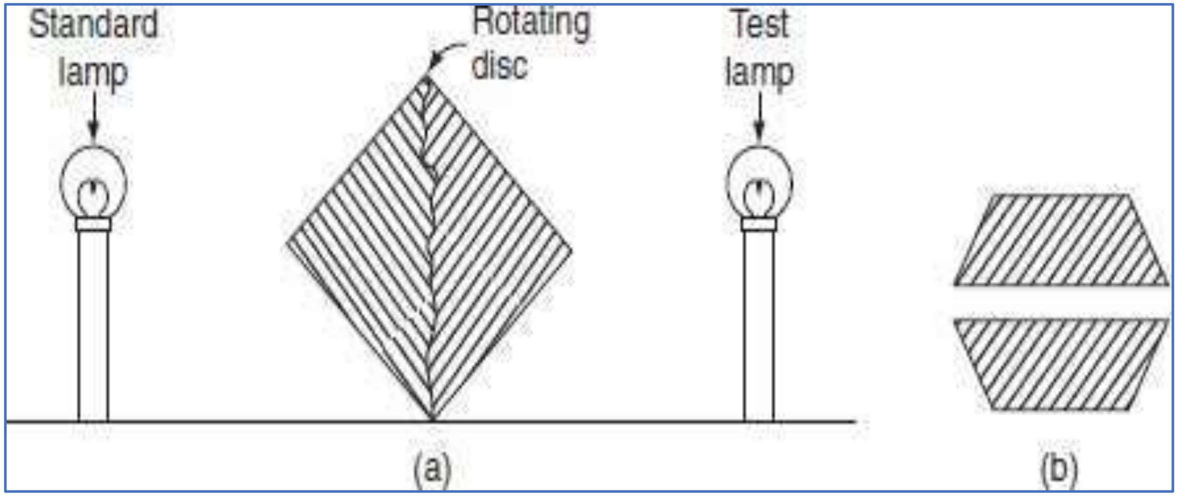
1. The photometer head essentially consists of screen made of plaster of Paris, two mirrors M_1 and M_2 , glass cube (or) compound prism, and a telescope. The two sides of the screen are illuminated by two sources such as the standard and test lamps . The luminous flux lines emitting from the two sources are falling on the screen directly and reflected by it onto the mirrors M1 and M2, which in turn reflects the same onto the compound prism then which pass through the telescope.

2. Thus, observer view the center portion of the circular area(ring shape) illuminated by both the test lamp and the standard lamp. The positioning of the photometer head is adjusted in such away that the both circular areas has same intensity (or) brightness. Now, the distance of photometer head from the two sources are measured and the candle power or luminous intensity of test lamp can be calculated by using inverse square law.

3. Flicker photometer:

1. The flicker photometers are employed when two sources giving light of different colors to be compared. A typically used flicker photometer is a Simmance–Abady flicker photometer, where used rotating disc made up of plaster of Paris, is in the form of a double- truncated cone as shown in Figure.

2. The truncated portions of cone are fitted together to form the disc. The disc is continuously rotated at the required minimum speed by small motor in between the two sources to be compared.



6). Various illumination Methods:

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

1. Electric arc lamps.
2. Incandescent lamps.
3. Gaseous discharge lamps.
4. Fluorescent lamps.

5. Electric 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, then ionization of air present between the two electrodes produces an arc and provides intense light when an arc is struck between two electrodes.

These are 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.

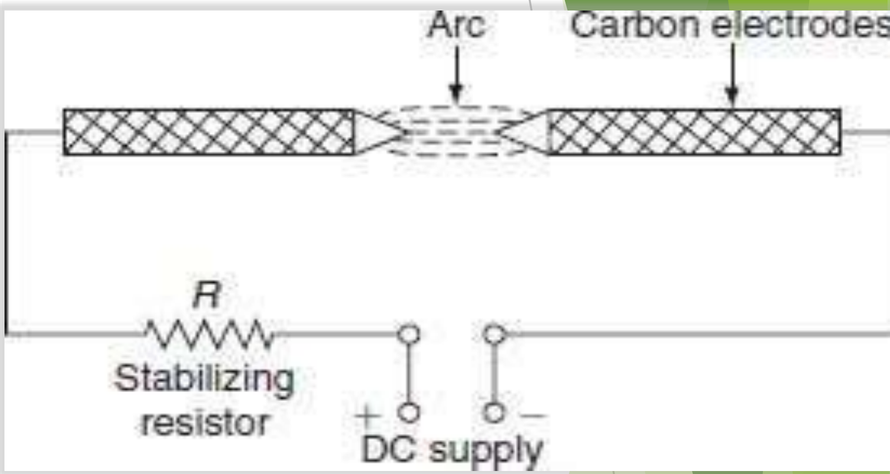
2. Flame arc lamp.
3. Magnetic arc lamp.

Carbon arc lamp:

1. 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.

2. The DC supply across the two electrodes must not be less than 45V. 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.

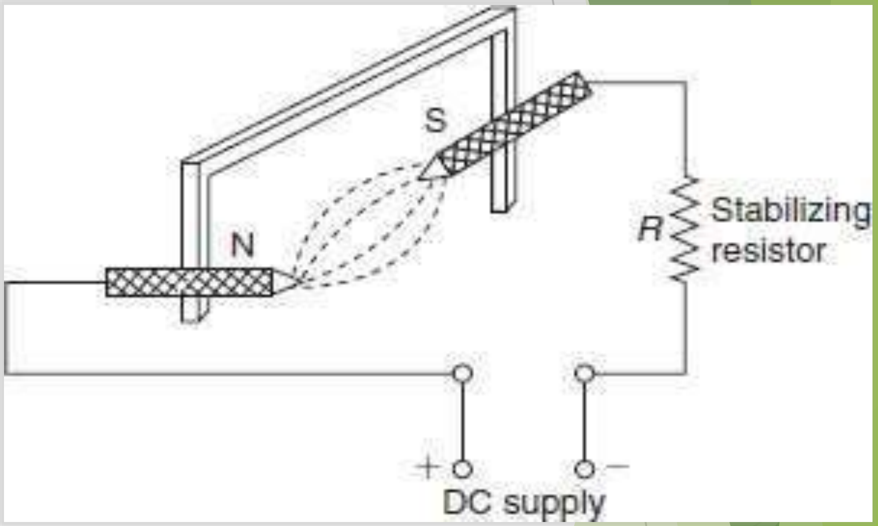
3. It is observed that carbon particles transfer from the positive rod to the negative one. So that the positive electrode gets consumed earlier than the negative electrode. Hence, the positive electrode is of twice the diameter than that of the negative electrode.



2. Flame arc lamp:

1. 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.** 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.

2. 2. 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. Resistance** is connected in service with the electrodes to **stabilize the arc.**



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.

2. Incandescent lamps:

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.

Tungsten filament lamps:

Construction

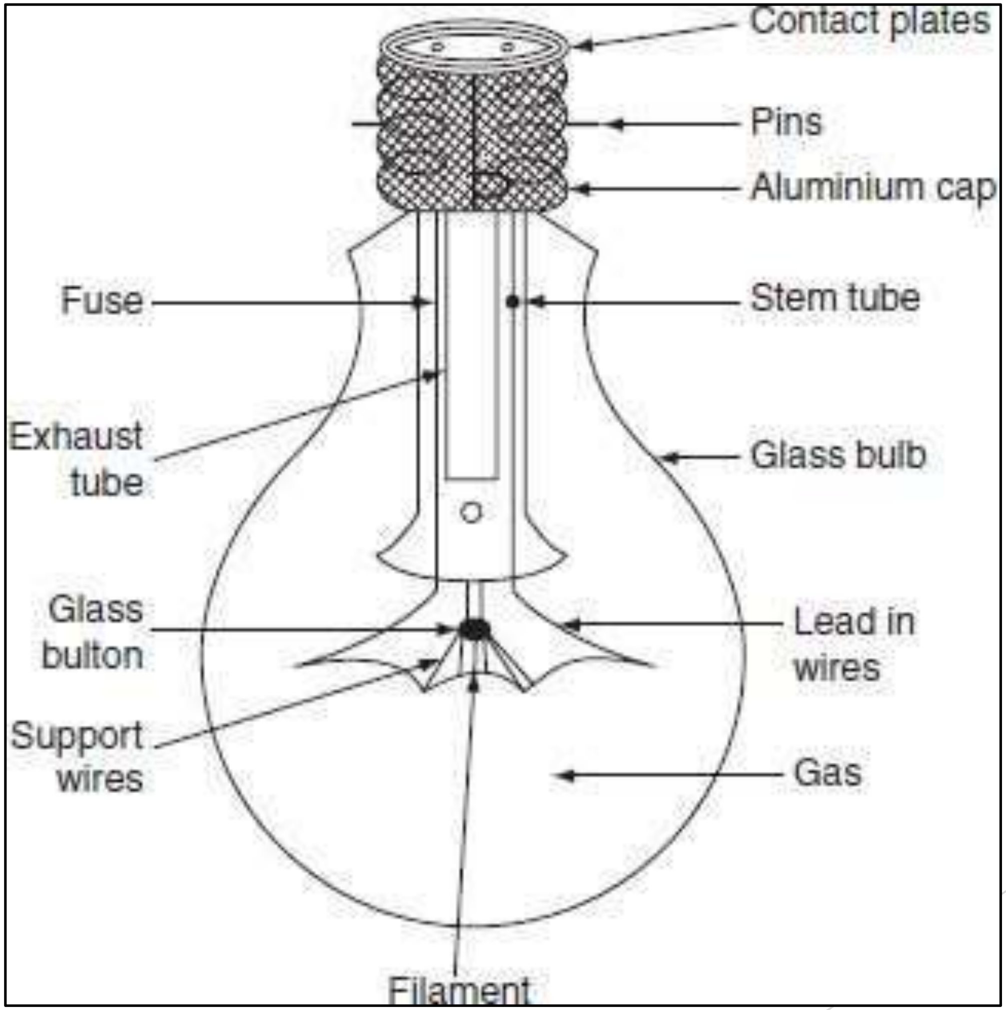
1. Figure shows the construction of the pure tungsten filament incandescent lamp. It consists of an evacuated glass bulb and an aluminum or brass cap is provided with two pins to insert the bulb into the socket(holder).

2. 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.

Operation

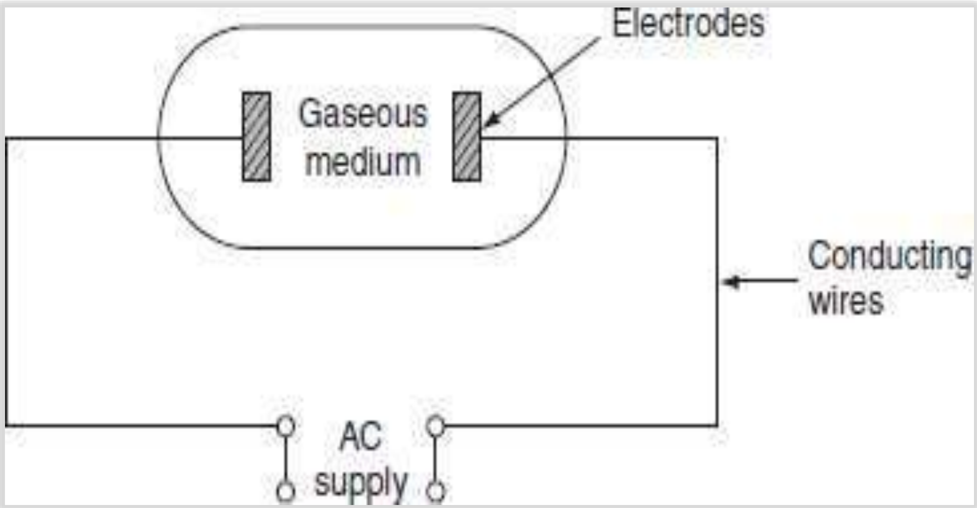
1. When electric current is made to flow through the fine metallic tungsten filament, its temperature increases. At very high temperature, the filament emits both heat and light radiations, which fall in the visible region.

2. 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.



3. Gaseous discharge lamps:

Discharge lamps have been developed to overcome the drawbacks of the incandescent lamp. Normally, at high pressures atmospheric conditions, all the gases are poor conductors of electricity. But on application of sufficient voltage across the two electrodes, the gases gets ionized then produce electromagnetic radiation. In the process light produced by gaseous conduction.



Volt–ampere characteristics of the arc in discharge tubes is negative, i.e., gaseous discharge lamp possess a negative resistance characteristics.

Types of discharge lamps:

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

1. The lamps that emit light of the color produced by discharge takes place through the gas or vapor present in the discharge tube.

Ex: *1*.**Neon gas**, **2.Sodium vapor lamp(Low-P)**, and **3. Mercury vapor lamp(High-P).**

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

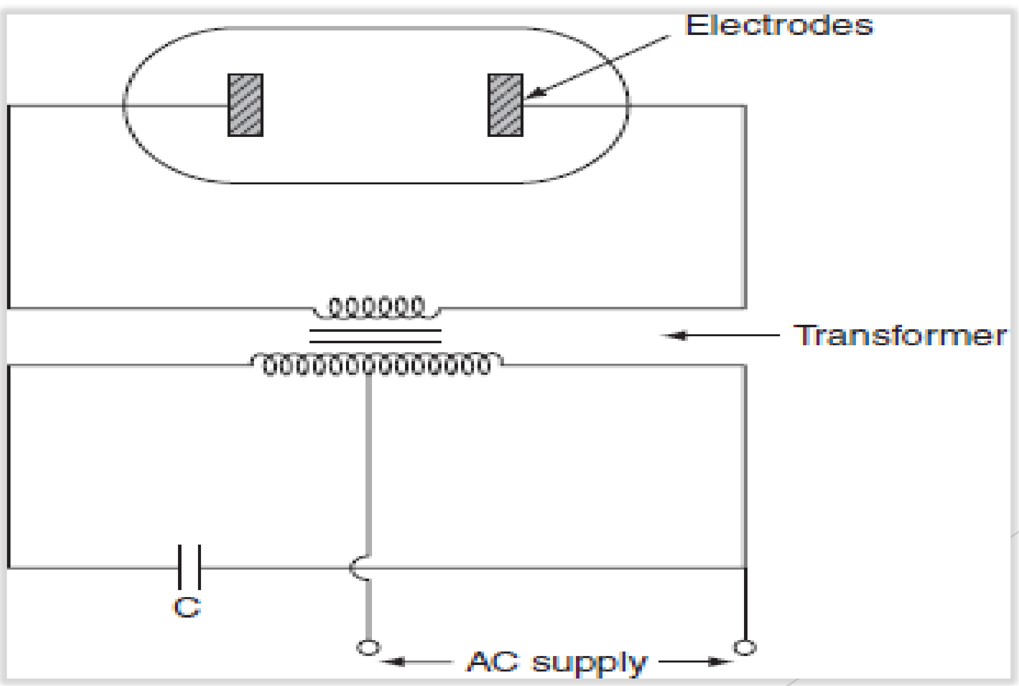
Ex: 4. **Fluorescent Mercury vapor tube(Low-P).**

➢ Neon Discharge Lamp:

1. This is a cold cathode lamp, in which no filament is used to heat the electrode. Neon lamp consists of two electrodes placed at the two ends of a long discharge tube is shown in Figure. The discharge tube is filled with neon gas.

2. A low voltage of 150 V on DC (or) 110 V on AC is impressed across the two electrodes using a step- down transformer(central tapped) with high leakage

- reactance in order to stabilize the arc. The discharge takes place through the neon gas that emits light or electromagnetic radiation reddish in color.



➢ Sodium Vapor Lamp:

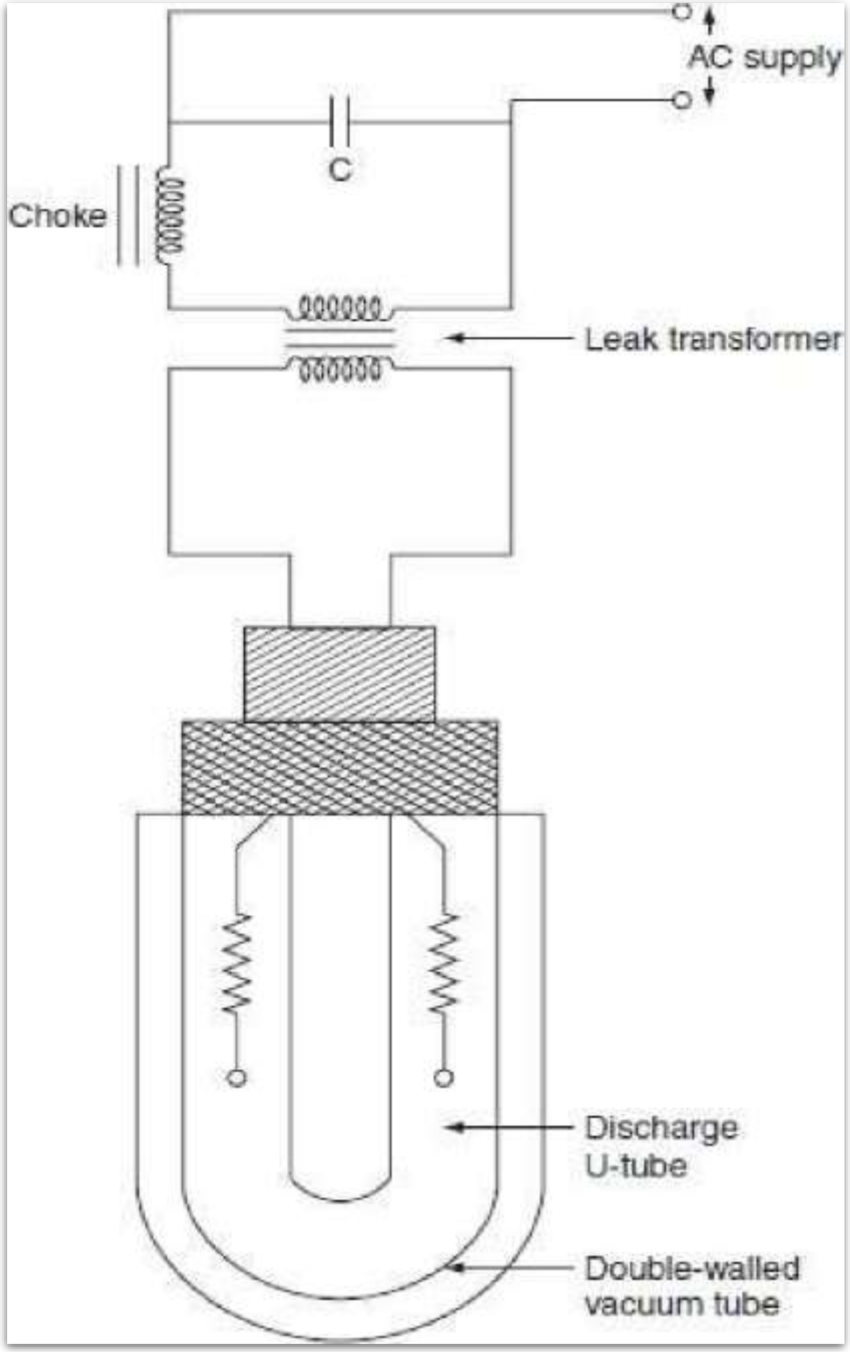
construction

1. 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.

2. 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 discharge tube.

working

1. Initially, the sodium is in the form of a solid, deposited on the walls of inner tube. When sufficient voltage is impressed across the electrodes, the discharge starts in the inert gas, i.e., neon; it operates as a low-pressure neon lamp with pink color.



AC supply
C
Choke
Leak transformer
Discharge
U-tube
Double-walled
vacuum tube

➢ 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:

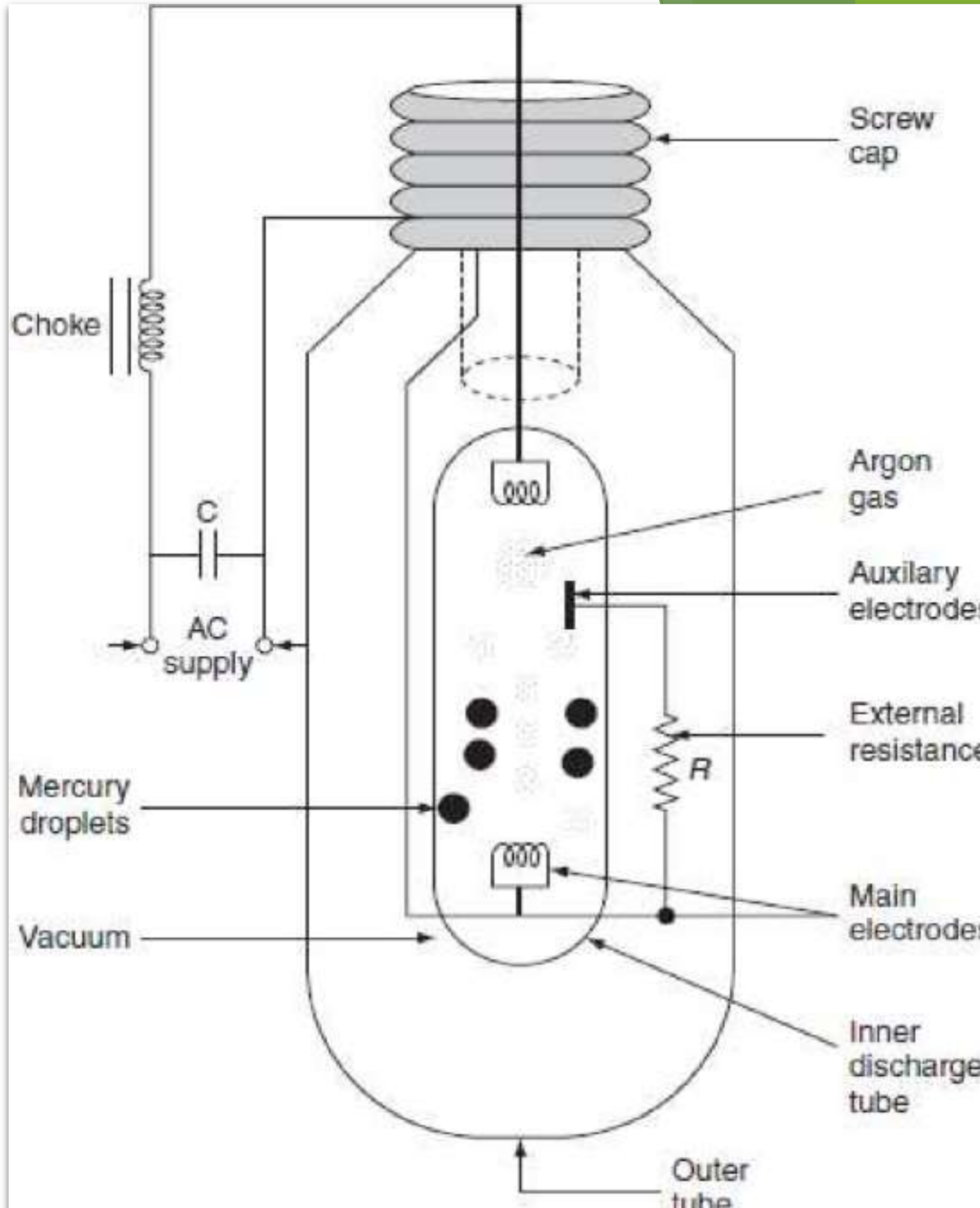
1. **MA type:** Preferred for 250- and 400-W rating bulbs on 200–250-V AC supply.
2. **MAT type:** Preferred for 300- and 500-W rating bulbs on 200–250-V AC supply.

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

1. MA type Lamp

Construction

1. MA type mercury vapor discharge lamp that is similar to the construction of sodium vapor lamp. MA type lamp consists of a long discharge tube in long/*U*-shape and is made up of hard glass or quartz. This discharge tube is enclosed in an outer tube of ordinary glass.



Working

1. 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.

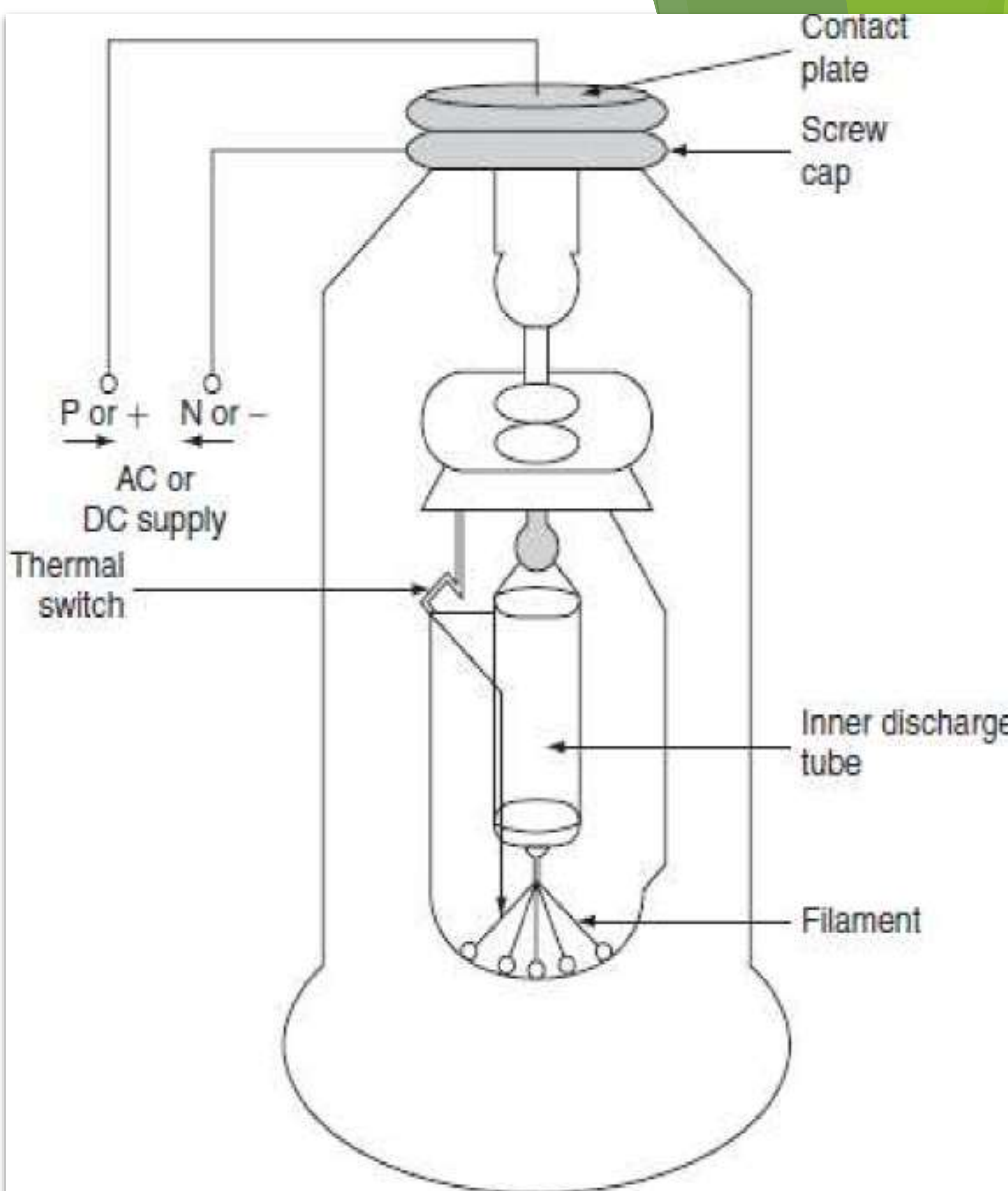
2. After few minutes, the argon gas, as a whole, gets ionized between the two main electrodes. Hence, the discharge shifts from the auxiliary electrode to the two main electrodes. During the discharge process, heat is produced and this heat is sufficient to vaporize the mercury. As a result, After **5–7 min,** the lamp starts and gives its full output.

3. 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.

4. The operating temperature of the inner discharge tube is about 600°C. The efficiency of this type of lamp is 30–40 lumens/W. These lamps are manufactured in 250 and 400 W ratings for use on 200–250 V on AC supply. Generally, the MA type lamps are used for general industrial lighting, ports, shopping centers, railway yards

2. MAT type Lamp construction

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 that, it consists of **tungsten filament** so that at the time of starting, it works as a tungsten filament lamp and also acts as a **choke** to limit the high currents to a safe value.



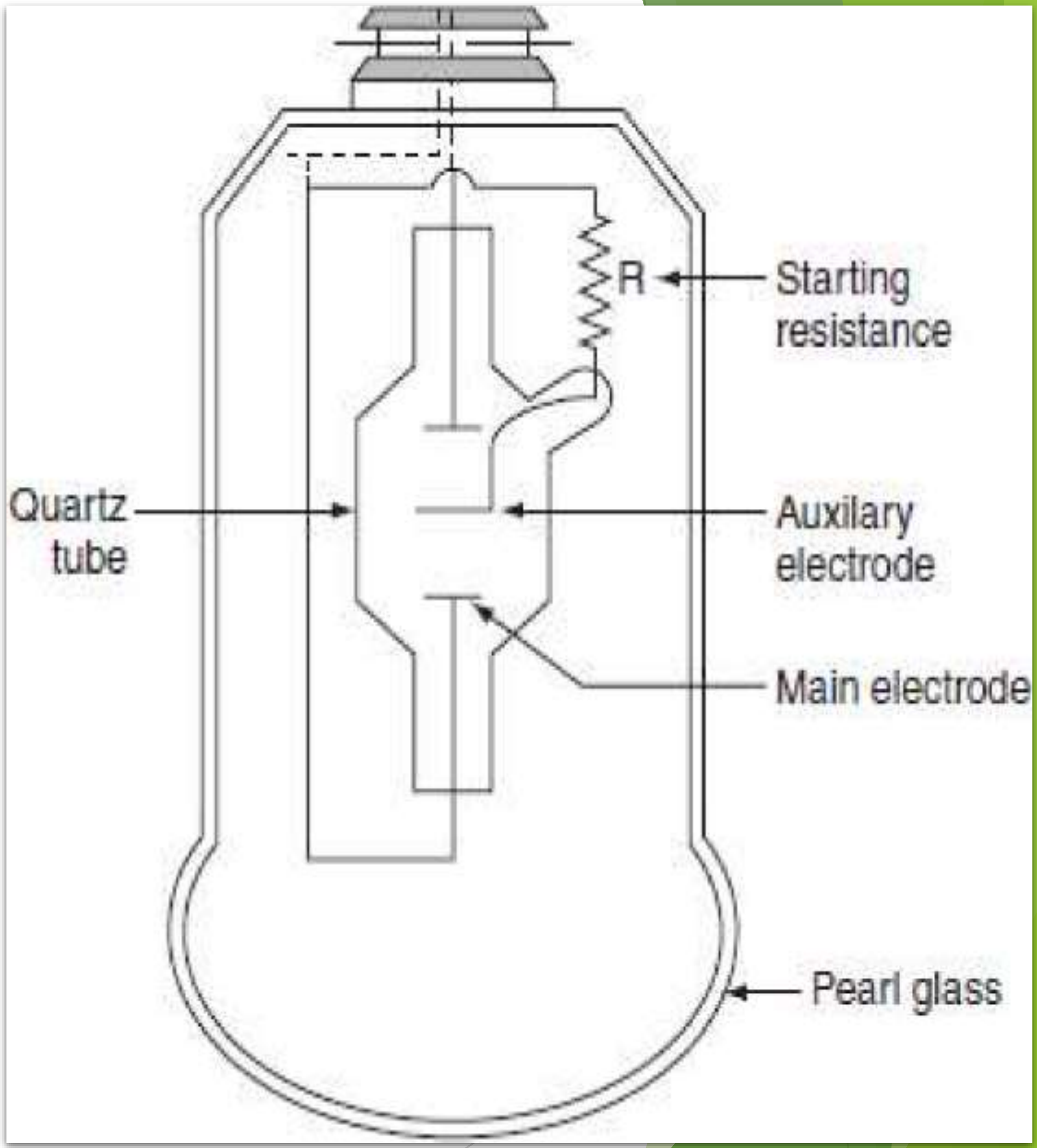
Working

1. When the supply is given, it works as a tungsten filament lamp, then argon gas present in it starts ionizing in the discharge tube at any particular temperature is attained then **thermal switch**(bi-metallic strip) gets opened, and the part of the filament is detached and voltage across the discharge tube increases.

2. Now, the discharge takes place through the **mercury vapor** and **emits blue colored light** 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.

1. MB type Lamp

1. The MB type lamp is also **similar to the MA type lamp.** But, very high pressure is maintained inside the discharge tube and it is about **5–10 times greater than atmospheric pressure.** The inner discharge tube for the MB type lamp is about **5 -cm long** and is made up of **quartz material.**

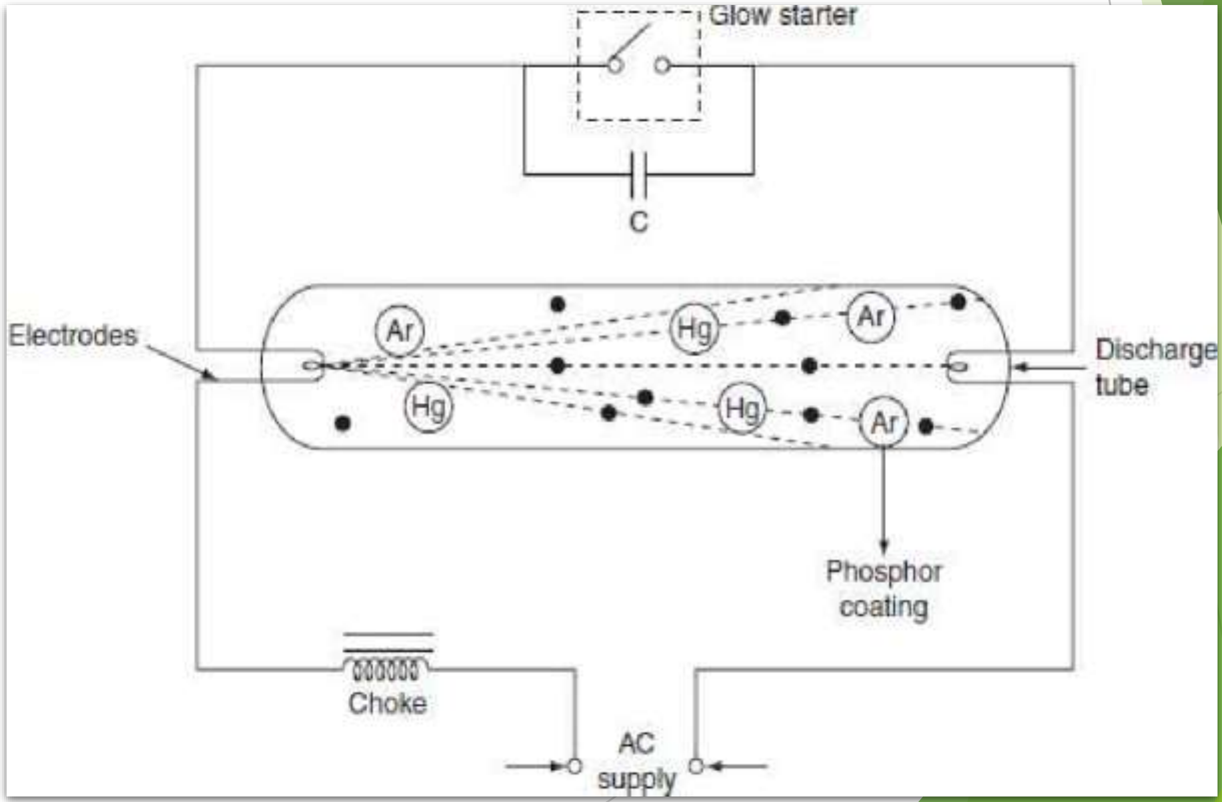


2. Fluorescent lamps(Low-pressure Mercury Vapor Lamp):

Fluorescent lamp is a **hot cathode low-pressure mercury vapor lamp.**

Construction

1. It consists of a long horizontal tube, due to low pressure maintained inside of the bulb. The tube consists of two spiral tungsten electrode coated with electron emissive material and are placed at the two edges of long tube.



7). Comparison between "Tungsten Filament" Lamps And "Fluorescent Tubes":

Incandescent Lamp	Fluorescent Lamp
1. Initial cost is less.	**1.** Initial cost is more.
2. Fluctuations in supply voltage has comparatively more effect on the light output.	2. Fluctuation in supply voltage has less effect on light output, as the variations in voltage are absorbed in choke.
3. It radiates the light; the color of which resembles the natural light.	**3.** It does not give light close to the natural light.
4.It works on AC as well as DC.	**4.** Change of supply needs additional equipment.
5. The luminous efficiency of the lamp is low is, about 8 – 40 lumens/W.	5. The luminous efficiency is high, which is about 50– 100 lumen/W.
6. Different color lights can be obtained by using different colored glasses.	**6.** Different color lights can be obtained by using different composition of fluorescent powder.

Incandescent Lamp	**Fluorescent Lamp**
1. Initial cost is less.	**1.** Initial cost is more.
2. Fluctuations in supply voltage has comparatively more effect on the light output.	2. Fluctuation in supply voltage has less effect on light output, as the variations in voltage are absorbed in choke.
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9). Types and design of lighting schemes:

Types of lighting schemes:

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.
5. General lighting.

UNIT-IV : ELECTRIC TRACTION – I

CONTENTS:-

1. System of Electric Traction.
2. Track Electrification.
3. Special Features of Traction Motor.
4. Methods of Electric Braking.
   - Plugging.
   - Rheostat Braking and
   - Regenerative Braking.
5. Mechanics of Train Movement(Unit-5)
6. Types of Services In India.
7. Speed-time Curves For Different Services.
   - Trapezoidal Speed Time Curves.
   - Quadrilateral Speed Time Curves.

Electric Traction

7.1 Basic definition

(a) Traction System

- Propulsion of vehicle is called the traction.

(b) Electric Traction System

- The system of traction involving the use of electricity is called the electric traction system.

7.2 Ideal traction system

(the force which is exerted by powered equipment)

- High starting tractive effort in order to have rapid acceleration.
- Self contained and compact locomotive (train unit) so that it may be able to run on any route
- Equipment capable of withstanding large temporary overloads.
- Minimum wear on the track.
- Braking should be such that minimum wear is caused on the brake shoes, and if possible the energy should be regenerated and returned to the supply.
- Equipment required should be minimum, high efficiency, low initial and maintenance cost.
- No interference to the communication line running along the track.
- Easy speed control.
- It should be pollution free.

Since the invention of locomotives in the 1800s, the way trains are powered has changed beyond all recognition. Formerly powered by burning solid fuel to generate steam, trains today run on a mix of either pure electric, diesel-electric, or gas-turbine engines.

Electrical trains rose to prominence in the early-20th century. Some of the first appeared in around 1910 with the opening of the Hudson River Tunnels on the New York mainline.

As these tunnels were so long, steam locomotives were prohibited from being used, due to the dense fumes they generate. An alternative way of moving trains was needed, and the electric train was born.

Over the next few decades, electrical trains became more popular around the world and were notably used for various high-speed projects around the world.

Different system of traction

Non-electric Traction System

Direct Steam Engine Drive

Direct Internal Combustion Engine Drive

Electric Traction System

Steam Electric Drive

Internal Combustion Engine Electric Drive

Battery Electric Drive

Electric Traction Drive

[Note: Trains are the mode of transport of land that is used to cover long distances, there are several carriages and coaches attached to it to increase its capacity.

Trams are also a land mode of transportation and are used to cover shorter distances as compared to the distance covered by a train.

Regenerative braking is a way of taking the wasted energy from the process of slowing down a car and using it to recharge the car's batteries.]

TRAM

Trams have flanged wheels and run on rails like a train [whether on reserved track like most railways or in streets on grooved track]

Trolley buses or tramways supplied with DC supply (i.e., battery electric drives)

TROLLEY BUS

Trolleybuses have conventional rubber tyres for ordinary road surface and are essentially electrically powered buses.

Drawbacks of Electric Traction

- 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.

1.2 System of Traction In India

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.

3. Non-electric traction system:

Traction system develops the necessary propelling torque, which do not involve the use of electrical energy at any stage to drive the traction vehicle known as electric traction system.

Ex: Direct steam engine drive and direct internal combustion engine drive.

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:

A) Self-contained locomotives.

B) Electric vehicle fed from the distribution networks.

2. Track Electrification

Now a day, based on the available supply, the track electrification system is categorized into:

1. DC system.
2. Single-phase AC system.
3. Three-phase AC system.
4. Composite system.

1. DC system:

In this system of traction, the electric motors employed for getting necessary propelling torque should be selected in such a way that they should be able to operate on DC supply. **Examples** for such vehicles operating based on DC system are tramways and trolley buses.

The operating voltages of vehicles for DC track electrification system are 600, 750, 1,500, and 3,000 V. Direct current at 600–750 V is universally employed for tramways in the urban areas and for many sub-urban and main line railways 1,500–3,000 V is used.

****The DC system is preferred for suburban services and road transport where stops are frequent and distance between the stops is small*****.**

2. Single-phase AC system:

In this system of track electrification, usually AC series motors are used for getting the necessary propelling power. The distribution network employed for such traction systems is normally 15–25 kV at reduced frequency of 25 Hz. The main reason of operating at reduced frequencies is AC series motors that are more efficient and show better performance at low frequency.

These high voltages are stepped down to suitable low voltage of 300–400 V by means of step-down transformer. Low frequency can be obtained from normal supply frequency with the help of frequency converter.

******AC system is mainly preferred for main line services where the cost of overhead structure is not much importance moreover rapid acceleration and retardation is not required for main line services*****.**

3. Three-phase AC system:

In this system of track electrification, 3-φ induction motors are employed for getting the necessary propelling power. The operating voltage of induction motors is normally 3,000–3,600-V AC at either normal supply frequency or 16⅔-Hz frequency.

Usually 3-φ induction motors are preferable because they have simple and robust construction, high operating efficiency, provision of regenerative braking without placing any additional equipment.

The main disadvantage of such track electrification system is high cost of overhead distribution structure. This distribution system consists of two overhead wires and track rail for the third phase and receives power either directly from the generating station or through transformer substation.

Table 7.2 DC System

S. No.	Operating Voltage in Volts	Spacing between Sub-Station in km	Application
1.	600	3 to 5	Tramways, Trolley Bus
2.	1500 to 3000	30 to 40	Main Line Services

- The distribution system consists of one contact wire in case of tramways and two contact wires in case of trolley buses.
- The spacing of sub-stations depends upon the operating voltage and the traffic density of the route.

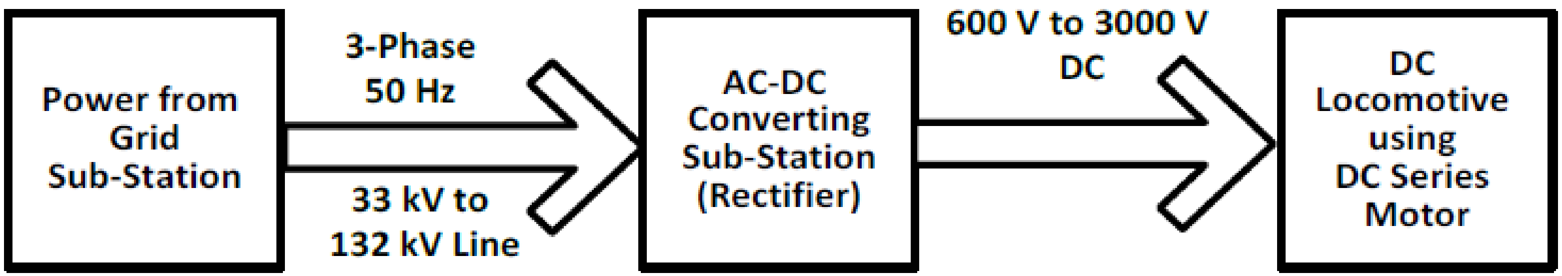
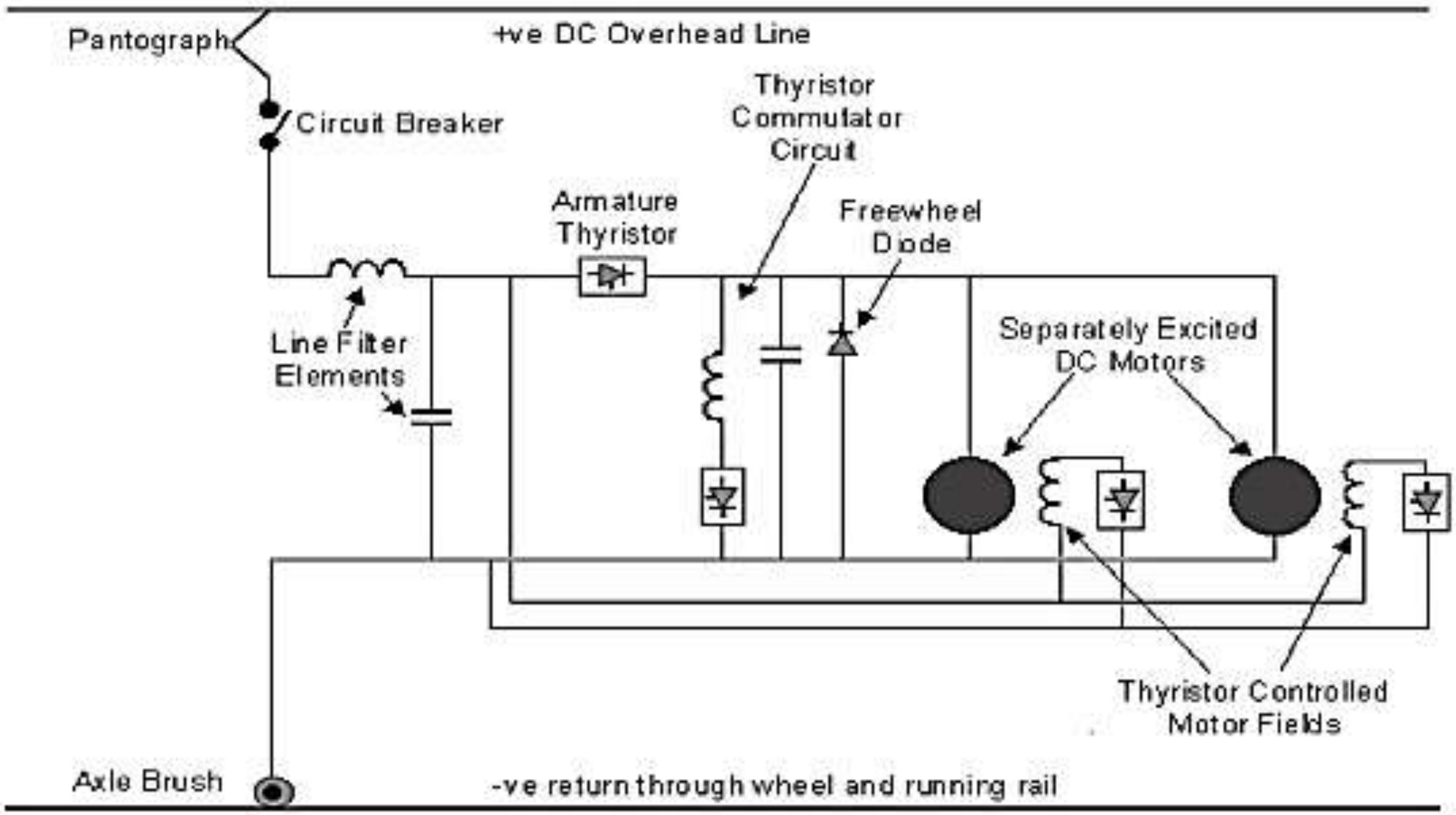


Figure 7.1 DC System

With two wires, they have to connect to them with poles, because the two sides of the circuit have to be kept apart.
Trains, by contrast, are grounded through the rails and therefore need only one wire above.

Power conversion for DC systems tends to take place at a railway substation using large, heavy, and more efficient hardware compared to AC systems.
Power conversion for AC systems, on the other hand, tend to convert current to AC onboard the train where space is limited and losses can be significantly higher.
Whichever is chosen is usually a trade-off between these considerations, but can also be dictated by existing infrastructure.
DC consumes less energy compared to an AC unit for operating the same service conditions. The equipment in the DC traction system is less costly, lighter, and more efficient than an AC traction system. It also causes no electrical interference with nearby communication lines.


Pantograph
+ve DC Overhead Line
Circuit Breaker
Thyristor
Commutator
Circuit
Armature
Thyristor
Freewheel
Diode
Line Filter
Elements
Separately Excited
DC Motors
Thyristor Controlled
Motor Fields
Axle Brush
-ve return through wheel and running rail

(a) Advantages

- DC series motor has better speed torque characteristics and smooth speed control.
- It offers high starting torque.
- It has low maintenance cost.
- Smaller weight per kW output.
- Batter speed control.
- Efficient braking system.

(b) Disadvantages

- This system has high cost of sub-station due to converting equipments.
- More number of sub-stations is required as they are spaced at shorter distance.
- Additional equipments like negative boosters are also required to maintain return voltage within specified limit.

7.12 The single phase AC system

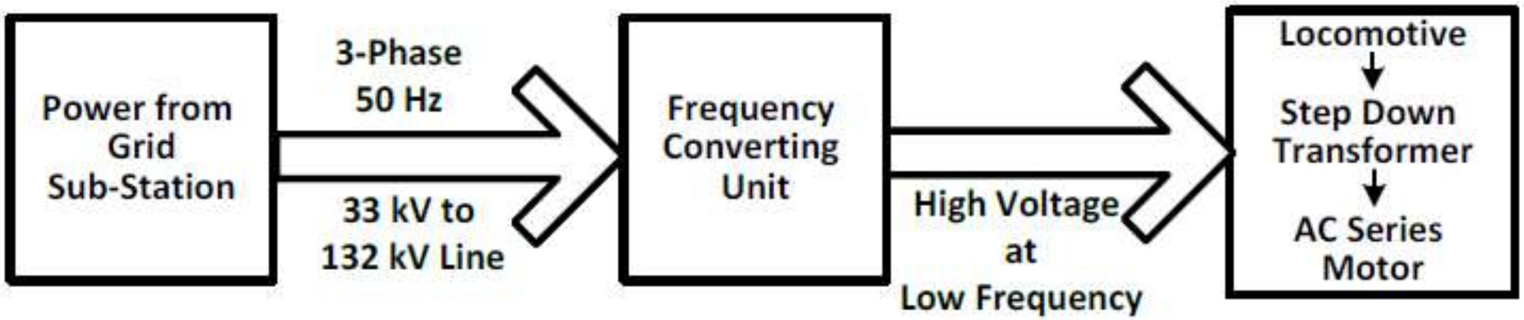
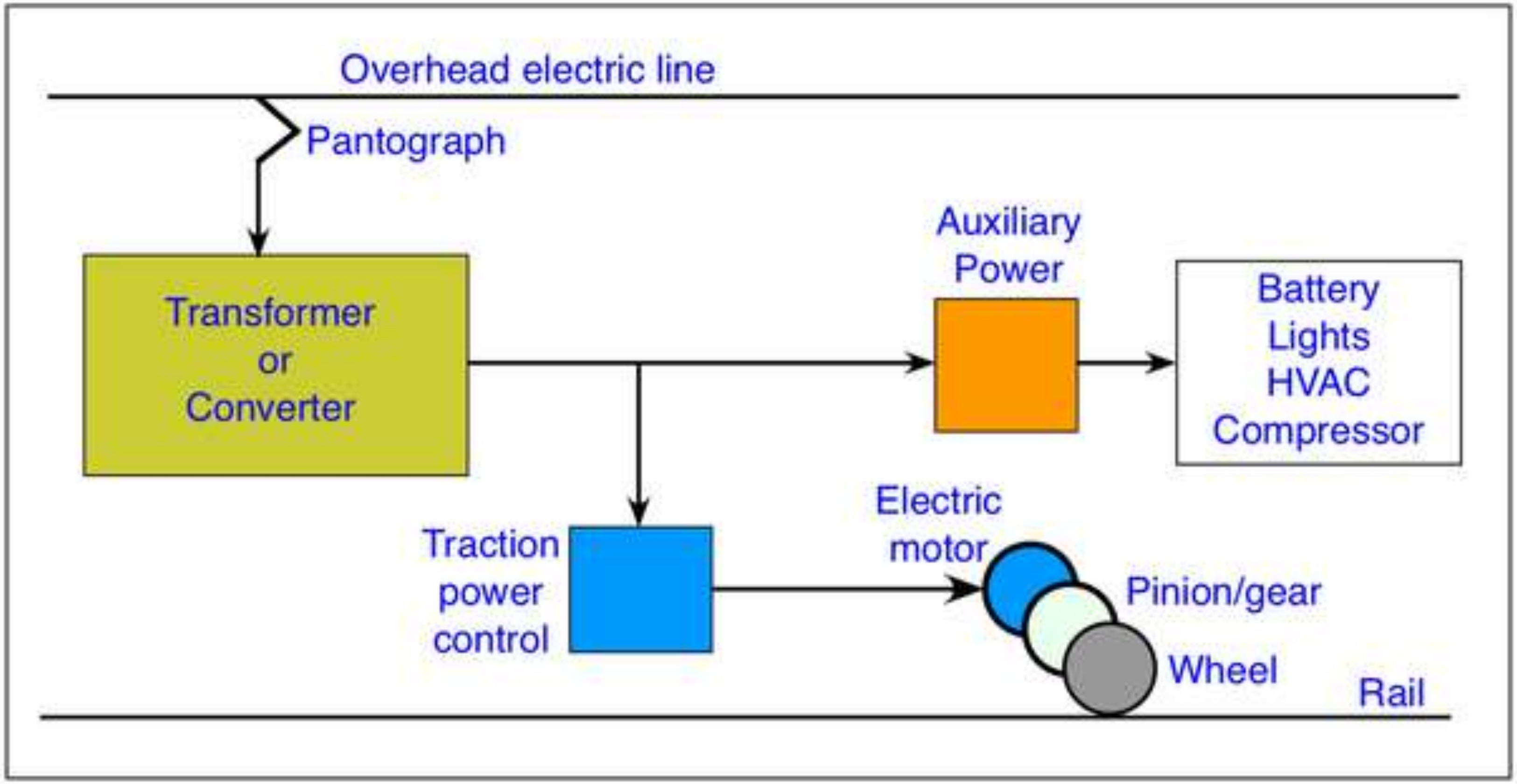


Figure 7.2 Single Phase AC System

- In single phase AC system ac series motors are used for getting necessary motive power.
- The voltage employed for distribution network is 15 to 25 kV at $6\frac{2}{3}$ or 25 Hz, which is stepped down on locomotive to a low voltage suitable for supplying to single ac series motor.
- The spacing of substation is 50 to 80 km.
- The change of supply frequency become necessary because of
  - Batter performance.
  - Improves its commutation properties, power factor and efficiency.
  - Reduces the line reactance and hence the voltage drop.
- AC single phase system is invariably adopted for main line service.


Overhead electric line
Pantograph
Transformer
or
Converter
Auxiliary
Power
Battery
Lights
HVAC
Compressor
Traction
power
control
Electric
motor
Pinion/gear
Wheel
Rail

7.13 The three phase AC system

- In this system 3-phase induction motor operating at 300 to 3600 V and low frequency are employed for getting the required motive power.
- The 3-phase induction motor
  - Simple
  - Robust in construction
  - High operating efficiency
  - Automatic regenerative braking without required any additional equipment.

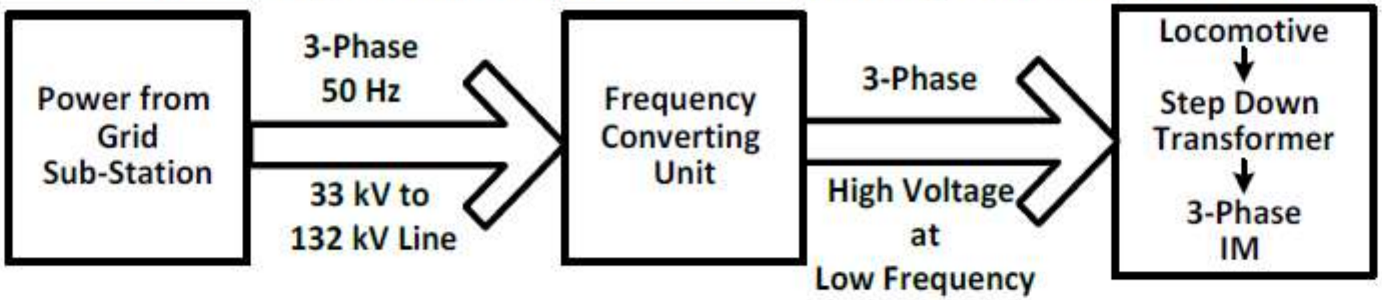
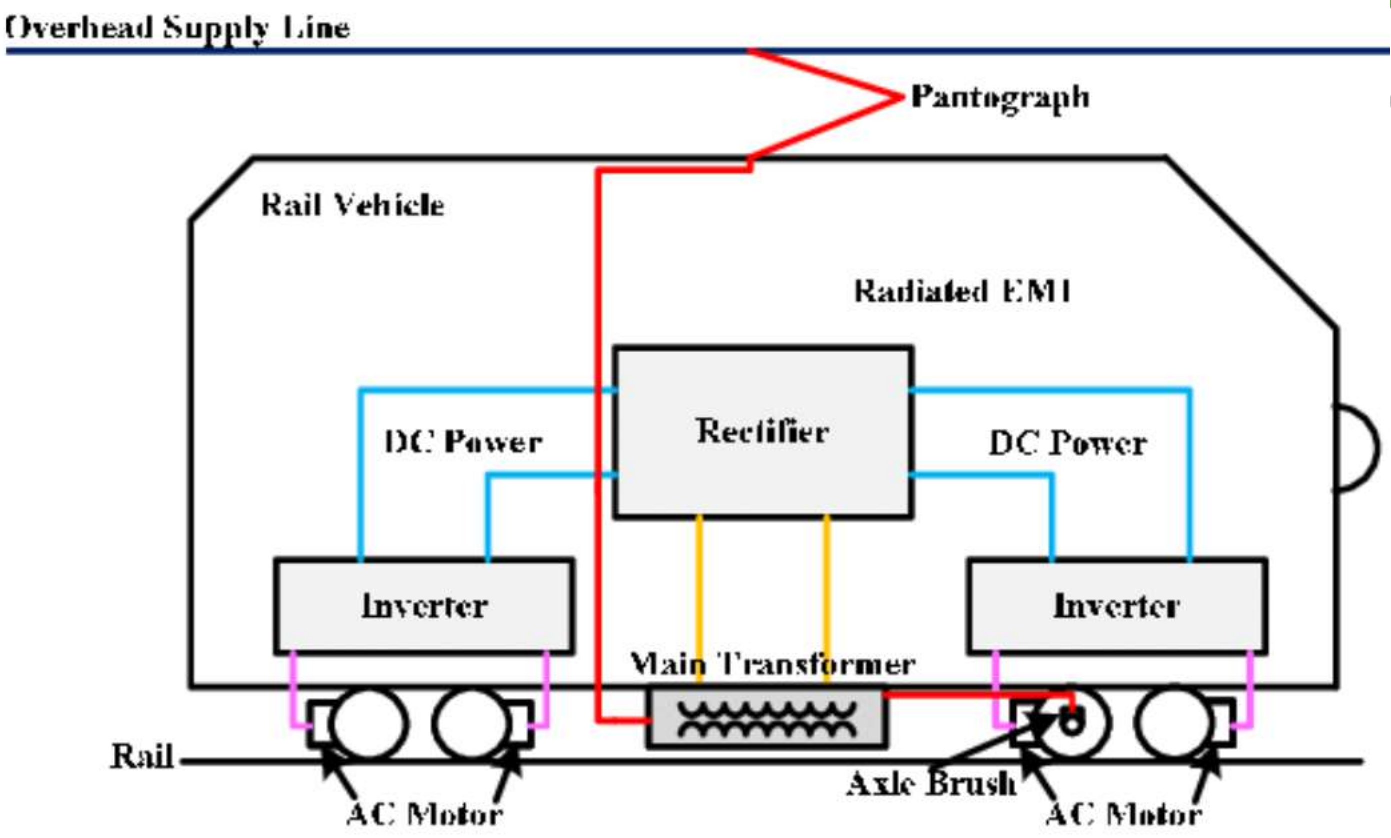


Figure 7.3 Three Phase AC System

- Drawbacks
  - Low starting torque
  - High starting current
  - Two overhead contact wires

7.14 The kando system (single phase to three phase system)

- In this system single phase high voltage (25 kV) at normal supply frequency is used to distribute power.
- The locomotive which carries a phase convertor which converts single phase AC to three-phase AC. The three-phase power is then fed to three-phase induction motors for getting necessary motive force.
- In this system only one contact wire of overhead system which is overcome the disadvantage of 3 phase AC system
- This system was adopted in Hungary in 1932.


Overhead Supply Line
Pantograph
Rail Vehicle
Radiated EMI
Rectifier
DC Power
DC Power
Inverter
Inverter
Main Transformer
Rail
Axle Brush
AC Motor
AC Motor

7.15 The single phase AC to DC system

- In this system of track electrification single phase AC 25 kV at normal frequency is fed to overhead distribution.
- The AC locomotive carries transformer to step down high input voltage and rectifying equipments to convert AC into DC This system is adopted in India for track electrification.
- This system becomes most popular because of various salient advantages over other systems particularly DC system.
- This system has got numerous advantages over dc system
  - The line current for a given demand of power is reduced on account of high system voltage
  - On account of high voltage the substations can be spaced at longer distances (50 to 80 km) whereas the substations are spaced at 12 to 30 km in case of 3000 V DC system and at 5 to 12 km in case of 1500 V DC system.
  - Since the dc series motors having ideal traction characteristics are employed in this system for getting the required propelling power, therefore, this system have got the advantages of the dc system.

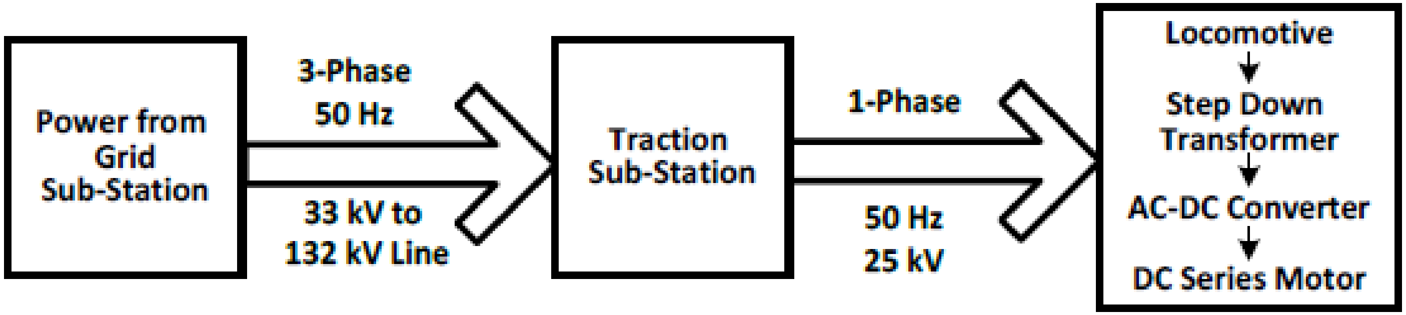


Figure 7.5 Single Phase AC to DC System

Pantograph

The main function of pantograph is to maintain link between overhead conductor and power circuit of locomotive at different speeds of the vehicle under all wind conditions. It collects the current from overhead conductor and supplies to rest circuit.

Circuit Breaker

It protects the power circuit in the event of any fault by isolating it from the supply. It also isolates the circuit during maintenance.

Transformer

It receives the high voltage from overhead conductor via pantograph and circuit breaker and then step-down the voltage to desired level required by the rest circuit.

Rectifier

It converts a low voltage AC supply from the secondary of transformer to a DC supply.

DC Link

It connects the rectifier and inverter circuits. It consists of filter arrangement (capacitor and inductor arrangement) that filters the output from rectifier (by removing the harmonics form it) and then supplies it to the inverter.

Main Inverter

It converts the DC power to three phase AC power in order to drive three phase AC motors.

Axle Brush

It acts as a return path for the supply. Once the power is drawn to the locomotive from overhead system, the current complete its path through axle brush and one of running tacks.

Auxiliary Inverter

This inverter supplies the power to other parts in the locomotive unit including fans, motor blowers, compressors, etc.

Battery

It supplies the necessary starting current and also power up the essential circuits such as emergency lighting.

Compressor

It maintains the cooling/heating requirement in the locomotive unit.

Cooling Fans

These fans maintain the necessary cooling for the power circuits. Modern locomotive systems use electronically controlled air management systems to keep the desired temperature.

7.16 Comparison of DC and AC system of railway electrification from the point of view of main line and suburban line railway service

(a) Main Line Railway Service

- The essential requirements of main line railway service are :
  - Higher maximum speed. (V_m)
  - Minimum cost of track electrification.
- Single phase AC system is preferred for main line service because of following features
  - 25 kV overhead systems reduce conductor section and hence simplified structure design due to high voltage.
  - Higher spacing of sub-station reduces number of sub-station and increases flexibility of selecting cheaper, land Maintenance cost is less due to cheap and efficient equipment of AC system.

(b) Sub-urban Railway Service

- The essential requirements of sub-urban railway service are :
  - Rapid acceleration and retardation rates due to frequent starting and stopping.
  - Motor performance should not affected by voltage fluctuations.
  - Less chances of interference in the telecommunication lines running along the track.

Table 7.4 Characteristics of Various type of Services

S. No.	Type of Service	Acceleration in kmphps	Retardation in kmphps	Maximum Speed in kmph	Distance between Stations in km
1.	Urban	1.5 to 4.00	3 to 4	60	1
2.	Suburban	1.5 to 4.00	3 to 4	75	1 to 8
3.	Main Line	0.6 to 0.8	1.5	110	More than 10

Table 7.3 Comparison of DC and AC Traction

Factor	DC Traction	AC Traction
Motor	DC series motor.	AC series motor.
Performance	Good performance.	Not as good as that used for DC traction.
Starting torque	More.	Less.
Speed control	The speed control of DC series Motor is limited.	Wide range of speed control is Possible.
Interference	DC system causes less interference with Communication lines.	It will produce more interference with Communication lines.
Overhead distribution	Heavier and more costly Comparatively.	Lighter and less costly.
Substations	The number of substations required for a given track distance on DC traction is More.	The number of substations required in AC traction is less.
Weight of cu	Weight of cu required per track km is more.	Weight of cu required per track km is less.
Application	Tramway, Trolley bus.	Main Line Service.

7.25 Mechanics of train movement

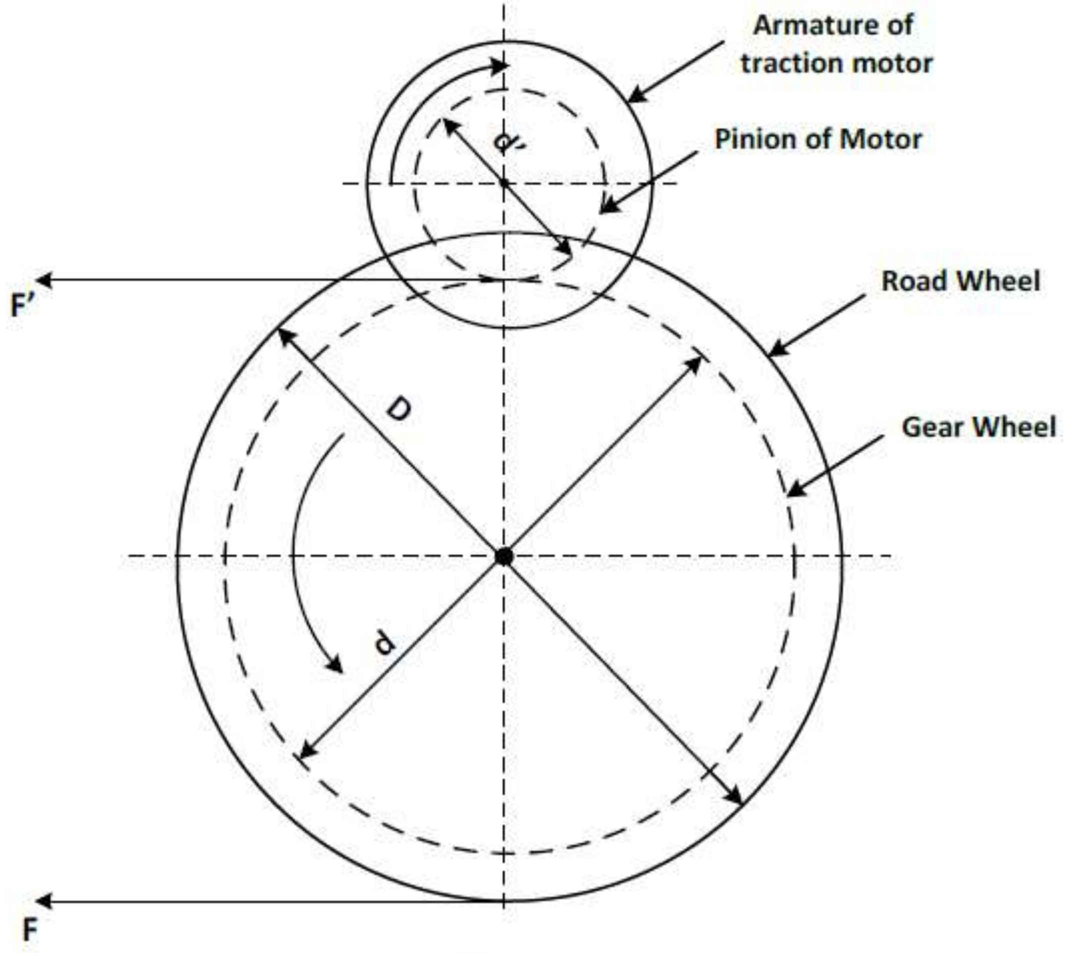


Figure 7.15 Transmission of Tractive Effort

$T = \text{Torque exerted by Motor}$
$F' = \text{Tractive effort at Pinion}$
$F = \text{Tractive effort at Wheel}$
$d' = \text{Diameter of Pinion}$
$d = \text{Diameter of gear Wheel}$
$D = \text{Diameter of Road Wheel}$
$\gamma = \text{gear ratio} = \frac{d}{d'}$
$\eta = \text{Efficiency of Transmission}$

Let, driving Motor exert a torque T in Nm
Tractive Effort at edge of pinion is given by

$$T = F'\frac{d'}{2} \text{ or } \boxed{F' = \frac{2T}{d'}}$$

Tractive effort transferred the driving wheel

$$F = \eta F'\left(\frac{d}{D}\right)$$

$$F = \eta \frac{2T}{d'}\left(\frac{d}{D}\right)$$

$$\boxed{F = \eta T \frac{2\gamma}{D}}$$

7.26 Co-efficient of adhesion(μ)

- Maximum friction force between driving wheel and track=μW
  Where, μ=co-efficient of adhesion between driving wheel and track
  W=Weight of train on driving axles
- Motion of train without slipping

$$\boxed{F \leq \mu W}$$

- Co-efficient of adhesion (μ)

$$\mu = \frac{\text{Tractive effort to slip the wheels}}{\text{Adhesive Weight}}$$

Table 7.5 Co-efficient of Adhesion

Speed in kmph	0	15	30	45	60	75
μ	0.25	0.18	0.14	0.12	0.10	0.09

- For clean dry rails μ=0.25
- For wet or greasy rails μ=0.08
- Depends upon
  - Friction between wheels and the rail track.
  - Series-Parallel connection of Motor.
  - Speed of Response of drive.
  - Smoothness with which torque can be controlled.
  - Nature of motor torque-speed characteristics.

7.18 Typical speed-time curve for main line service

- The Curve drawn between Speed and Time, taking Speed in km/hr on Y-axis and Time in Sec or min on X-axis is known as speed-time curve.
- It's give complete information of the motion of the train. (*Distance=Speed × Time*)
- Speed time curve mainly consists of
  - Acceleration.
  - Free Run or Constant Speed Run.
  - Coasting.
  - Retardation or Braking.

(a) Acceleration

- Constant Acceleration of Acceleration During Notching up
  - Nothing up period. (0 to t_1)
  - Current will remain constant.
  - Supply voltage will be increase. (By cutting out the starting resistance)
  - Tractive effort will remain constant.
  - Acceleration will be constant.
- Speed curve Running or Acceleration on speed curve
  - Speed curve running period. (t_1 to t_2)
  - Voltage will be constant. (Approx.)
  - Current will be decreasing and become constant.

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S. No.	Type of Service	Acceleration in kmphps	Retardation in kmphps	Maximum Speed in kmph	Distance between Stations in km
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2.	Suburban	1.5 to 4.00	3 to 4	75	1 to 8
3.	Main Line	0.6 to 0.8	1.5	110	More than 10

- Acceleration will be decreases and finally become zero.
- Tractive effort is equal to resistance to motion of train.

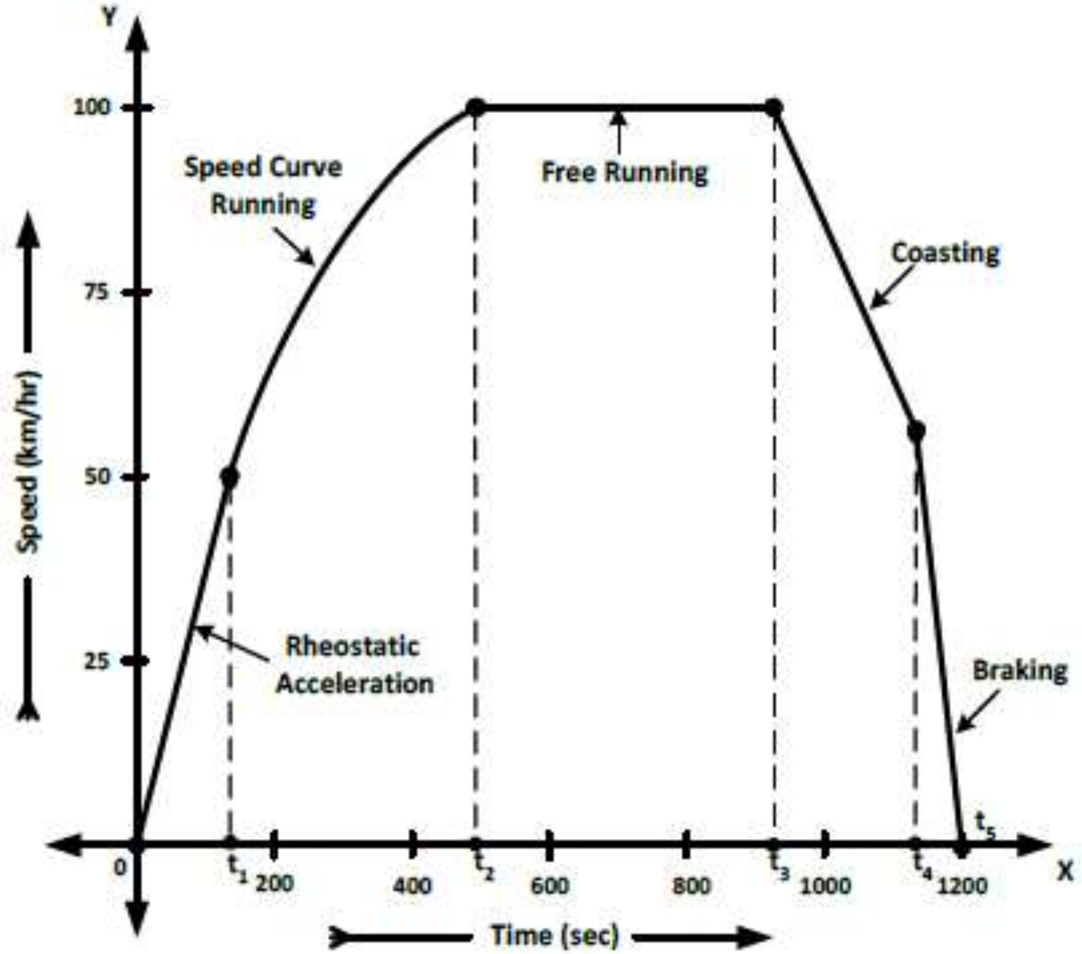


Figure 7.8 Typical Speed-Time curve for Main Line Service

(b) Free Run or Constant Speed Run

- Free run period. (t_2 to t_3)
- The train attains the maximum speed.
- During this period the train runs with constant speed and constant power is drawn.

(c) Coasting

- At the end of free running period (t_3 to t_4), power supply is cut off and the train is allowed to run under its own momentum.
- The speed of train starts decreasing on account of resistance to the motion of train.
- The rate of decrease of speed during coasting period is known as coasting retardation.

(d) Retardation or Braking Period

- At the end of coasting period (t_4 to t_5), the brakes are applied to bring the train to rest.
- During this period speed decreases rapidly and finally reduces to zero.

7.19 Typical speed-time curve for suburban and urban service

(a) Suburban Service

- In this service the distance between the stops is little longer than urban service but smaller than main line service (between 1 to 8 km).
- Free run is not possible.
- Coasting is for comparatively longer period.
- Acceleration and retardation required are as high as for urban service.

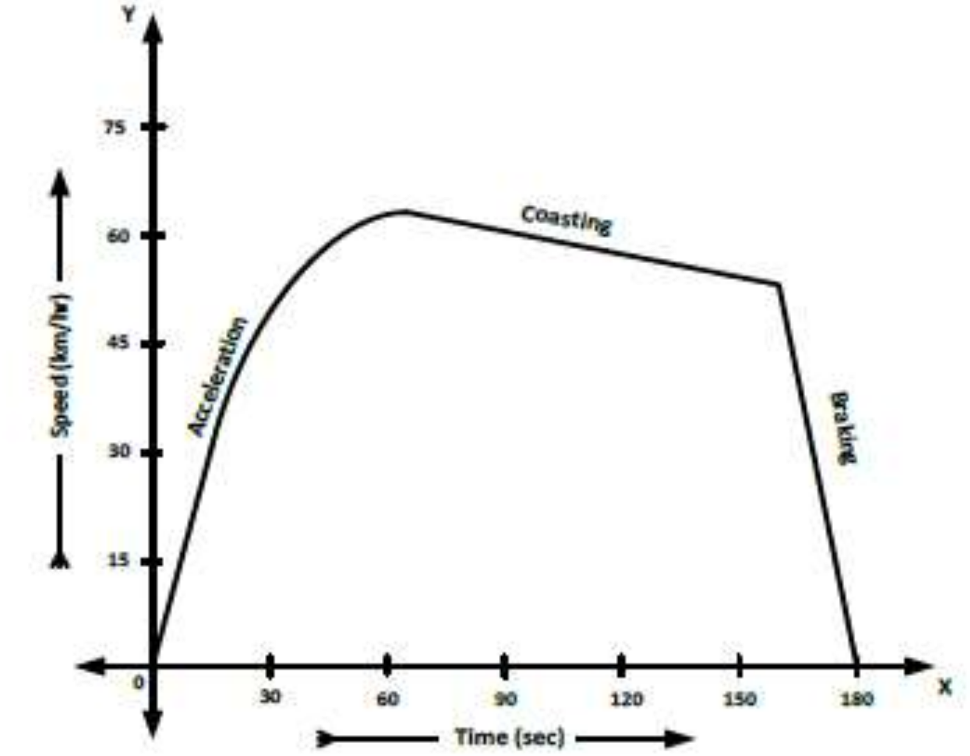


Figure 7.9 Typical Speed-Time curve for Suburban Service

(b) Urban Service or City Service

- In this service the distance between the stops is comparatively very short. (say 1 km or so)
- Time required for this run is very small.
- The acceleration as well as retardation is required to be high so that high average speed and short time run is obtained.
- Free run is not possible.
- Coasting period is also small.

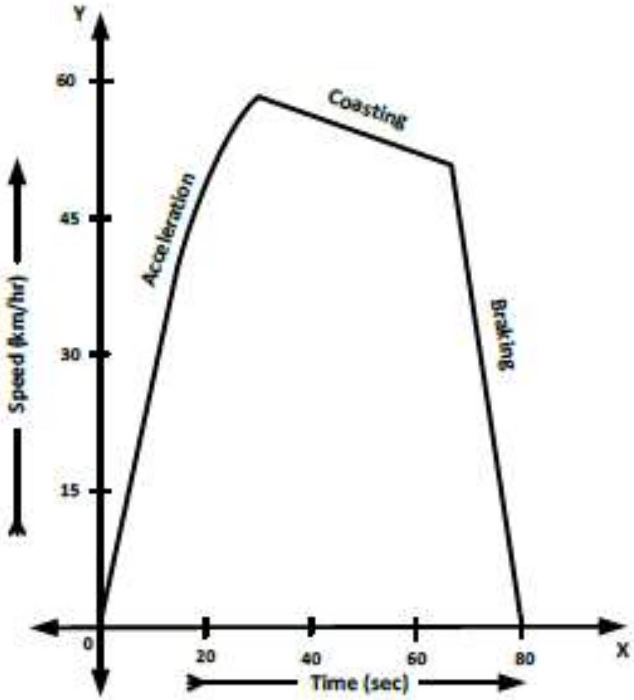


Figure 7.10 Typical Speed-Time curve for Urban Service

Table 7.4 Characteristics of Various type of Services

S. No.	Type of Service	Acceleration in kmphps	Retardation in kmphps	Maximum Speed in kmph	Distance between Stations in km
1.	Urban	1.5 to 4.00	3 to 4	60	1
2.	Suburban	1.5 to 4.00	3 to 4	75	1 to 8
3.	Main Line	0.6 to 0.8	1.5	110	More than 10

7.20 Crest speed, average speed and schedule speed

(a) Crest Speed

- The maximum speed attained by the vehicle during the run is known as crest speed.

(b) Average Speed

- The distance covered between two stops divided by the actual time of run is known as average speed.

$$Average\ Speed = \frac{Distance\ between\ Stops}{Actual\ Time\ of\ run, T}$$

(c) Schedule Speed

- The ratio of distance covered between two stops and total time of run including time of stop is known as schedule speed.

$$Schedule\ Speed = \frac{Distance\ between\ Stops}{Actual\ Time\ of\ run + Stop\ Time}$$

- Schedule Speed < Average Speed
- Difference is large in case of urban & sub-urban, negligibly small in case of main line service.

7.21 Factor affecting on schedule speed

- The Schedule speed of a given is affected by the following factors:

(a) Effect of acceleration and Braking Retardation

- For a given run and with fixed crest speed the increase in acceleration will result in decrease in actual time of run and therefore increase in schedule speed.
- Similarly increase in braking retardation will affect the schedule speed.
- Variation in acceleration and retardation will have more effect on schedule speed in case of shorter distance run in comparison to longer distance run.

(b) Effect on maximum speed

- For constant distance run and with fixed acceleration and retardation the actual time of run will decrease, and therefore schedule speed will increase with the increase in crest speed.
- The effect of variation in crest speed on schedule speed in considerable in case of long distance run.

(c) Effect on duration of stop

- For a given average speed the schedule will increase by reducing the duration of stop.
- The variation in duration of stop will affect the schedule speed more in case of shorter distance run as compared to longer distance run.

7.22 Simplified speed-time curve

- "Convert or Replace typical speed-time curve to simple geometric shaped curve is known as simplified speed-time curve."
- From these simplified curves, the relationships between acceleration, retardation, average speed and distance can be easily workout.
- Trapezoidal curve can be used for main line service and quadrilateral curve can be used for urban and sub-urban service.

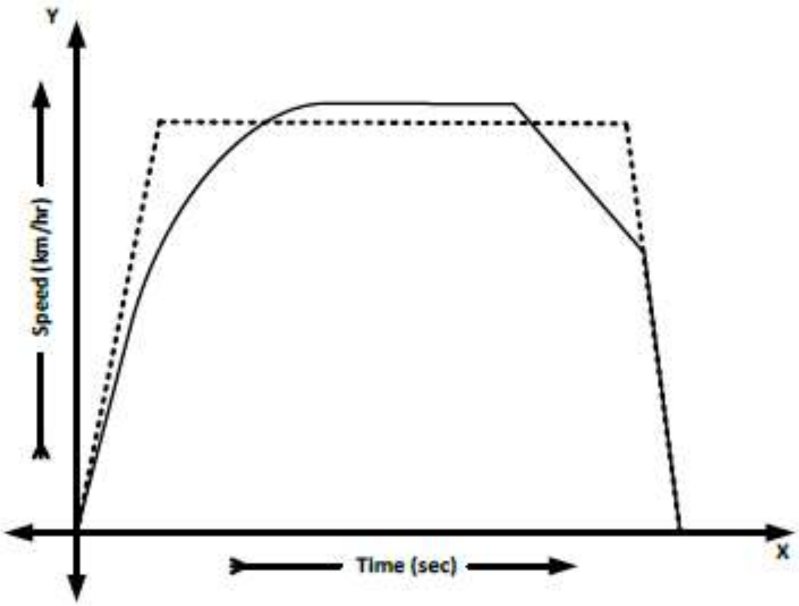


Figure 7.11 Approximate Trapezoidal Speed-Time Curves

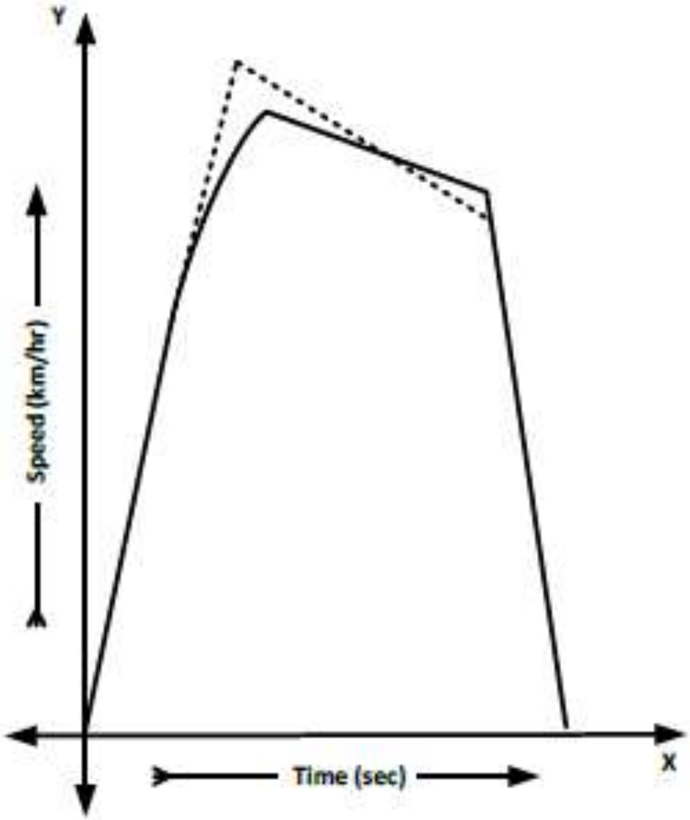


Figure 7.12 Approximate Quadrilateral Speed-Time Curves

7.23 Calculation by trapezoidal speed-time curve

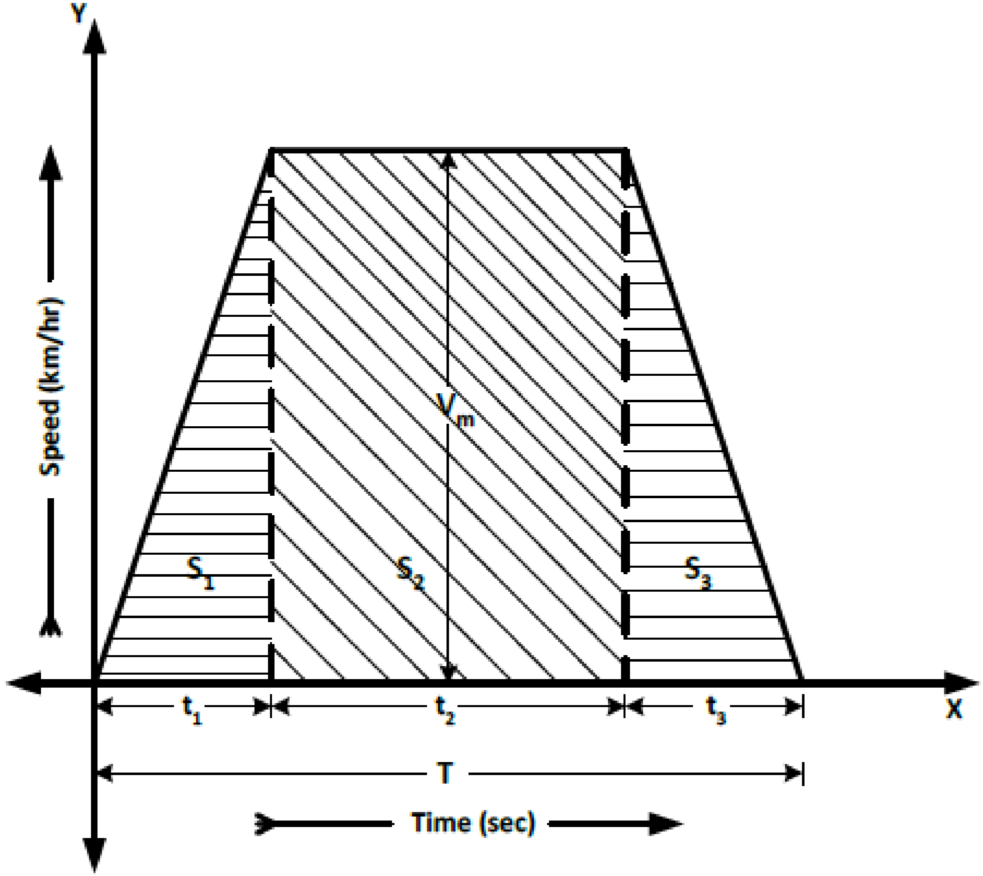


Figure 7.13 Trapezoidal Speed-Time Curves

α = *Acceleration in kmphps*

β = *Retardation in kmphps*

V_m = *Crest speed in kmph*

T = *Total time of run in sec*

$$Time\ for\ Acceleration\ in\ \sec,\ t_1 = \frac{V_m}{\alpha}$$

$$Time\ for\ Retardation\ in\ \sec,\ t_3 = \frac{V_m}{\beta}$$

$$Time\ for\ Free\ Run\ in\ \sec,\ t_2 = T - (t_1 + t_3)$$

$$= T - \left[\frac{V_m}{\alpha} + \frac{V_m}{\beta}\right]$$

Total Distance of Run, in km(S) = Distance travelled during acceleration + Distance travelled during free run + Distance travelled during retardation

$$S = S_1 + S_2 + S_3$$

$$S_1 = \frac{1}{2}\frac{V_m t_1}{3600}$$

$$put,\ t_1 = \frac{V_m}{\alpha}$$

$$S_1 = \frac{V_m^2}{7200\alpha}$$

$$S_2 = \frac{V_m t_2}{3600}$$

$$put,\ t_2 = T - \left[\frac{V_m}{\alpha} + \frac{V_m}{\beta}\right]$$

$$S_2 = \frac{V_m}{3600}\left[T - \left(\frac{V_m}{\alpha} + \frac{V_m}{\beta}\right)\right]$$

$$S_2 = \frac{V_m T}{3600} - \frac{V_m^2}{3600\alpha} - \frac{V_m^2}{3600\beta}$$

$$S_3 = \frac{1}{2}\frac{V_m t_3}{3600}$$

$$put,\ t_3 = \frac{V_m}{\beta}$$

$$S_3 = \frac{V_m^2}{7200\beta}$$

Now,

$$S = S_1 + S_2 + S_3$$

$$= \frac{V_m^2}{7200\alpha} + \frac{V_m T}{3600} - \frac{V_m^2}{3600\alpha} - \frac{V_m^2}{3600\beta} + \frac{V_m^2}{7200\beta}$$

$$= \frac{V_m^2}{\alpha}\left[\frac{1}{7200} - \frac{1}{3600}\right] + \frac{V_m^2}{\beta}\left[\frac{1}{7200} - \frac{1}{3600}\right] + \frac{V_m T}{3600}$$

$$= \frac{V_m^2}{\alpha}\left[\frac{1-2}{7200}\right] + \frac{V_m^2}{\beta}\left[\frac{1-2}{7200}\right] + \frac{V_m T}{3600}$$

$$S = \frac{V_m T}{3600} - \frac{V_m^2}{7200\alpha} - \frac{V_m^2}{7200\beta}$$

$$\therefore \frac{V_m^2}{3600}\left[\frac{1}{2\alpha} + \frac{1}{2\beta}\right] - \frac{V_m T}{3600} + S = 0$$

$$\therefore V_m^2\left[\frac{1}{2\alpha} + \frac{1}{2\beta}\right] - V_m T + 3600S = 0$$

$$take,\ K = \left[\frac{1}{2\alpha} + \frac{1}{2\beta}\right]$$

$$\therefore V_m^2 K - V_m T + 3600S = 0$$

Using quadratic equation,
$a = K, b = -T, c = 3600S$

$$V_m = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$V_m = \frac{T \pm \sqrt{T^2 - 4K3600S}}{2K}$$

$$V_m = \frac{T}{2K} \pm \sqrt{\frac{T^2}{4K^2} - \frac{3600S}{K}}$$

for +Ve sign will be much higher value than that is possible in practical value.
so, take -Ve sign for calculation

$$\boxed{V_m = \frac{T}{2K} - \sqrt{\frac{T^2}{4K^2} - \frac{3600S}{K}}}$$

7.24 Calculation by quadrilateral speed-time curve

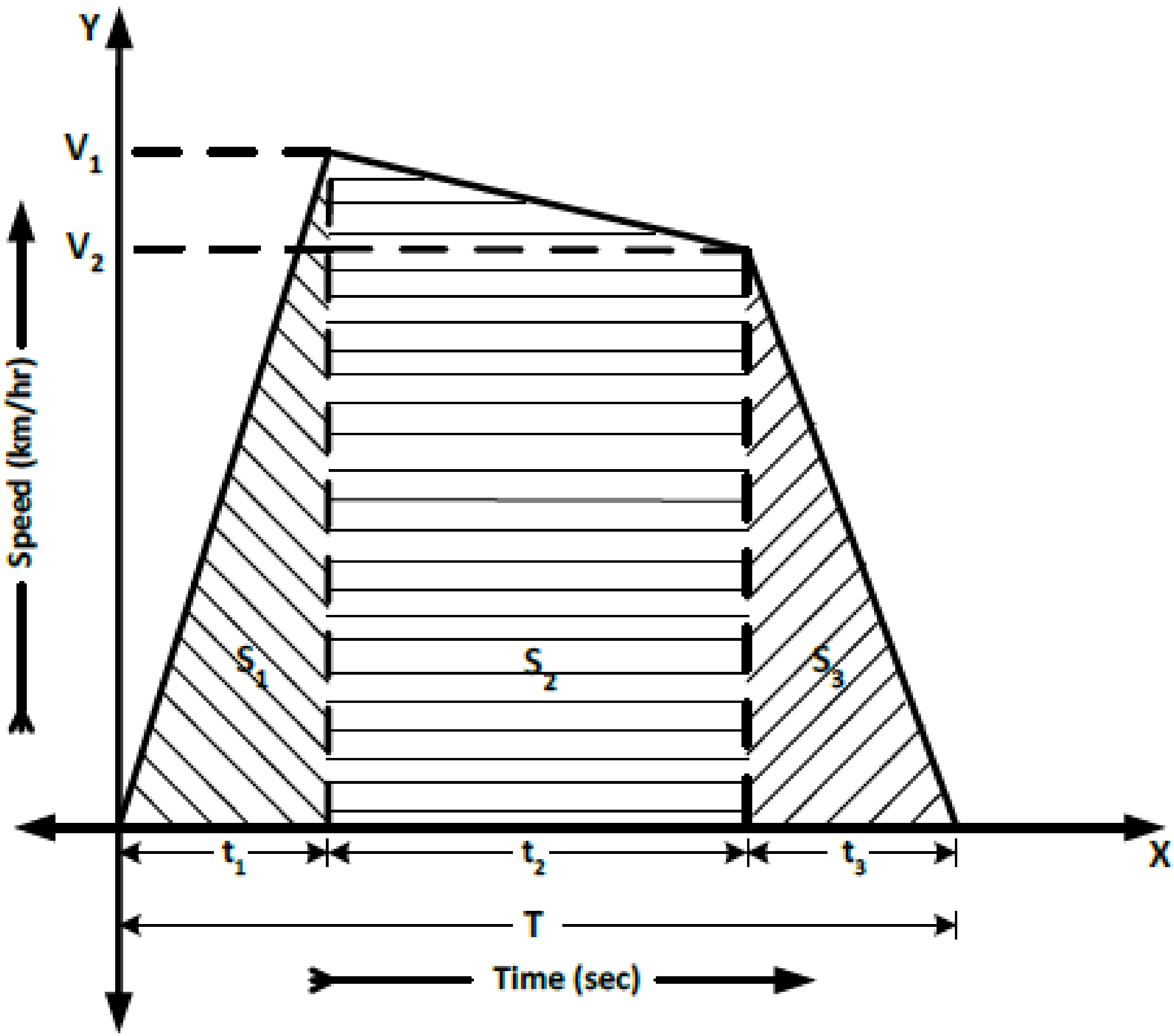


Figure 7.14 Quadrilateral Speed-Time Curves

α = Acceleration in kmphps
β_c = Coasting Retardation in kmphps
β = Braking Retardation in kmphps
V_1 = Maximum speed at the end of acceleration in kmph
V_2 = Maximum speed at the end of Coasting in kmph
T = Total time of run in sec

Time for Acceleration in sec, $t_1 = \frac{V_1}{\alpha}$

Time for Retardation in sec, $t_3 = \frac{V_2}{\beta}$

Time for Free Run in sec, $t_2 = \frac{V_1 - V_2}{\beta_c}$

Total Distance of Run, in km(S) = Distance travelled during acceleration + Distance travelled during coasting + Distance travelled during braking

$$S = S_1 + S_2 + S_3$$

$$S_1 = \frac{1}{2}\frac{V_1 t_1}{3600}$$

$$S_2 = \frac{V_2 t_2}{3600} + \frac{1}{2}\frac{(V_1 - V_2)t_2}{3600} = \left(\frac{V_1 + V_2}{2}\right)\frac{t_2}{3600}$$

$$S_3 = \frac{1}{2}\frac{V_2 t_3}{3600}$$

Now,

$$S = S_1 + S_2 + S_3$$

$$S = \frac{1}{2}\frac{V_1 t_1}{3600} + \left(\frac{V_1 + V_2}{2}\right)\frac{t_2}{3600} + \frac{1}{2}\frac{V_2 t_3}{3600}$$

$$= \frac{V_1 t_1}{7200} + \frac{V_1 t_2}{7200} + \frac{V_2 t_2}{7200} + \frac{V_2 t_3}{7200}$$

$$S = \frac{V_1}{7200}(t_1 + t_2) + \frac{V_2}{7200}(t_2 + t_3)$$

$$Put\ \ t_1 + t_2 + t_3 = T$$

$$S = \frac{V_1}{7200}(T - t_3) + \frac{V_2}{7200}(T - t_1)$$

$$= \frac{T}{7200}(V_1 + V_2) - \frac{V_1 t_3}{7200} - \frac{V_2 t_1}{7200}$$

$$Put,\ t_1 = \frac{V_1}{\alpha}\ \ \&\ \ t_3 = \frac{V_2}{\beta}$$

$$S=\frac{T}{7200}(V_1+V_2)-\frac{V_1}{7200}\frac{V_2}{\beta}-\frac{V_2}{7200}\frac{V_1}{\alpha}$$

$$\boxed{7200S=T(V_1+V_2)-V_1V_2\left[\frac{1}{\alpha}+\frac{1}{\beta}\right]}$$

Now,

$$t_2=\frac{V_1-V_2}{\beta_c}$$

$$V_2=V_1-t_2\beta_c$$

$$V_2=V_1-\beta_c\,(T-t_1-t_3)$$

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

$$\left[V_2-\frac{\beta_c}{\beta}V_2\right]=V_1-\beta_c\,(T-\frac{V_1}{\alpha})$$

$$\boxed{V_2=\frac{V_1-\beta_c\,\mathrm{T}+\frac{\beta_c}{\alpha}V_1}{1-\frac{\beta_c}{\beta}}}$$

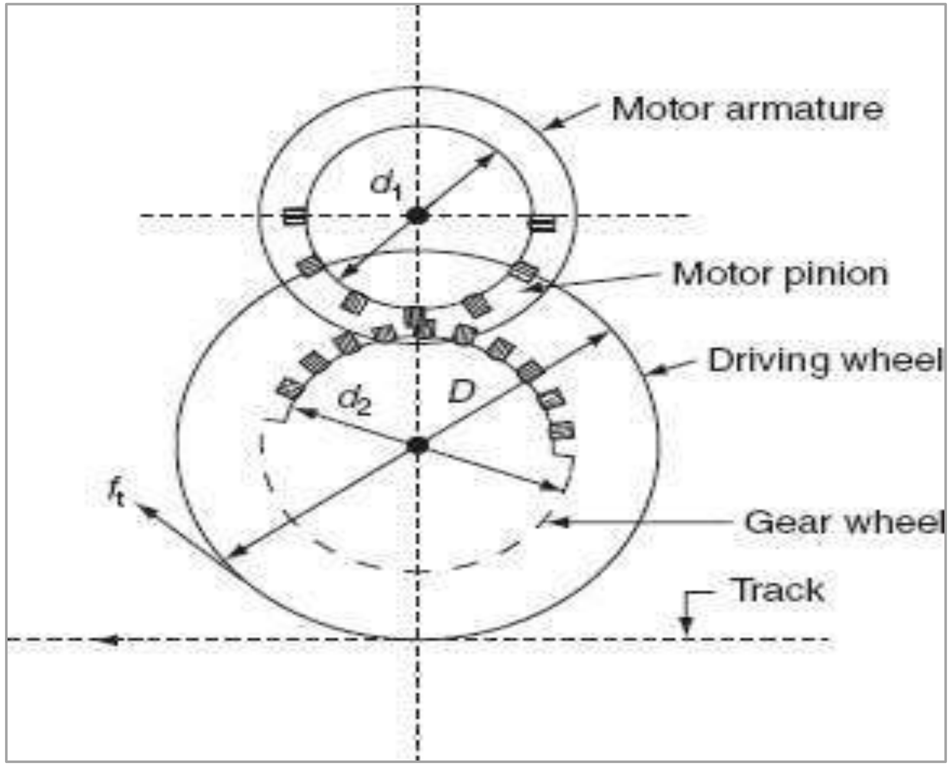
UNIT-V: Electric Traction-II

CONTENTS:-

1. Mechanics of train movement.
2. Calculations of tractive effort (F_T).
3. Power output from the driving axle.
4. Specific energy consumption.
5. adhesive weight and coefficient of adhesion

Mechanics of train movement:

The essential driving mechanism of an electric locomotive is shown in Figure. The electric locomotive consists of **pinion and gear wheel meshed with the traction motor** and the wheel of the locomotive. Here, the gear wheel transfers the tractive effort at the edge of the pinion to the driving wheel.



Let , T = torque exerted by the motor in N-m,

F_p = tractive effort at the edge of the pinion in Newton,

Ft **=** tractive effort(Force) at the wheel.

D = diameter of the driving wheel.

d1 & d2 = diameter of pinion and gear wheel respectively and

η = efficiency of the power transmission for the motor to the driving axle.

The torque developed by the **motor to pinion** is,

The torque developed by the **motor to pinion** is,

$$T = F_P \times \frac{d_1}{2}, \text{ N-m}$$

$$Hence, \quad F_P = \frac{2T}{d_1}, Newtons$$

The tractive effort(force) at the **edge of the pinion transferred to the wheel of locomotive is**:

$$F_t = F_P \times \frac{d_2}{D}, Newtons$$

From the above equations, $F_t = \eta \times \frac{2T}{d_1} \times \frac{d_2}{D}$

$$= \eta \times T \times \frac{2}{D} \times \frac{d_2}{d_1}$$

$$= \eta \times T \times \frac{2}{D} \times r$$

2. Calculations of Tractive effort (F_t):

It is the effective force acting on the wheel of locomotive is necessary to propel the train is known as '*tractive effort*'. It is denoted with the symbol ***F*t.** The tractive effort is a vector quantity always acting tangential to the wheel of a locomotive. It is measured in newton.

The net effective force (or) the total tractive effort ***(Ft)*** on the wheel of a locomotive to run on the track is equals to the sum of tractive effort,

$$F_t = (F_a + F_r \pm F_g)$$

where ***F*a** is the force required for linear and angular acceleration, ***F*g** is the force required to overcome the gravity, and ***F*r** is the force required to overcome the resistance to the motion.

Factors affecting the Specific Energy Consumption:

Four factors mainly that affect on the specific energy consumption are:

(1) Distance between stations:-

From equation of specific energy consumption is inversely proportional to the distance between stations. Greater the distance between stops is, the lesser will be the specific energy consumption.

The typical values of the specific energy consumption is less for the main line service of 20–30 W-hr/ton-km and high for the urban and suburban services of 50–60 W-hr/ton-km.

(2) Acceleration and Retardation:-

For a given schedule speed, the specific energy consumption will accordingly be less for more acceleration and retardation.

(3) Maximum speed:-

For a given distance between the stops, the specific energy consumption increases with the increase in the speed of train.

(4) Gradient and train resistance:

From the specific energy consumption, it is clear that both gradient and train resistance are proportional to the specific energy consumption. For high gradients ang train resistance the specific energy consumption will be more.

5. adhesive weight and coefficient of adhesion:

(1) Dead weight:-

It is the total weight of train to be propelled by the locomotive. It is denoted by **' W '.**

(2) 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 **'We'.**

This effective weight of a 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.

(3) Adhesive weight:

The total weight of the train and locomotive to be carried out on the driving wheels of a locomotive is known as **adhesive weight (Wa),** which determines the **frictional grip between wheels and locomotive.**

(4). 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.

$$\mu = \frac{F_t}{W_a}$$

where , **Ft** = tractive effort.

Wa = adhesive weight.

μ = Coefficient of adhesion.

Normally, the coefficient of adhesion will be affected by the speed of a running train, percentage gradient, condition of track, etc. For the wet and greasy track conditions, The value of the coefficient of adhesion is less compared to dry and sandy conditions.

7.27 Tractive effort for propulsion of train

- "The effective force necessary to propel the train at the wheel of locomotive is called the tractive effort." It measured in N.
- Total tractive effort required to run a train on track = Tractive effort required for linear and angular acceleration + Tractive effort to overcome the effort of gravity + Tractive effort to overcome the train resistance.
- $Ft = F_a \pm F_g + F_r$

(a) Tractive effort for Acceleration

- According to laws of dynamics,

$$Force = mass(kg) \times Acceleration(m/s^2)$$

$$F = m\,\alpha\ (N \text{ or } kg{\cdot}m/s^2)$$

$m = W$ (tones) (weight of train)

$m = 1000W$ kg-- (1)

Acceleration $= \alpha$ (km/h/s)

$= \alpha \times 1000/3600\ (m/s^2)$

$= 0.2778\ \alpha\ (m/s^2)$--------------------- (2)

- So, tractive effort required for linear acceleration

$F_a = m\,\alpha = 1000W \times 0.2778\,\alpha$

$\underline{F_a = 277.8\ W\alpha\ (N)}$

- Rotating parts of train such as wheels & motor also accelerate in angular direction.
- Tractive effort required is equal to tractive effort required to have angular acceleration of rotating parts and tractive effort required to have the linear acceleration.
- Angular acceleration depends on individual weight and radius of gyration of the rotating parts of train,

W_e = Equivalent or acceleration weight of train

$W_e > W$ (8 to 15%)

- Tractive effort required for acceleration

$\underline{F_a = 277.8\ W_e\ \alpha\ (N)}$

(b) Tractive effort to overcoming the effect of gravity

"When a train is on a slope, a force of gravity equal to the component of the dead weight along the slope acts on the train and tends to cause its motion down the gradient or slope."

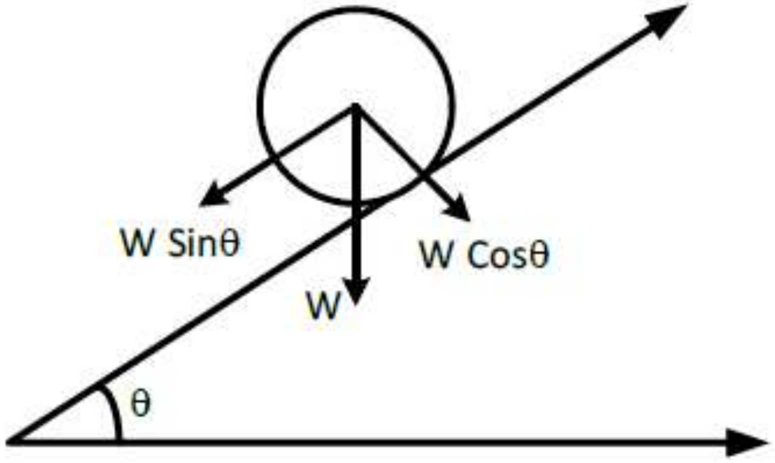


Figure 7.16 Effect of Gravity

- *Force due to gradient,* $F_g = 1000W\sin\theta$ *(kg).*
- *Percentage gradient (G%)*

$G = \sin\theta$

$G\% = 100 * \sin\theta$

$\underline{\sin\theta = (G\%)/100}$

$F_g = 10WG\%$ (kg)

$= 10WG\% * 9.81$ (N)

$\underline{F_g = 98.1WG\%\ (N)}$

(c) Tractive effort to overcome train resistance

- Train Resistance consists of all the forces resisting the motion of a train when it is running at uniform speed on a straight and level track.
- Train resistance
  - The friction at the various parts of the rolling stock.
  - The friction between the track and wheel.
  - Air resistance.
- The general equation for the train resistance is given as

  $R=K_1+K_2V+K_3V^2$

  Where, K_1, K_2, K_3 are constant and depends upon type of train and track

  R is resistance in N

  V is speed in km/hr
- Tractive effort required to overcome the train resistance

  $F_r=W*r$ (N)

  Where, r=Specific train Resistance, N/tonne of dead weight

Total Tractive Effort:-

$F_t=F_a \pm F_g F_r$

$F_t=277.8\ W_e\alpha \pm 98.1WG\%+W*r$

+ve sign for the motion up the gradient

-ve sign for the motion down the gradient

SPECIFIC ENERGY CONSUMPTION

The energy input to the motors is called the *energy consumption*. This is the energy consumed by various parts of the train for its propulsion. The energy drawn from the distribution system should be equals to the energy consumed by the various parts of the train and the quantity of the energy required for lighting, heating, control, and braking. This quantity of energy consumed by the various parts of train per ton per kilometer is known as specific energy consumption. It is expressed in watt hours per ton per km.

$$\therefore \left.\begin{array}{r}\text{Specific energy}\\ \text{consumption}\end{array}\right\} = \frac{\text{total energy consumption in W} - \text{h}}{\text{the weight of the train in tons} \times \text{the distance covered by train in km}}$$

Determination of specific energy output from simplified speed–time curve

Energy output is the energy required for the propulsion of a train or vehicle is mainly for accelerating the rest to velocity 'V_m', which is the energy required to overcome the gradient and track resistance to motion.

Energy required for accelerating the train from rest to its crest speed 'Vm'

The energy required for accelerating the train = power × time

$$= \frac{\text{work done}}{\text{time}} \times \text{time}$$

$$= \text{tractive effort} \times \text{velocity} \times \text{time}$$

$$= F_t \times \frac{V_m}{3,600} \times t_1 \text{ N-km/h-sec}$$

$$= F_t \times \frac{1}{2} \times \frac{V_m}{3,200} \times \frac{t_1}{3,600} \text{ N-km (or) kW-hr}$$

$$= \frac{1}{2} \times \frac{V_m^{\,2}}{(3,600)^2\,\alpha} F_t \text{ kw-hr} \left[\because t_1 = \frac{V_m}{\alpha}\right]$$

$$= \frac{1}{2} \times \frac{V_m^{\,2}}{(3,600)^2\,\alpha} [277.8 W_e \alpha + 98.1\, WG + Wr] \text{kW-hr.}$$

$[\because F_t = 277.8 W_e\,\alpha + 98.1\ WG + Wr]$.

Energy required for overcoming the gradient and tracking resistance to motion

Energy required for overcoming the gradient and tracking resistance:

$$= \text{tractive effort} \times \text{velocity} \times \text{time}$$
$$= F_t' \times \frac{V_m}{3,600} \times \frac{t_2}{3,600} \text{kW-hr}$$
$$= \frac{V_m t_2}{(3,600)^2}[Wr + 98.1 WG] \text{kW-hr},$$

where F_t' is the tractive effort required to overcome the gradient and track resistance, W is the dead weight of train, r is the track resistance, and G is the percentage gradient.

Total energy output = energy required for acceleration + energy required to overcome gradient and to resistance to motion.

$$= \frac{V_m^2}{2(3,600)^2\alpha}[277.8\,W_e\alpha + 98.1\,WG + Wr] + \frac{V_m t_2}{(3,600)^2}[Wr + 98.1\,WG]\,\textbf{kW-hr}$$

$$= \frac{V_m^2(1,000)}{2(3,600)^2\alpha}[277.8\,W_e\alpha + 98.1\,WG + Wr] + \frac{V_m t_2 \times 1,000}{(3,600)^2}[Wr + 98.1\,WG]\,\text{W-hr}$$

$$= \frac{V_m^2(1,000)}{2\alpha(3,600)^2}[27.8\,W_e\alpha] + \left[\frac{V_m^2(1,000)}{2\alpha(3,600)^2} + \frac{V_m t_2 \times 1,000}{(3,600)^2}\right][Wr + 98.1\,WG]\,\text{W-hr}$$

$$= 0.01072\,W_e V_m^2 + \frac{1,000}{(3,600)}[Wr + 98.1\,WG]\left[\frac{V_m^2}{2\alpha 3,600} + \frac{V_m t_2}{3,600}\right]\text{W-hr}$$

$$= 0.01072\,W_e V_m^2 + 0.2778[Wr + 98.1\,WG][D_1 + D_2]\,\text{W-hr},$$

where $D_1 = \frac{V_m^2}{2\alpha 3,600} = \frac{V_m^2}{7,200\alpha}$.

$D_2 = \frac{V_m t_2}{3,600}$.

$\therefore$ The specific energy output $= \frac{\text{energy output in Whr}}{\text{weight of train in tons} \times \text{distance of running}}$

$$= \frac{0.001072 V_m^2 W_e + 0.2778[98.1 WG + Wr][D_1 + D_2]}{W \times D}$$

$$= \frac{0.001072 V_m^2}{D}\left[\frac{W_e}{W}\right] + \left[\frac{98.1\ G + r}{D}\right] \times 0.2778 \times D',$$

where $D' = D_1 + D_2$.

For uniform level track $G = 0$:

$\therefore$ The specific energy output $= \frac{0.001072 V_m^2}{D} \frac{W_e}{W} + 0.2778 r \times \frac{D'}{D}$ W-hr/ton-km.

$\therefore$ The specific energy consumption $= \frac{\text{specific energy output}}{\text{efficiency of motors}}$

$$= \frac{0.001072 V_m^2}{\eta D} \frac{W_e}{W} + 0.2778 \frac{D'}{D} \frac{r}{\eta} \text{ W-hr/ton-km.} \qquad \textbf{(10.21)}$$

Factors affecting the specific energy consumption

Factors that affect the specific energy consumption are given as follows.

Distance between stations

From equation specific energy consumption is inversely proportional to the distance between stations. Greater the distance between stops is, the lesser will be the specific energy consumption. The typical values of the specific energy consumption is less for the main line service of 20–30 W-hr/ton-km and high for the urban and suburban services of 50–60 W-hr/ton-km.

Acceleration and retardation

For a given schedule speed, the specific energy consumption will accordingly be less for more acceleration and retardation.

Maximum speed

For a given distance between the stops, the specific energy consumption increases with the increase in the speed of train.

Gradient and train resistance

From the specific energy consumption, it is clear that both gradient and train resistance are proportional to the specific energy consumption. Normally, the coefficient of adhesion will be affected by the running of train, parentage gradient,

condition of track, etc. for the wet and greasy track conditions. The value of the coefficient of adhesion is much higher compared to dry and sandy conditions.

1 Dead weight

It is the total weight of train to be propelled by the locomotive. It is denoted by 'W'.

2 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.

3 Adhesive weight

The total weight to be carried out on the drive in wheels of a locomotive is known as adhesive weight.

4 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.

$$F_t \propto W$$

$$= \mu W, \qquad \therefore \mu = \frac{F_t}{W}.$$

where F_t is the tractive effort and W is the adhesive weight.

Example 10.1: The distance between two stops is 1.2 km. 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 2 kmphp and 3 kmphp, respectively. Then, determine the maximum speed over the run. Assume a simplified trapezoidal speed–time curve.

Solution:

Acceleration $\alpha = 2.0$ kmphp.

Retardation $\beta = 3$ kmphp.

Schedule speed $V_s = 40$ kmph.

Distance of run, D = 1.2 km.

$$\text{Schedule time, } T_s = \frac{D \times 3,600}{V_s} = \frac{1.2 \times 3,600}{40} = 108 \text{ s.}$$

Actual run time, $T = T_s -$ stop duration

$$= 108 - 18$$

$$= 90 \text{ s.}$$

Maximum speed $V_m = \frac{T}{2X} - \sqrt{\frac{T^2}{4X^2} - \frac{3,600D}{X}}$,

$$X = \frac{1}{2\alpha} + \frac{1}{2\beta}$$

$$= \frac{1}{2\times 2} + \frac{1}{2\times 3}$$

$$= 0.416.$$

$$\therefore V_m = \frac{90}{2\times 0.416} - \sqrt{\frac{(90)^2}{4\times(0.416)^2} - \frac{3,600\times 1.2}{0.416}}$$

$$= 108.173 - \sqrt{(1,1701.414) - (1,0384.61)}$$

$$= 71.88 \text{ kmph.}$$

Example 10.2: The speed–time curve of train carries of the following parameters:

1. Free running for 12 min.
2. Uniform acceleration of 6.5 kmphp for 20 s.
3. Uniform deceleration of 6.5 kmphp to stop the train.
4. A stop of 7 min.

Then, determine the distance between two stations, the average, and the schedule speeds.

Solution:

Acceleration (α) = 6.5 kmphps.

Acceleration period t_1 = 20 s.

Maximum speed $V_m = \alpha t_1$

$$= 6.5 \times 20 = 130 \text{ kmph.}$$

Free-running time $(t_2) = 12 \times 60$

$$= 720 \text{ s.}$$

$$\text{Time for retardation, } (t_3) = \frac{V_m}{\beta}$$

$$= \frac{130}{6.5} = 20 \text{ s.}$$

The distance travelled during the acceleration period:

$$D_1 = \frac{1}{2}\frac{V_m t_1}{3,600}$$

$$= \frac{1}{2} \times \frac{130 \times 20}{3,600}$$

$$= 0.36 \text{ km.}$$

The distance travelled during the free-running period:

$$D_2 = \frac{V_m t_2}{3,600}$$

$$= \frac{130 \times 720}{3,600}$$

$$= 26 \text{ km.}$$

The distance travelled during the braking period $D_3 = \frac{V_m t_3}{7,200}$

$$= \frac{130 \times 20}{7,200}$$

$$= 0.362 \text{ km.}$$

The distance between the two stations:

$$D = D_1 + D_2 + D_3$$

$$= 0.36 + 26 + 0.362$$

$$= 26.724 \text{ km.}$$

$$\text{Average distance } (V_{avg}) = \frac{D \times 3600}{T}$$

$$= \frac{26.724 \times 3600}{20 + 720 + 20}$$

$$= 126.58 \text{ kmph.}$$

$$\text{Schedule speed } (V_s) = \frac{D \times 3600}{T + \text{stoptime}}$$

$$= \frac{26.724 \times 3,600}{20 + 720 + 20 + 70 \times 60}$$

$$= 81.53 \text{ kmph.}$$