LECTURE NOTES

ON

FUNDAMENTALS OF UTILIZATION OF ELETRICAL ENERGY

ACADEMIC YEAR 2023-2024

III B.tech II SEM (R20)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

III Year – II SEMESTER		L	T	P	C
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FUNDAMENTALS OF UTILIZATION OF ELECTRICAL ENERGY
(OPEN ELECTIVE – II)

Preamble:

In the modern society, every engineer is using electrical energy irrespective of their branch of specialization. To provide knowledge about the various electrical energy utilization technologies to non-electrical engineering students this course is developed. In this course, a detailed description about the illumination requirements and energy storage, various techniques used for heating & welding applications, and brief description about the electric traction are presented. At the end of the course, an insight in to the important techniques of various energy storage systems is also presented.

Course Objectives:

- To study the various types of Illumination equipment, measurement of Illumination, Illumination techniques.
- To know the various technologies used for heating applications using electrical energy.
- To understand the various welding techniques and operations of welding equipment and comparison.
- To know the various systems of traction, equipment used for traction.
- To understand the importance and operation of various Energy storage systems and comparison & applications.

UNIT - I

Illumination fundamentals

Introduction - terms used in illumination–Laws of illumination–Lux meter–Sources of light.

Various Illumination Methods

Tungsten filament lamps and fluorescent lamps - Comparison –Basic principles of light control– Types and design of lighting and flood lighting–LED lighting - Energy conservation.

UNIT - II

Electric Heating

Advantages and methods of electric heating–Resistance heating induction heating and dielectric heating.

UNIT - III

Electric Welding

Electric welding–Resistance and arc welding–Electric welding equipment–Comparison between AC and DC Welding

UNIT - IV

Electric Traction

System of electric traction and track electrification– Review of existing electric traction systems in India–Special features of traction motor– Mechanics of train movement–Speed–time curves for different services – Trapezoidal and quadrilateral speed time curves. Calculations of tractive effort– power –Specific energy consumption for given run–Effect of varying acceleration and braking retardation–Adhesive weight and braking retardation adhesive weight and coefficient of adhesion.

UNIT - V

Introduction to Energy Storage Systems

Need for energy storage - Types of energy storage-Thermal - electrical - magnetic and chemical storage systems - Comparison of energy storage technologies-Applications.

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Course Outcomes:
After the completion of the course the student should be able to:

- Know the concepts of illumination and various illumination methods.
- Know about the resistance - induction and dielectric heating.
- Learn about the resistance and arc welding and welding equipment
- Know about the mechanisms - equipment and technology used in the electric traction.
- Differentiatethe importance of various energy storage systems

Text Books:

1. Electrical Power Systems(Generation, Transmission, Distribution, Protecection and Utilization of Electrical Energy) – Dr. S.L.Uppal and Prof. Sunil S.Rao – Khanna Publisher, 15th edition, 1987.
2. Electric Power Distribution – A S Pabla – McGrawHill.

Reference Books:

1. Generation Distribution and Utilization of Electrical Energy – C.L.Wadhwa- New Age International Publishers- revised third edition.

UNIT-1

Selection of Motors

1) List the advantages and disadvantages of Electric drive.

There are a number of inherent advantages that the electric drive possesses over the other forms of conventional drives are:

- They have comparatively long life than the mechanical drive.
- It is cleaner, as there are no flue gases, etc.
- It is more economical.
- They have flexible control characteristics.
- There is no need to store fuel or transportation.
- It requires less maintenance.
- Do not pollute environment.
- It is the reliable source of drive.
- The electrical energy can be easily transmitted by using transmission lines over long distances.
- Available in wide range of torque, speed, and power.
- High efficiency.
- Electric braking system is much superior and economical.
- Smooth speed control is easy.
- They can be started instantly and can immediately be fully loaded.
- They can operate in all the quadrants of speed torque plane.
- Being compactness, they require less space.
- They can be controlled remotely.

The two inherit disadvantages of the electric drive system are:

- The non-availability of drive on the failure of electrical power supply.
- It cannot be employed in distant places where electric power supply is not available.

2) Explain how Electric drives are classified and illustrate them with their relative merits and demerits.

Depending on the type of equipment used to ran the electric motors in industrial purpose, they may be classified into three types. They are:

1. Group drives.
2. Individual drives.
3. Multi-motor drives.

Group drives

Electric drive that is used to drive one or more than two machines from line shaft through belts and pulleys is known as *group drive.* It is also sometimes called the *line shaft drive.*This drive is economical in the consideration of the cost of motor and control gear. A single motor of large capacity cost is less than the total cost of a number of small motors of the same total capacity

Advantages

o The cost of installation is less. For example, if the power requirement of each machine is 10 HP and there are five machines in the group, then the cost of five motors will be more than one 50-HP motor.

o If it is operated at rated load, the efficiency and power factor of large group drive motor will be high.

o The maintenance cost of single large capacity motor is less than number of small capacity motors.

o It is used for the processes where the stoppage of one operation necessitates the stoppages of sequence of operations as incase of textile mills.

o It has overload capacity.

Disadvantage

Even though group drive has above advantages, it suffers from the following disadvantages.

o If there is any fault in the main motor, all the machines connected to the motor will fail to operate; thereby, paralyzing a part of industry until the fault is removed.

o It is not possible to install any machine at a distant place.

o The possibility of the installation of additional machines in an existing industry is limited.

o The level of noise produced at the work site is quite large.

o The speed control of different machines using belts and pulleys is difficult.

o The flexibility of layout is lost due to line shaft, belts, and pulleys.

Individual drive

In individual drive, a single electric motor is used to drive one individual machine. Such a drive is very common in most of the industries.

Advantages

- It is more clean and safety.
- Machines can be located at convenient places.
- If there is a fault in one motor, the output and operation of the other motors will not be effected.
- The continuity in the production of the industry is ensured to a higher degree.
- Individual drive is preferred for new factories, as it causes some saving in the cost.

Disadvantage

- Initial cost will be high.
- Power loss is high.

Multi-motor drive

In multi-motor drives, several separate motors are provided for operating different parts of the same machine.

Ex: In traveling cranes, three motors are used for hoisting, long travel, and cross-travel motions. Multi-motor drive is used in complicated metal cutting machine tools, rolling mills, paper making machines, etc.

3) State the important factors on which the selection of Electric motor depends?

The selection of the driving motor for a given service depends upon the conditions under which it has to operate. Due to the universal adoption of electric drive, it has become necessary for the manufacturer to manufacture motors of various designs according to the suitability and the use in various designs according to the suitability and the use in various classes of industry.

The conditions under which an electric motor has to operate and the type of load it has to handle, determine its selection. While selecting a motor, the following factors must be taken into consideration:

Cost:

1. initial cost and
2. running cost.

Electric characteristics:

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

Mechanical characteristics:

1. Type enclosure and bearings,
2. Arrangement for the transmission of power,
3. Noise, and
4. Cooling.

Size and vetting of motors:

1. Requirements for continuous, Intermittent, or variable load cycle and
2. Overload capacity.

Type of drive:

The drive is for one or more machines and
The type of transmission through gears, belts, etc.

Nature of supply.

From the above, it is seen that a large number of factors are to be considered in making the choice of an electric motor for a given drive. The motor selected must fulfill all the necessary load requirements and at the same time, it should not be very costly if it has to be a commercial success.

4) State the important factors on which the selection of Electric drive depends?

Some of the *important factors* on which the selection of electrical drives depend a

1. *Steady state operation requirements :*
   - Nature of speed-torque characteristics.
   - Speed regulation.
   - Speed range.
   - Efficiency.
   - Duty cycle.
   - Quadrants of operation.
   - Speed fluctuations if any, ratings.
2. *Transient operation requirements :*
   - Values of acceleration and deceleration.
   - Starting, braking and reversing performance.
3. *Requirement related to the source :*
   - Type of source, and its capacity.
   - Magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads.
   - Ability to accept regenerated power.
4. *Capital and running cost, maintenance needs, life.*
5. *Reliability.*
6. *Environment and location.*
7. *Space and weight restrictions, if any.*

5) What are the different types of loads and explain how they are categorized?

The various types of loads that occur in industrial practice can be classified depending upon their variation with time and duty cycle.

Classification of loads with respect to time

The loads are classified with respect to time as follows.

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.

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.

Pulsating loads

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

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

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.

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.

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.

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.

Continuous duty cycle

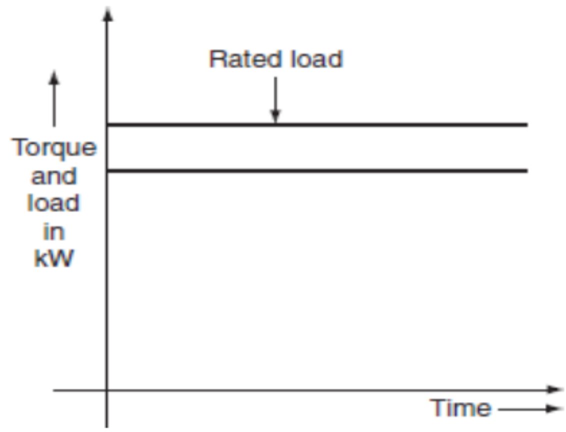
Continuous duty is the duty when the on-period is so long that the motor attains a steady-state temperature raise. The motor so selected should be able to withstand momentary overload capacity. This type of motors will have high efficiency because they will be operating almost at its full load and also have good power factor.

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

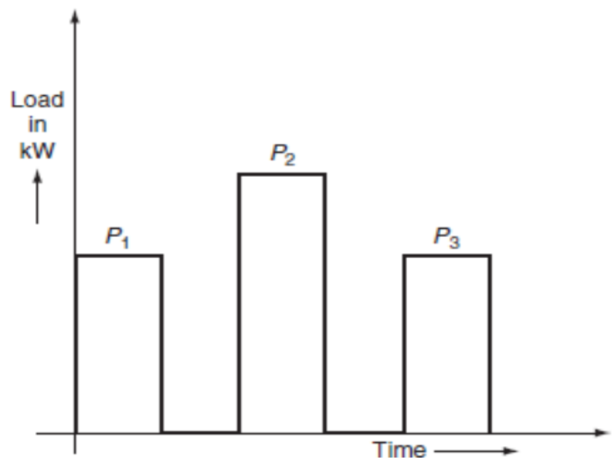
1. Continuous duty at constant load cycle.
2. Continuous duty at variable load cycle.

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 Fig.

Ex: Conveyors, compressors, fan, etc. in which continuous duty at constant load occurs.

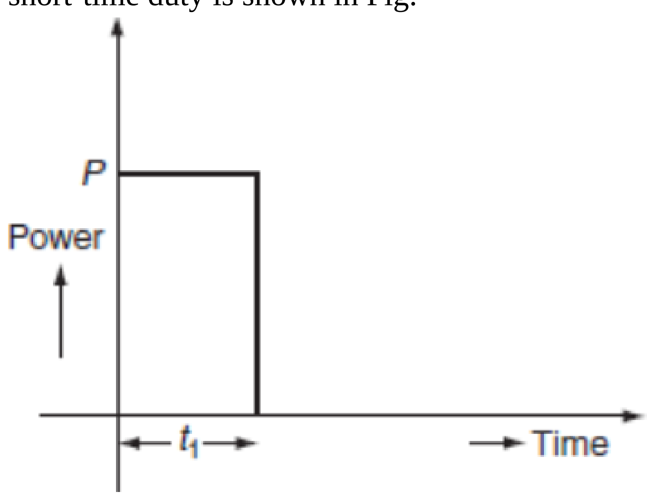


In continuous duty with variable load cycle, the load on the motor is not constant, but it has several phases in one cycle. The variation of load against time for variable load cycle is shown in Fig.



Short-time duty

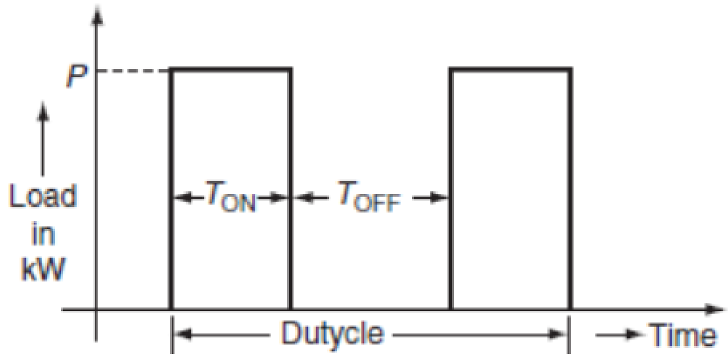
In this type of duty, the load occurs on the motor during a small interval and the remains idle for long time to re-establish the equality of temperature with the cooling medium. The variation of the load against time for short-time duty is shown in Fig.



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

Intermittent duty

The duty in which load on the motor varies periodically in a sequence of identical cycles shown in Fig. in which motor is loaded for sometimes 't_{on}' and shut off for a period of 't_{off}'.



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

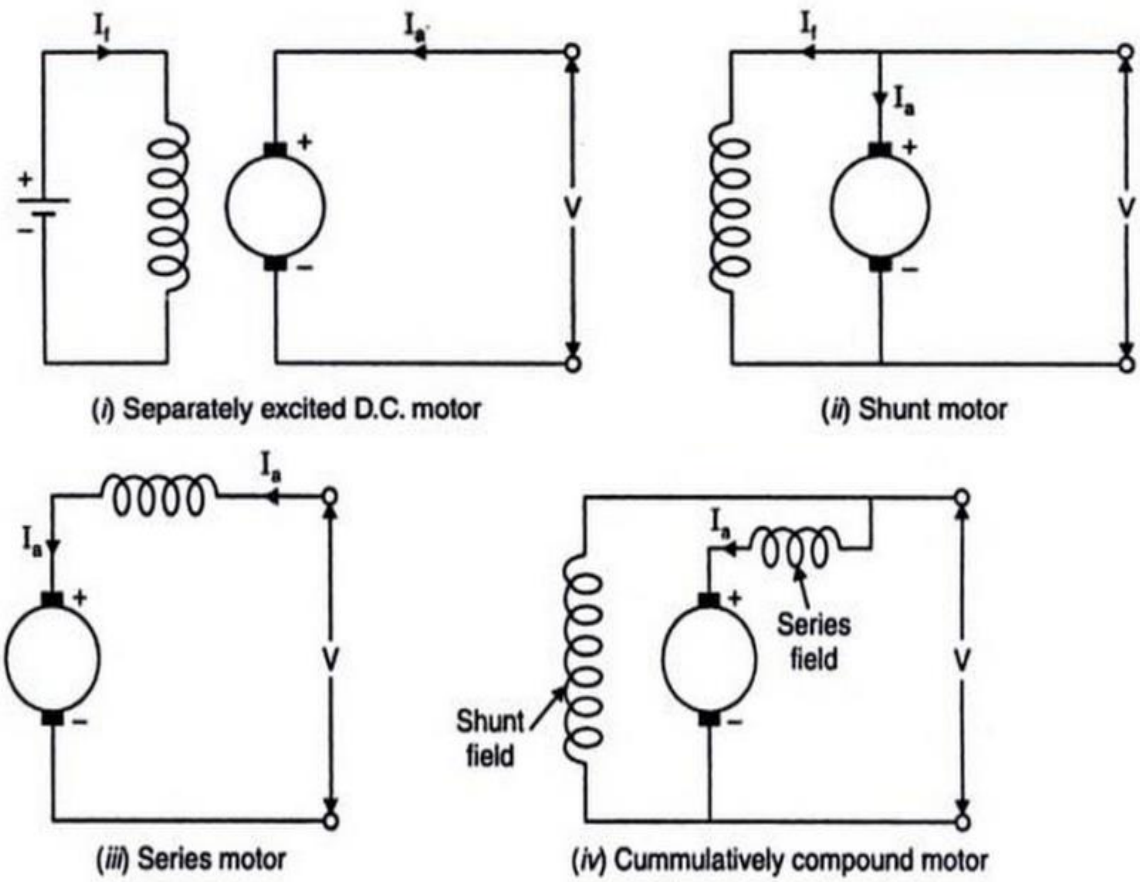
$$\text{Duty ratio} = \frac{t_{on}}{(t_{on} + t_{off})}.$$

6) Draw and explain the performance curves of DC (Shunt, Series and Compound) motors?

Commonly used D.C. motors are :

1. Shunt and separately excited motor.
2. Series motor.
3. Compound motor.
4. Universal motor.
5. Permanent magnet motors.
6. D. C. servo motors.
7. Moving coil motors.
8. Torque motors.

Commonly used motors are shown in Fig.



(*i*) Separately excited D.C. motor

(*ii*) Shunt motor

(*iii*) Series motor

(*iv*) Cummulatively compound motor

Steady state equivalent circuit of armature of a D.C. machine. The steady state equivalent circuit of armature of a D.C. machine is shown in Fig. 5.4.

Basic equations applicable to all D.C. motors are :

$$E_b = K_e \phi \omega_m \quad \text{....(5.1)}$$

$$V = E_b + I_a R_a \quad \text{...(5.2)}$$

$$T = K_e \phi I_a \quad \text{...(5.3)}$$

where, K_e = Motor constant,

ϕ = Flux per pole,

ω_m = Armature speed, rad/s,

V = Supply voltage,

E_b = Back e.m.f.,

I_a = Armature current,

R_a = Resistance of armature circuit, and

T = Torque developed by the motor.

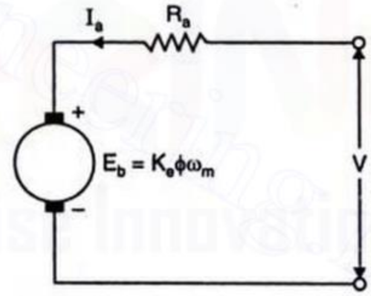


Fig. 5.4. Steady state equivalent circuit of the armature of a D.C. machine.

Inserting $E_b = K_e \phi \omega_m$ in eqn. (5.2), we get

$$V = K_e \phi \omega_m + I_a R_a$$

or,

$$\omega_m = \frac{V}{K_e\phi} - \frac{I_a R_a}{K_e\phi} \quad \text{...(5.4)}$$

Putting the value of $I_a = \frac{T}{K_e\phi}$ from eqn. (5.3) in eqn. (5.4), we get

$$\omega_m = \frac{V}{K_e\phi} - \frac{R_a T}{(K_e\phi)^2} \quad \text{...(5.5)}$$

Shunt and Separately Excited Motors

In these motors, with a *constant field current, the flux can be assumed to be constant.*

Let, $K_e \phi = K$ (constant) ...(5.6)

Then, from eqns. (5.1), (5.3), (5.4), (5.5) and (5.6), we have

$$E_b = K\omega_m \quad \text{...(5.7)}$$

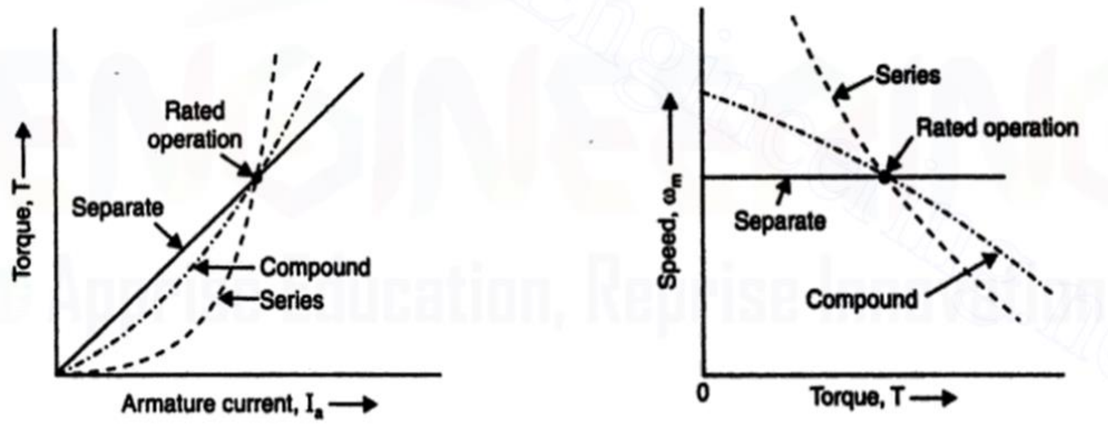
$$T = KI_a \quad \text{...(5.8)}$$

$$\omega_m = \frac{V}{K} - \frac{I_a R_a}{K} \quad \text{...(5.9)}$$

Again,

$$\omega_m = \frac{V}{K} - \frac{R_a T}{K^2} \quad \text{...(5.10)}$$

- The torque-current (T/I_a) and speed-torque (ω_m/T) characteristics of a separately excited motor for rated terminal voltage and full field are shown in Fig. 5.5.



(*i*) **Torque-current curves** (*ii*) **Speed-torque curves**

Fig. 5.5. Performance curves of D.C. motors.

- **The speed-torque curve is a straight line. The no-load speed ω_{m0} is determined by the values of armature voltage and field excitation.**
- **Speed decreases as torque increases and speed regulation depends on the armature circuit resistance [eqn. (5.10)].**
- **In a medium size motor, the usual *drop in speed from no load to full load* is of the order of *5 percent*.**

- **Separately excited motors are employed in *applications requiring good speed regulation and adjustable speed.***

Series Motors

In series motors, the *flux is a function of armature current.* In unsaturated region of magnetization characteristic, ϕ can be assumed to be proportional to I_a. Thus,

$$\phi = K_f I_a \quad ...(5.11)$$

Substituting $\phi = I_f I_a$ is eqns. (5.3), (5.4) and (5.5), we get

$$T = K_e K_f I_a^2 \quad ...(5.12)$$

$$\omega_m = \frac{V}{K_e K_f I_a} - \frac{R_a}{K_e K_f} \quad ...(5.13)$$

Again,

$$\omega_m = \frac{V}{K_e K_f I_a} - \frac{R_a T}{(K_e K_f I_a)^2} \quad ...[15.13\ (a)]$$

or,

$$\omega_m = \frac{V}{\sqrt{K_e K_f}} \cdot \frac{1}{\sqrt{T}} - \frac{R_a}{K_e K_f} \quad ...(15.14)$$

...[Substituting for I_a and I_a^2 from eqn. (5.12)]

Here, armature circuit resistance R_a is now the *sum of armature and field winding resistances.*

The *torque-current* (T/I_a) and *speed-torque* (ω_m/T) characteristics of a series motor at rated terminal voltage and full field are shown in Fig. 5.5.

***Series motors** are suitable to applications requiring high starting torque and heavy torque overloads.*

Compound Motor

The torque-current (T/I_a) and speed-torque (ω_m/T) characteristics of a cumulative compound motor are shown in Fig. 5.5.

— These characteristics which are obtained at rated terminal voltage and full field are known as *natural speed-torque characteristics*; rated (or full load) speed is known as the *base speed*.

— The no-load speed depends on the strength of shunt field and slope of the characteristic on the strength of series field.

Applications. (*i*) *"Cumulative compound motors"* are used in those applications where a drooping characteristic similar to that of a series motor is required and at the same time the no-load speed must be limited to a safe value ; typical *examples* are *"lifts and winches"*

(*ii*) A cumulative motor is also used in *intermittent load applications*, where the *load varies from almost no load to very heavy loads.* In these applications a flywheel may be mounted on the motor shaft for load equilisation. This apart from equilising load on the supply, permits the use, of a smaller size motor ; typical *example* of this type of application is *"pressing machine"*.

7) Explain the significance of heating and cooling curves of Electrical Machines used in Electric Drives.

Temperature raise of motor

The various losses takes place in any motor will be converted into heat. The heat thus produced will increase the temperature of various parts of the motor. The increase in temperature is mainly dependent on the following two factors:

1. Amount of heat developed internally at uniform rate.
2. The amount of heat dissipated from the surface of the motor.

In fact, the continuous rating of a machine is that rating for which the final temperature raise is equal to or just below the permissible value of the temperature raise for the insulating material used in protection of motor windings.

When the machine is overloaded for such a long time that its final temperature raise exceeds the permissible limit, it is likely to be damaged.

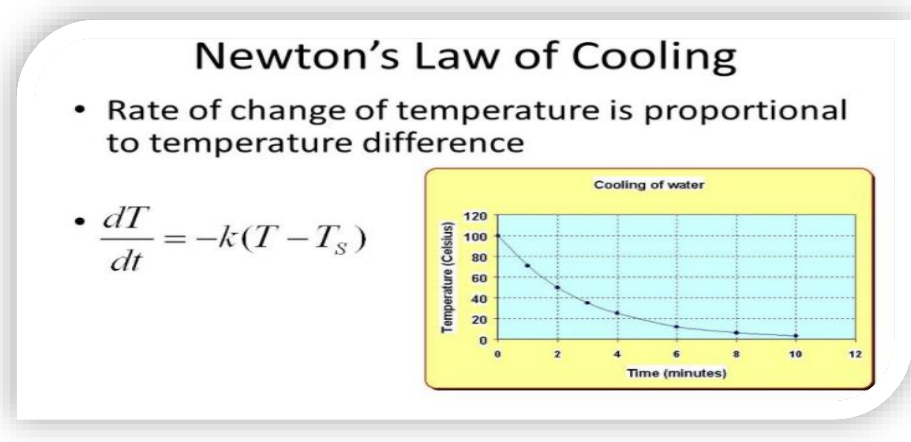
Sometimes, it will results immediate breakdown of insulating material which will cause a sudden short circuit in the motor, which may also lead to a fire. Since temperature raise is one of the chief features in fixing the size of motor.

The following assumptions are made considering heating calculations:

1. Heat developed, i.e., losses remains constant during temperature raise.
2. The heat dissipation is directly proportional to the difference in the temperature of motor and cooling medium, i.e., Newton's law of cooling holds good.
3. The temperature of cooling medium remains unchanged.

4. The motor is assumed to be a homogeneous mass having the same and uniform temperature in all parts. It implies high thermal conductivity.

For the determination of an expression for the temperature raise of an electrical machine after time'*t*' seconds from the instance of switching it on.



Let

- ❑ P is the electrical power converted into heat (W or J/sec)
- ❑ M is the mass of active parts of motor (kg),
- ❑ S is the specific heat of material (J/kg/°C),
- ❑ Θ is the temperature raise above the cooling medium or ambient temperature (°C),
- ❑ θ_f is the final temperature raise with constant load (°C), and
- ❑ λ is the coefficient of cooling or the rate of heat dissipation (W/m^2/°C raise).
- ❑ A is the surface area of cooling, (m^2),

Now, let us assume that the machine attains a temperature raise of θ°C above ambient temperature after '*t*' seconds of switching on the machine and further raise of temperature by dθ in very small time 'd*t*' seconds.

The rate at which the loss takes place or the heat is absorbed by the motor = $MS\,\frac{d\theta}{dt}$

The rate at which heat is dissipated = $A\theta\lambda$ J/sec.

But, the rate at which the electrical power converted into heat = the rate at which the heat is absorbed + the rate at which the heat dissipated by the motor.

$$P = MS\frac{d\theta}{dt} + A\lambda\theta$$

$$P - A\theta\lambda = MS\frac{d\theta}{dt}$$

$$dt = \frac{MS d\theta}{P - A\theta\lambda}$$

Integrating

$$\int dt = \int \frac{MS}{P - A\theta\lambda} d\theta$$

$$t = MS \log_e (P - A\theta\lambda) \times \left(\frac{-1}{A\lambda}\right) + K$$

By substituting $t = 0$ and $\theta = 0$

i.e., $0 = \frac{-MS}{A\lambda}\log_e (P - 0) + K$

or $K = \frac{MS}{A\lambda}\log_e P.$

Substituting the value of 'K'

$$t = \frac{-MS}{A\lambda}\log_e (P - A\lambda\theta) + \frac{MS}{A\lambda}\log_e P$$

$$= \frac{-MS}{A\lambda}\left[\log_e (P - A\theta\lambda) - \log_e P\right]$$

$$= \frac{-MS}{A\lambda}\log_e \left[\frac{P - A\theta\lambda}{P}\right]$$

$$\frac{-A\lambda t}{MS} = \log_e \left[\frac{P - A\theta\lambda}{P}\right].$$

By applying exponential on both side, we get:

$$e^{\frac{-A\lambda t}{MS}} = 1 - \frac{A\theta\lambda}{P} \qquad \left[\therefore \log_e^e = 1\right]$$

$$\frac{A\theta\lambda}{P} = 1 - e^{\frac{-A\lambda t}{MS}}$$

$$\theta = \frac{P}{A\lambda}\left(1 - e^{\frac{-A\lambda t}{MS}}\right).$$

$$\theta = \frac{P}{A\lambda}\left(1 - e^{\frac{-A\lambda t}{MS}}\right).$$

by substituting $t = \infty$ and $\theta = \theta_f$

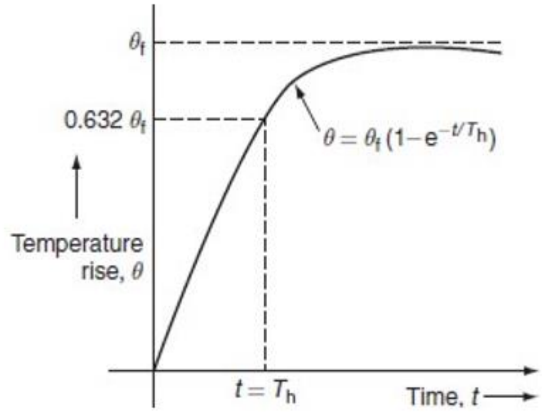
$$\theta_f = \frac{P}{A\lambda}\left[1 - e^{-\infty}\right]$$

$$\theta_f = \frac{P}{A\lambda}$$

$$\theta = \theta_f\left[1 - e^{\frac{-A\lambda}{MS}t}\right]$$

$$= \theta_f\left[1 - e^{\frac{-t}{T_h}}\right] \qquad `T_h' = \frac{MS}{A\lambda}$$

$$\theta = \theta_f\left[1 - e^{\frac{-t}{T_h}}\right]$$



At $t = T_h$, $\theta = \theta_f\,[1 - e^{-1}]$

$\theta = 0.632\ \theta_f$

Thus, *heating time constant* can be defined as follows:

The heating time constant is the time taken by the machine to attain 63.2% of its final steady temperature raise (θ_f).

The heating time constant of the conventional electrical machines is usually within the range of 0.5–3 for 4 h.

Cooling of motor

Let us assume, if the supply to the motor is switched off, after attaining the final steady temperature raise of ‘θ_f”, the motor starts cooling. When the machine is switched off, no heat is produced, therefore:

Heat absorbed + heat dissipated = 0

$$\therefore MS\frac{d\theta}{dt} + A\lambda'\theta = 0,$$

where λ = heat dissipation during cooling of motor.

$$MSd\theta + A\lambda'\theta \cdot dt = 0$$

$$dt = -\frac{MS}{\theta A\lambda'}d\theta.$$

Integrating

$$\int dt = \frac{-MS}{A\lambda^1}\int\frac{d\theta}{\theta}$$

$$t = \frac{-MS}{A\lambda^1}\log_e\theta + K^1$$

where K^1 is the integration constant.

when $t = 0$ and $\theta = \theta_f$, we get:

$$0 = \frac{-MS}{A\lambda^1}\log_e\theta_f + K^1$$

$$K^1 = \frac{MS}{A\lambda^1}\log_e\theta_f.$$

$$t = \frac{-MS}{A\lambda^1}\log_e\theta + \frac{MS}{A\lambda^1}\log_e\theta_f$$

$$= \frac{-MS}{A\lambda^1}[\log_e\theta - \log_e\theta_f]$$

$$= \frac{-MS}{A\lambda^1}\log_e\left(\frac{\theta}{\theta_f}\right)$$

$$\therefore \frac{-A\lambda^1 t}{MS} = \log_e\left(\frac{\theta}{\theta_f}\right).$$

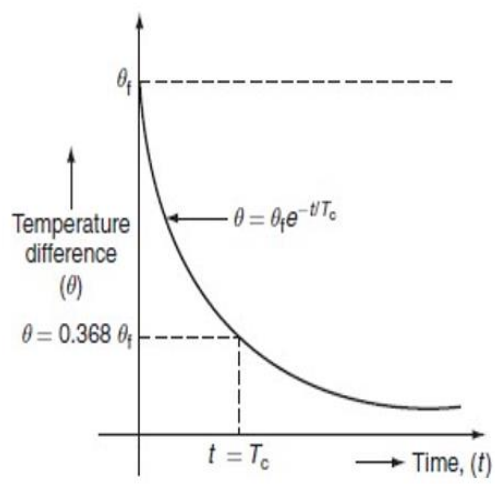
Applying exponentials on both side λ:

$$e^{\frac{-A\lambda^1}{MS}t} = \log_e e\left(\frac{\theta}{\theta_f}\right) \qquad [\because \log_e e^x = x]$$

$$\frac{\theta}{\theta_f} = e^{\frac{-A\lambda^1}{MS}t}$$

$$\theta = \theta_f e^{\frac{-A\lambda^1}{MS}t}$$

$$\theta = \theta_f e^{\frac{-t}{T_c}},$$



Cooling curve

From the cooling equation, at time $t = T_c$

We have $\theta = \theta_f\ (e^{-1})$

$\theta = 0.368\theta_f$

Thus, we can define the *cooling time constant* as:

The cooling time constant is defined as the time required cooling the machine down to 36.8% of the initial temperature raise above the ambient temperature.

The heating and cooling curves follows an exponential law. Heating time constant and cooling time constant may be different for the same machine and also the cooling time constant of rotating machine is larger than its heating time constant, due to poorer ventilation conditions when the machine cools.

The heating and cooling curves follows an exponential law.

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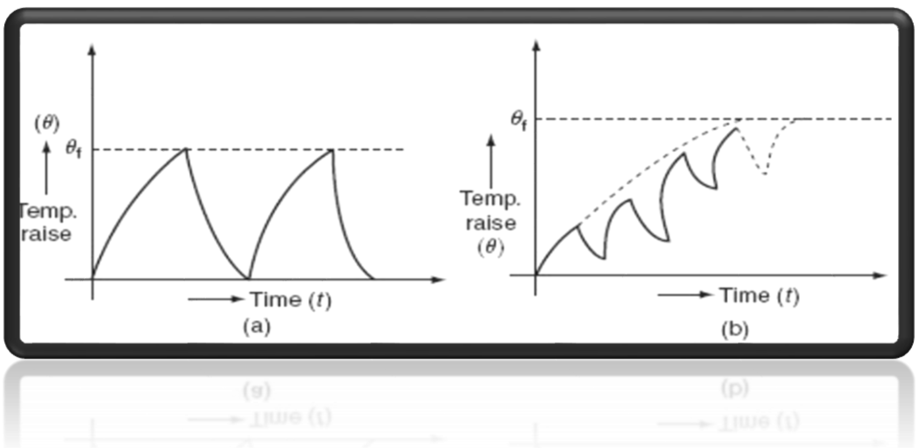
Figure shows the heating and cooling curves of a motor for short-time and intermittent loads.



8) Explain the term "Load Equalization" and give its significance and its role in Electric drives

LOAD EQUALIZATION

The load fluctuations take place in many of the industrial drives such as rolling mills, planning machines presses, and reciprocating pumps, where the load on the motor varies widely within a span of few seconds.

The sudden and peak load requires very large current from the supply results high voltage drop in the system or alternately would require very large size of cables. It is very essential to smooth out fluctuating load is known as '*load equalization*'.

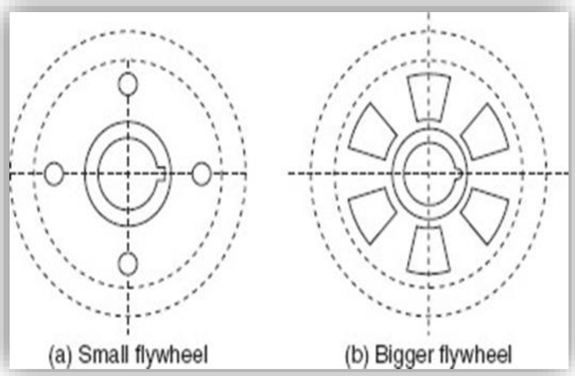
The load equalization involves the storage of energy during the off-peak period and gives out during the peak load period.

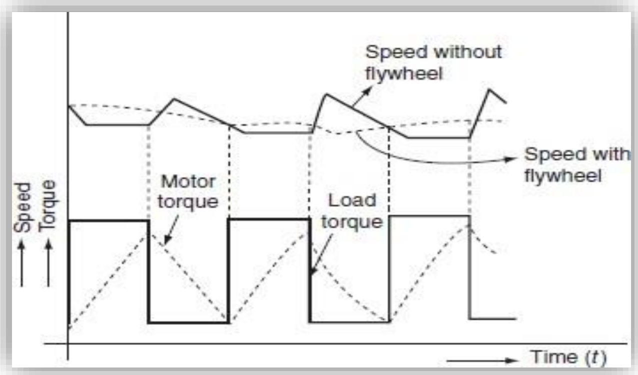
Load equalization process is commonly achieved by means of a flywheel. A flywheel is nothing but a big wheel that is mounted on the same shaft of motor, if the speed of the motor is not to be reversed or a heavy rotating body that acts as a reservoir for absorbing and redistributing stored energy is also known as flywheel.

Function of flywheel

To operate the flywheel efficiently, the driving motor should have drooping speed characteristics.

During the light load, the acceleration of the flywheel is increased and it stores the kinetic energy and at the time of peak load, the flywheel slows down and the stored kinetic energy is given out to the load; so that, the demand of the load from the motor or supply is reduced.





It is necessary that the motor used for load equalization should have drooping characteristics. The flywheel is not used with motors having constant speed for example synchronous motor.

The torque developed by the motor and the load torque required as well as the speed variations with time are shown.

Flywheel calculations

Let us consider a flywheel is attached to a variable speed motor to achieve load equalization.

Let T_L be the load torque (assumed constant during particular interval) in N-m.
T_M is the motor torque in N-m, T_F is the flywheel torque in N-m,
T_0 is the no-load torque in N-m, ω_0 is the motor speed on no-load in rad/sec,
ω is the motor speed at any instant in rad/sec,
J is the moment of inertia of flywheel in kg-m^2.
Case (i): Let us consider that the load on the motor is increasing; during this period, the flywheel will decelerate and impart its stored kinetic energy to the load. The torque required to be supplied by the motor:

$$T_M = T_L - T_F.$$

The kinetic energy given by the flywheel when its speed reduced from ω_0 to ω is:

$$\mathrm{KE} = \frac{1}{2}J\left(\omega_0^2 - \omega^2\right)$$
$$= \frac{1}{2}J\left(\omega_0 + \omega\right)\left(\omega_0 - \omega\right)$$
$$= J\left(\frac{\omega_0 + \omega}{2}\right)\left(\omega_0 - \omega\right).$$
$$\text{Let } \left(\frac{\omega_0 + \omega}{2}\right) = \omega \qquad \text{(mean speed)}$$

$$\omega_0 - \omega = S \qquad \text{(Slip).}$$
$$\mathrm{KE} = \frac{1}{2}J\left(\omega_0^2 - \omega^2\right)$$
$$= \frac{1}{2}J\left(\omega_0 + \omega\right)\left(\omega_0 - \omega\right)$$
$$= J\left(\frac{\omega_0 + \omega}{2}\right)\left(\omega_0 - \omega\right)$$
$$\text{Let } \left(\frac{\omega_0 + \omega}{2}\right) = \omega \qquad \text{(mean speed)}$$
$$\omega_0 - \omega = S \qquad \text{(Slip).}$$

KE = $J\omega S$

The power given out by the flywheel = the rate of change of the energy given up by the flywheel.

$$= \frac{d}{dt}(J\omega S)$$
$$= J\omega\frac{dS}{dt}.$$

$$\text{The flywheel torque } (T_F) = \frac{\text{power given out by flywheel}}{\omega}$$
$$= \frac{J\omega\left(\frac{dS}{dt}\right)}{\omega}$$
$$= J\frac{dS}{dt}.$$

If the slip, i.e., drop in speed limited to 10%,

then the slip is proportional to the motor torque: i.e., $S \propto T_M$

$S = KT_M$.

$$T_L - T_M = JK\frac{dT_M}{dt}$$

$$\frac{dT_M}{T_L - T_M} = \frac{dt}{JK}.$$

Integrating

$$\int \frac{dT_M}{T_L - T_M} = \int \frac{dt}{JK}$$

$$-\log_e(T_L - T_M) = \frac{t}{JK} + C$$

At time $t = 0$, the motor torque will be equals to the no-load torque i.e., at $t = 0$, $T_M = T_0$

$$-Log_e(T_L - T_0) = \frac{0}{JK} + C$$

$$C = -\log_e(T_L - T_0).$$

$$\therefore -\text{Log}_e(T_L - T_M) = \frac{t}{JK} - \text{Log}_e(T_L - T_0)$$

$$-\text{Log}_e(T_L - T_0) + \log_e(T_L - T_M) = \frac{-t}{JK}$$

$$\text{Log}_e\left[\frac{T_L - T_M}{T_L - T_0}\right] = \frac{-t}{JK}.$$

Applying exponentials on both sides:

$$\left[\frac{T_L - T_M}{T_L - T_0}\right] = e^{-t/JK}$$

$$T_L - T_M = (T_L - T_0)e^{-t/JK}$$

$$T_M = T_L - (T_L - T_0)e^{-t/JK}$$

Case (ii): Now consider that the load is totally removed or decreasing, the motor starts accelerating and so the KE is stored by the flywheel is varied, Hence, the flywheel regains its normal speed; therefore, the slip decreases, i.e. $\frac{dS}{dt}$ is negative.

Now, motor torque will be:

$$T_M = T_0 + T_F.$$

$$T_F = -J\frac{dS}{dt}.$$

$$\therefore T_M = T_0 - J\frac{dS}{dt}.$$

We know that $S \propto T_M$:

$$S = KT_M$$

$$\therefore T_M = T_0 - JK\frac{dT_M}{dt}$$

$$-JK\frac{dT_M}{dt} = T_M - T_0$$

$$\frac{dT_M}{T_M - T_0} = -\frac{dt}{JK}.$$

Integrating on both sides:

$$\int\frac{dT_M}{T_M - T_0} = -\int\frac{dt}{JK}$$

$$\text{Log}_e(T_M - T_0) = \frac{-t}{JK} + C_2,$$

The value of constant can be obtained by substituting the initial conditions

At $t = 0$; $T_M = T_M^1$ (motor torque when load is decreased)

$$\therefore \text{Log}\left(T_M^1 - T_0\right) = \frac{0}{JK} + C_2$$

$$\therefore C_2 = \text{Log}_e\left(T_M^1 - T_0\right).$$

$$\text{Log}_e(T_M - T_0) = \frac{-t}{JK} + \text{Log}_e\left(T_M^1 - T_0\right)$$

$$\text{Log}_e(T_M - T_0) - \text{Log}_e\left(T_M^1 - T_0\right) = \frac{-t}{JK}$$

$$\text{Log}_e(T_M - T_0) - \text{Log}_e(T_M^1 - T_0) = \frac{-t}{JK}$$

$$\text{Log}_e\left(\frac{T_M - T_0}{T_M^1 - T_0}\right) = \frac{-t}{JK}.$$

Applying exponentials on both sides:

$$\frac{T_M - T_0}{T_M^1 - T_0} = e^{-t/JK}$$

$$\therefore T_M - T_0 = (T_M^1 - T_0)(e^{-t/JK})$$

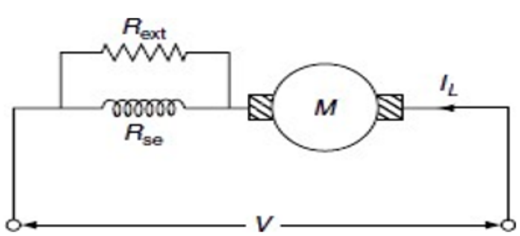
$$\therefore T_M = T_0 + (T_M^1 - T_0)e^{-t/JK}.$$

9) **Problem: A 500-V DC series motor runs at 500 rpm and takes 60 A; the resistances of the field and the armature are 0.3 and 0.2 Ω, respectively. Calculate the value of the resistance to be shunted with series field winding in order that the speed may be increased to, 600 rpm, if the torque were to remain constant. Saturation may be neglected.**

Solution:

Given that:

$V = 500$ V
$N_1 = 500$ rpm
$I_{a1} = 60$ A
$R_a = 0.2\ \Omega$
$R_{se} = 0.3\ \Omega$
$N_2 = 600$ rpm
$I_{L1} = I_{a1} = I_{se1} = 60$ A.



After connecting resistance across field winding, let Ia2 be the armature current

$$\therefore I_{se2} = I_{a2} \times \frac{R_{ext}}{R_{ext} + 0.3}.$$

DC series motor

Given that the load torque is constant:

We know that:

$T \propto \phi\, I_a$ and $N \propto E_b/\phi$

$\therefore I_{a1}\phi_1 = I_{a2}\phi_2.$

For series motor $\varphi \propto I_{se}$:

$$\therefore I_{a1}\, I_{se1} = I_{a2}\, I_{se2}$$

$$I_{a1}^2 = I_{a2} \times I_{se2}$$

$$I_{a1}^2 = I_{a2} \times \left[I_{a2} \times \frac{R_{ext}}{R_{ext} + 0.3}\right]$$

$$60^2 = I_{a2}^2\left[\frac{R_{ext}}{R_{ext} + 0.3}\right].$$

$$N \propto E_b/\phi$$

$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{\phi_2}{\phi_1}$$

$$\text{or} \quad \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{600}{500} = \frac{V - I_{a2}R_{a2}}{V - I_{a1}R_{a1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{600}{500} = \frac{500 - I_{a2}\left[0.2 + \frac{R_{ext} \times 0.3}{R_{ext} + 0.3}\right]}{500 - 60(0.2 + 0.3)} \times \frac{I_{se1}}{I_{se2}}$$

$$\frac{600 \times 470}{500 \times 60} = \frac{500 - I_{a2}\left(0.2 + \frac{R_{ext} \times 0.3}{R_{ext} + 0.3}\right)}{I_{a2} \times \frac{R_{ext}}{R_{ext} + 0.3}}$$

$$\frac{60^2}{I_{a2}} = I_{a2}\left[\frac{R_{ext}}{R_{ext} + 0.3}\right].$$

$$9.4 = \frac{500 - 0.2I_{a2} - 0.3 \times \frac{60^2}{I_{a2}}}{\frac{60^2}{I_{a2}}}$$

$$\frac{60^2 \times 9.4}{I_{a2}} = 500 - 0.2I_{a2} - \frac{0.3 \times 60^2}{I_{a2}}$$

$$500I_{a2} - 0.2I_{a2}^2 - 1,080 - 33,840 = 0$$

$$0.2I_{a2}^2 - 500I_{a2} + 34,920 = 0$$

$$I_{a2} = \frac{+500 \pm \sqrt{500^2 - 4 \times 0.2 \times 34,920}}{2 \times 0.2}$$

$$I_{a2} = \frac{500 \pm 471.23}{0.4} = 71.9 \text{ A.}$$

$$60^2 = I_{a2}^2 \times \frac{R_{ext}}{R_{ext} + 0.3}$$

$$60^2 = 71.9^2 \times \frac{R_{ext}}{R_{ext} + 0.3}$$

$$R_{ext} + 0.3 = 1.436\ R_{ext}$$

$$0.436\ R_{ext} = 0.3$$

$$R_{ext} = \frac{0.3}{0.436} = 0.6878\ \Omega$$

$$\therefore\ R_{ext} = 0.6878\ \Omega.$$

10) **Problem:A 15-HP, three-phase, eight-pole, and 50-Hz induction motor provided with a flywheel has to supply a load torque of 600 N-m for 10 s followed by a no-load during which the flywheel regains the full speed. The full-load slip of the motor is 4% and the torque‒speed curve may be assumed linear over the working range. Find the moment of inertia of the flywheel if the motor torque is not to exceed twice the full-load torque.**

Solution:

Given data:

P_0= 15 HP

= 15 × 735.5 = 11.03 kW.

f = 50 Hz

T_L = 600 N-m

T_M = 2. TFL

No.of poles $P = 8$

$S_f = 0.04$

$t = 10$ sec

$T_0 = 0.$

Now, synchronous speed $N_s = \frac{120f}{P}$

$$= \frac{120 \times 50}{8} = 750 \text{ rpm.}$$

Full-load torque $T_{FL} = \frac{60 \times P_o}{2\pi N_{FL}}$

$$N_{FL} = N_s (1 - S_f) = 750\ (1 - 0.04)$$

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

$$T_{FL} = \frac{60 \times 11.03 \times 10^3}{2\pi \times 720} = 146.39 \text{ N-m.}$$

$\therefore T_M = 2T_{FL} = 2 \times 146.39 = 292.78$ N-m.

Slip speed $= S_f \times N_s = 0.04 \times 750$

$$= 30 \text{ rpm}$$

$$= \frac{30 \times 2\pi}{60} = 3.14 \text{ rad/s.}$$

And, $K = \frac{S}{T_{FL}} = \frac{3.14}{146.39} = 0.0214$

$$\therefore T_M = T_L - (T_L - T_0)e^{-t/JK}$$

$$-t/JK = \ln\left(\frac{T_L - T_M}{T_L - T_0}\right)$$

$$-t/JK = \ln\left[\frac{600 - 292.78}{600}\right] = 0.669$$

$$J = \frac{t}{0.669 \times K} = \frac{10}{0.669 \times 0.0914} = 698.49 \text{ kg-m}^2.$$

$$T_M = T_L - (T_L - T_0)e^{-t/KJ}$$

$$e^{-t/JK} = \frac{T_L - T_M}{T_L - T_0}$$

$$e^{-t/JK} = \frac{800 - 600}{800 - 0} = 0.25$$

$$-t/JK = \ln(0.25) = \frac{5}{1.386 \times 0.01134}$$

$$J = 318.12 \text{ kg-m}^2.$$

11) **Problem: A series motor takes 20 A at 400 V to drive a fan at 200 rpm. Its resistance is 1 ohm (field and armature). If the torque required to drive the fan varies as the square of the speed, find the necessary applied voltage and current to drive the fan at 300 rpm.**

Solution. *Given :* $V = 400$ volts ; $I_1 (= I_{a1}) = 20$ A ; $N = 200$ r.p.m., $(R_a + R_{se}) = 1\ \Omega$; $T \propto N^2$, $N_2 = 300$ r.p.m.

I_2 ; V_2 :

Back e.m.f., $E_{b1} = V - I_1 (R_a + R_{se})$

$$= 400 - 20 \times 1 = 380 \text{ V}$$

Since $T \propto N^2$ ...(Given)

$$\therefore \quad \frac{T_2}{T_1} = \frac{N_2^2}{N_1^2} \quad \text{or} \quad \frac{\phi_2 I_2}{\phi_1 I_1} = \frac{N_2^2}{N_1^2}$$

or, $\frac{I_2^2}{I_1^2} = \left(\frac{300}{200}\right)^2$ $(\because \phi \propto I$, neglecting saturation) or, $$\frac{I_2}{I_1} = 1.5$$

or, $$\mathbf{I_2} = 1.5I_1 = 1.5 \times 20 = \mathbf{30\ A.} \quad \textbf{(Ans.)}$$

Also, $$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{300}{200} = \frac{E_{b2}}{380} \times \frac{I_1}{I_2} = \frac{E_{b2}}{380} \times \frac{1}{1.5}$$

$\therefore$ $$E_{b2} = \frac{300}{200} \times 380 \times 1.5 = 85\ \text{V}$$

$\therefore$ $$\mathbf{V_2} = E_{b2} + I_2(R_a + R_{se})$$
$$= 855 + 30 \times 1 = \mathbf{885\ V.} \quad \textbf{(Ans.)}$$

UNIT-2

Electric Heating and Welding

1) Explain tha advantages of Electric Heating?

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

(i) Economical

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

(ii) Cleanliness

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

(iii) Pollution free

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

(iv) Ease of control

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

(v) Uniform heating

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

(vi) High efficiency

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

(vii) Automatic protection

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

(viii) Heating of non-conducting materials

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

(ix) Better working conditions

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

(x) Less floor area

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

(xi) High temperature

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

(xii) Safety

The electric heating is quite safe.

2) Discuss different 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, and
3. radiation.

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.

The amount of heat passed through a cubic body with two parallel faces with thickness '*t*' meters, having the cross-sectional area of '*A*' square meters and the temperature of its two faces $T1$°C and $T2$°C, during '*T*' hours is given by:

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

where *k* is the coefficient of the thermal conductivity for the material and it is measured in MJ/m_3/°C/hr.

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

Ex: Immersion water heater.

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

$H = a\,(T_1 - T_2)\,b$ W/m_2,

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

Radiation

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.

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

$$\text{Heat dissipation, } H = 5.72\times10^4 k\, e\left[\left(\frac{T_1}{1{,}000}\right)^4 - \left(\frac{T_2}{1{,}000}\right)^4\right] \text{W/m}^2,$$

where T_1 is the temperature of the source in kelvin, T_2 is the temperature of the substance to be heated in kelvin, and k is the radiant efficiency:
= 1, for single element
= 0.5–0.8, for several elements
e = emissivity = 1, for black body
= 0.9, for resistance heating element.

3) What are the essential requirements of good Heating Element?

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

o **High-specific resistance**

Material should have high-specific resistance so that small length of wire may be required to provide given amount of heat.

o **High-melting point**

It should have high-melting point so that it can withstand for high temperature, a small increase in temperature will not destroy the element.

o **Low temperature coefficient of resistance**

For accurate temperature control, the variation of resistance with the operating temperature should be very low. This can be obtained only if the material has low temperature coefficient of resistance

o **Free from oxidation**

The element material should not be oxidized when it is subjected to high temperatures; otherwise the formation of oxidized layers will shorten its life.

o **High-mechanical strength**

The material should have high-mechanical strength and should withstand for mechanical vibrations.

o **Non-corrosive**

The element should not corrode when exposed to atmosphere or any other chemical fumes.

o **Economical**

The cost of material should not be so high.

4) Explain about the Design process of Heating Elements?

By knowing the voltage and electrical energy input, the design of the heating element for an electric furnace is required to determine the size and length of the heating element. The wire employed may be ***circular or rectangular like a ribbon***.

Circular-type heating element:

Initially when the heating element is connected to the supply, the temperature goes on increasing and finally reaches high temperature.

Let *V* be the supply voltage of the system and *R* be the resistance of the element, then electric power input,

$$P = \frac{V^2}{R}\ \text{W}.$$

If ρ is the resistivity of the element, *l* is the length, '*a*' is the area, and *d* is the diameter of the element, then:

$$R = \rho\frac{l}{a} = \frac{\rho l}{\frac{\pi d^2}{4}}.$$

Therefore, power input,

$$P = \frac{V^2 \pi d^2}{4\rho l}.$$

By rearranging the above equation, we get:

$$\frac{l}{d^2} = \frac{\pi V^2}{4P\ \rho},$$

where *P* is the electrical power input per phase (watt), *V* is the operating voltage per phase (volts), *R* is the resistance of the element (Ω), *l* is the length of the element (*m*), *a* is the area of cross-section (m^2), *d* is the diameter of the element (*m*), and ρ is the specific resistance (Ω-m)

According to Stefan's law, heat dissipated per unit area is

$$H = 5.72 \times 10^4\ k\ e\left[\left(\frac{T_1}{1{,}000}\right)^4 - \left(\frac{T_2}{1{,}000}\right)^4\right] \text{W/m}^2,$$

where T_1 is the absolute temperature of the element (K), T_2 is the absolute temperature of the charge (K), *e* is the emissivity, and *k* is the radiant efficiency.

The surface area of the circular heating element:

$S = \pi dl.$

∴ Total heat dissipated = surface area × *H*

$= H\pi dl.$

Under thermal equilibrium,

Power input = heat dissipated

$P = H \times \pi dl.$

Substituting *P* in above equation:

$$\frac{V^2}{\rho\, l}\left(\frac{\pi\ d^2}{4}\right) = H \times \pi\, dl$$

$$\therefore \frac{d}{l^2} = \frac{4\,\rho\,H}{V^2}.$$

By solving above Equations, the length and diameter of the wire can be determined.

Ribbon-type element

Let '*w*' be the width and'*t*' be the thickness of the ribbon-type heating element.

$$\text{Electrical power input } P = \frac{V^2}{R}.$$

We know that,

$$R = \frac{\rho l}{a} = \frac{\rho l}{w \times t}$$

$$\therefore P = \frac{V^2}{\left(\frac{\rho\, l}{w \times t}\right)}$$

$$\therefore \frac{l}{w} = \frac{V^2\, t}{P\,\rho}.$$

The surface area of the rectangular element (S) = 2 $l \times w$.

∴ Total heat dissipated = $H \times S$

= $H \times 2\, lw$.

∴ Under the thermal equilibrium,

Electrical power input = heat dissipated

$P = H \times 2\, lw$

$$lw = \frac{P}{2\,H}.$$

By solving above Equations, the length and width of the heating element can be determined.

5) List out Different Methods of Electric Heating?

Electric heating can be broadly classified as follows.

Direct resistance heating

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

Indirect resistance heating

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

Direct arc heating

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

Indirect arc heating

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

Direct induction heating

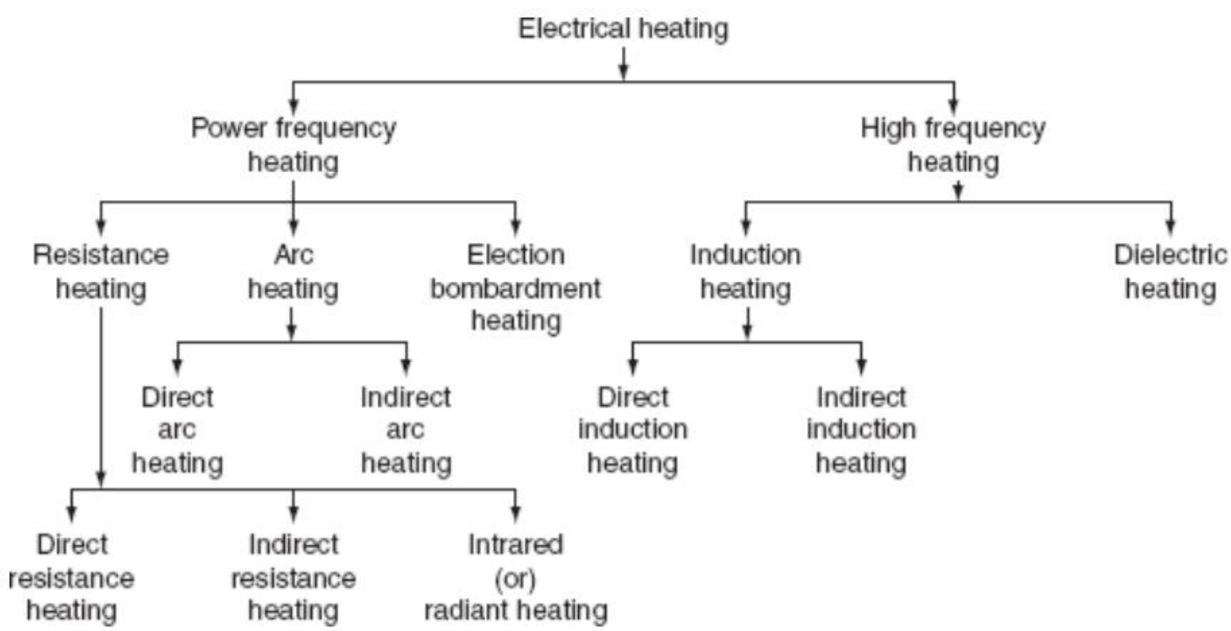
In this method of heating, the currents are induced by electromagnetic action in the charge to be heated. These induced currents are used to melt the charge in induction furnace.

Indirect induction heating

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

Dielectric heating

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



6) Explain about Resistane Heating and their types?

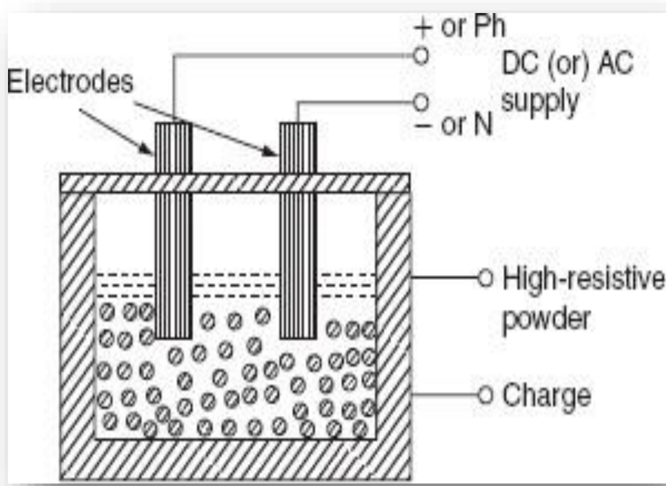
When the electric current is made to pass through a high-resistive body (or) substance, a power loss takes place in it, which results in the form of heat energy, i.e., resistance heating is passed upon the I^2R effect.

The resistance heating is further classified as:

1. Direct resistance heating,
2. Indirect resistance heating, and
3. Infrared (or) radiant heating.

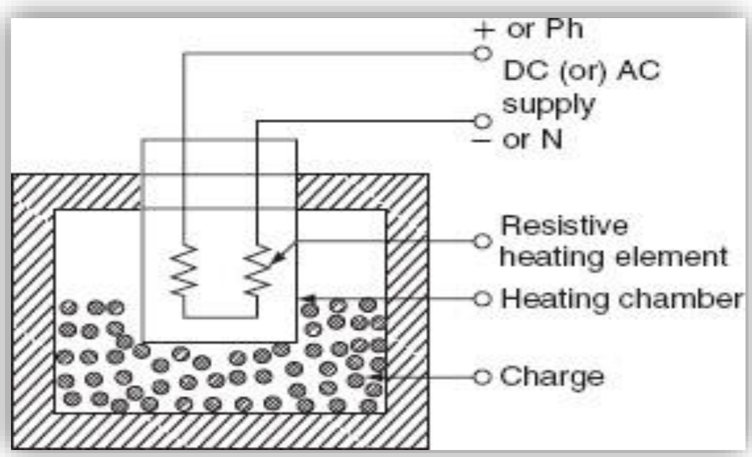
Direct resistance heating

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



Indirect resistance heating

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



7) Explain in detail about Arc Heating?

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

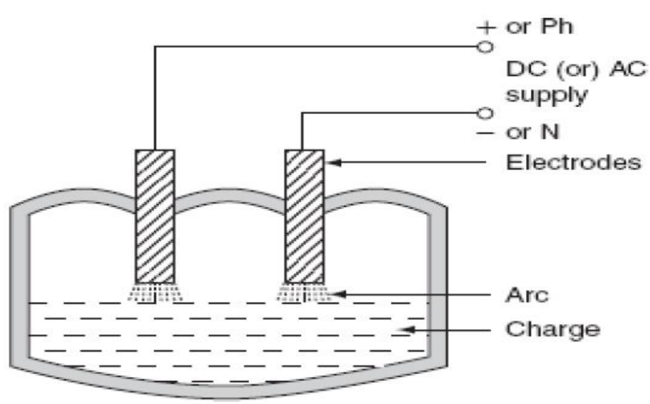
Types of arc furnaces

There are two types of arc furnaces and they are:

1. direct arc furnace and
2. indirect arc furnace.

(i) Direct arc furnace

- When supply is given to the electrodes, two arcs are established and current passes through the charge, as shown in Fig.
- As the arc is in direct contact with the charge and heat is also produced by current flowing through the charge itself, it is known as *direct arc furnace.*



- If the available supply is DC or 1-φ, AC, two electrodes are sufficient, if the supply is 3-φ, AC, three electrodes are placed at three vertices of an equilateral triangle.
- The most important feature of the direct arc furnace is that the current flows through the charge, the stirring action is inherent due to the electromagnetic force setup by the current, such furnace is used for manufacturing alloy steel and gives purer product.

Advantages

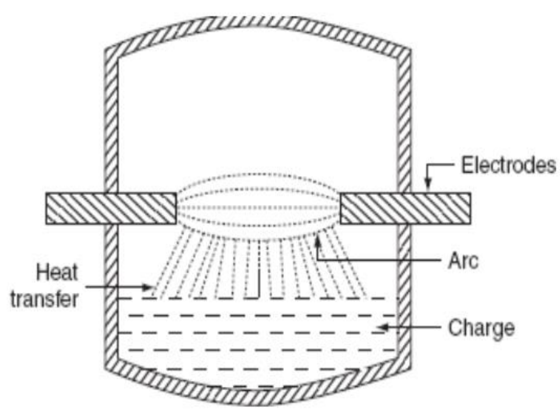
- High temperatures can be produced
- More uniform heating of the charge can be obtained

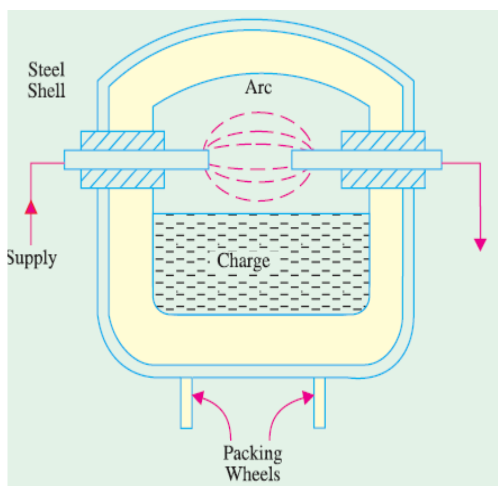
Applications

- The most common application of direct arc furnace is to produce steel
- It is used in pilot production plants (Pre-commercial Plants)

(ii) Indirect arc furnace

In indirect arc furnace, the arc strikes between two electrodes by bringing momentarily in contact and then with drawing them heat so developed, due to the striking of arc across air gap is transferred to charge is purely by radiation. A simple indirect arc furnace is shown in Fig.





Advantages

- High flexibility
- High melting
- Economical
- High efficiency

Applications

- Indirect arc furnace is used for melting of non-ferrous metals
- It can be used in iron foundries where small quantities of iron is required frequently
- It is more suitable when the charge is to be varied frequently or heating is intermittent

8) Explain about High Frequency heating and their types?

The high-frequency heating are divided in to two types.

- **Induction Heating**
- **Di-electric Heating**

The heating of the conducting materials, such as ferro-magnetic and non-ferro-magnetic, is known as ***induction heating.***

The process of heating of the insulating materials is known as ***dielectric heating.***

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

- **Core type** furnace.
- **Coreless type** furnace.

Core type furnace

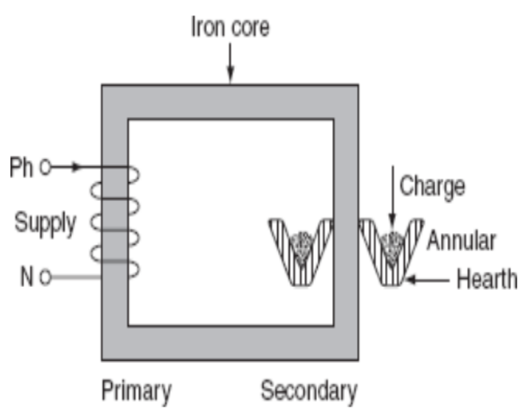
The operating principle of the core type furnace is the electromagnetic induction. This furnace operating just like a transformer. It is further classified as:

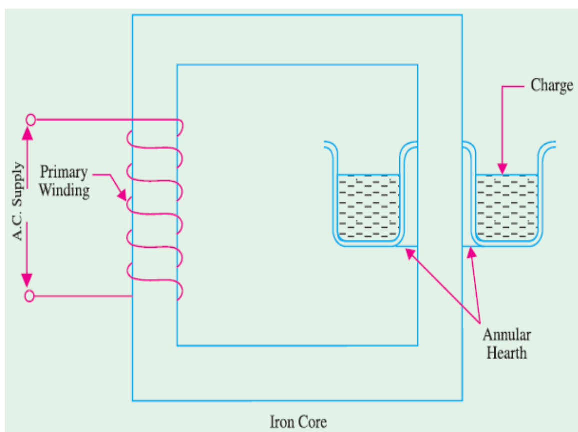
1. Direct core type.

2. Vertical core type.

(i) Direct core type induction furnace

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





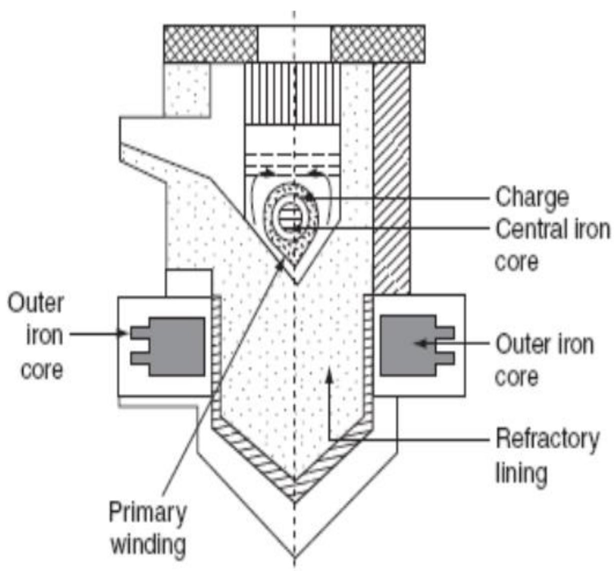
- The furnace consists of a Annular hearth which contains the charge to be melted in the form of an annular ring.
- To start the furnace, molted metal has to be poured in the annular hearth. Since, magnetic coupling between the primary and secondary is very poor, it results in high leakage and low power factor.
- However, in this furnace, melting is rapid and clean and temperature can be controlled easily.

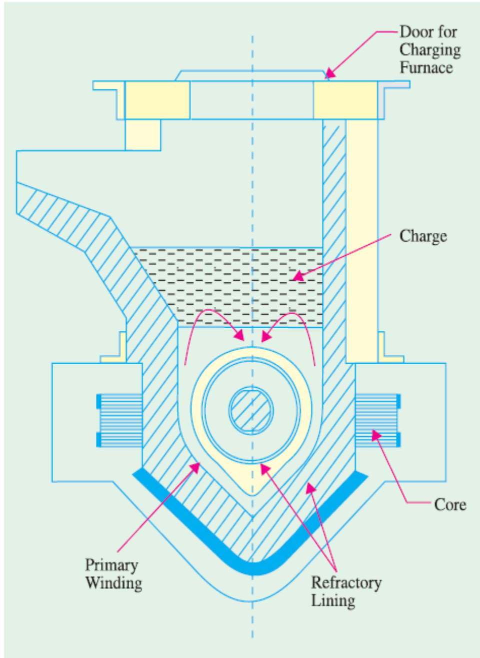
- If current density exceeds about 500 A/cm2, it will produce high-electromagnetic forces in the molten metal and hence adjacent molecules repel each other, as they are in the same direction. The repulsion may cause the interruption of secondary circuit (formation of bubbles and voids); this effect is known as ***pinch effect.***

ii) Vertical core type induction

- It is an improvement over the direct core type furnace, to overcome some of the disadvantages mentioned above. This type of furnace consists of a vertical core instead of horizontal core as shown in Fig.

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

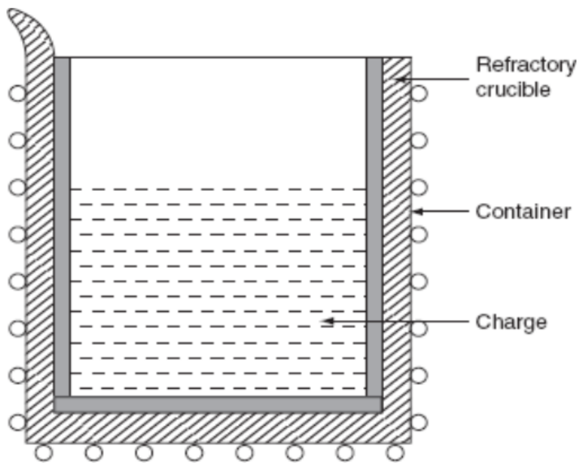


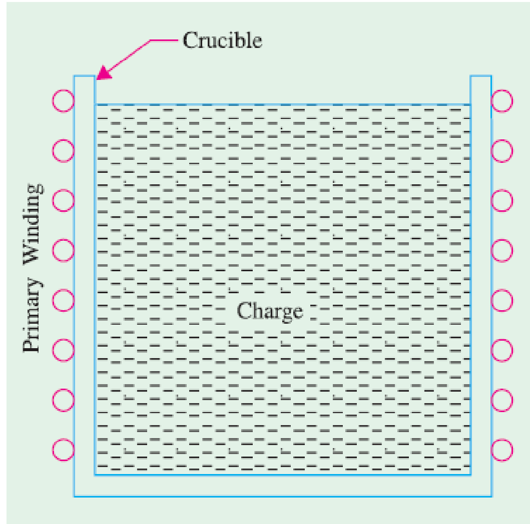


- Vertical core avoids the pinch effect due to the weight of the charge in the main body of the crucible. The leakage reactance is comparatively low and the power factor is high as the magnetic coupling is high compared to direct core type.
- There is a tendency of molten metal to accumulate at the bottom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

Coreless type induction furnace

- It is a simple furnace with the absence of Iron core is shown in Fig.. In this furnace, heat developed in the charge due to eddy currents flowing through it.

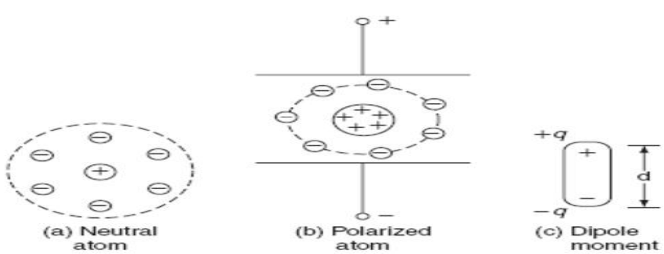




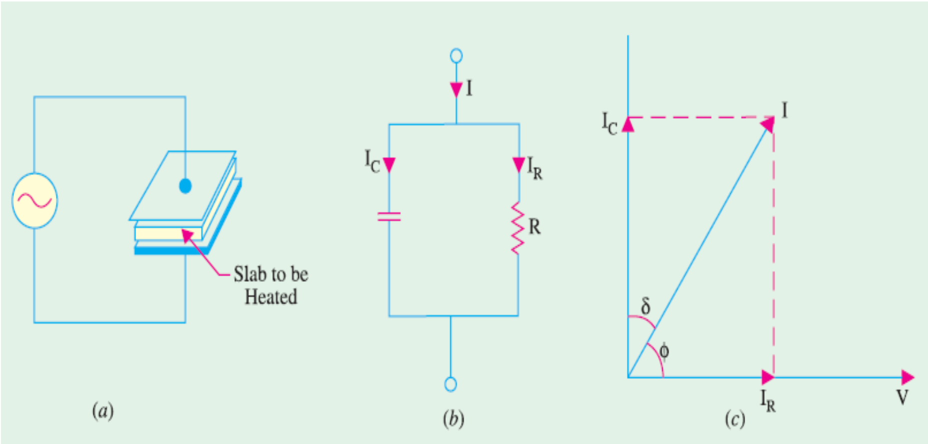
- The three main parts of the furnace are (*i) primary coil (ii) a ceramic crucible containing charge which forms the secondary and* (*iii) the furnace which is of Non conducting material.*
- The charge is put into the crucible and primary winding is connected to a high-frequency a.c. supply. The flux produce by the primary sets up eddy-currents in the charge and heats it up to the melting point.
- Such furnaces are commonly used for steel production and for melting of non-ferrous metals like brass, bronze, copper and aluminum etc., along with various alloys of these elements.

DIELECTRIC HEATING

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



- When a practical capacitor is connected across an a.c. supply, it draws a current which leads the voltage by an angle φ, which is a little less than 90° or falls short of 90° by an angle δ.
- It means that there is a certain component of the current which is in phase with the voltage and hence produces some loss called dielectric loss..
- At the normal supply frequency of 50 Hz, this loss is negligibly small but at higher frequencies of 50 MHz or so, this loss becomes so large that it is sufficient to heat the dielectric in which it takes place.



Advantages

o The heating of the non-conducting materials is very rapid.

o The uniform heating of material is possible.

o Heat is produced in the whole mass of the material.

Applications

o The drying of paper, wood, etc.

o The gluing of wood.

o The heat-sealing of plastic sheets.

o The heating for the general processing such as coffee roasting and chocolate industry.

o The heating for the dehydration such as milk, cream, and vegetables.

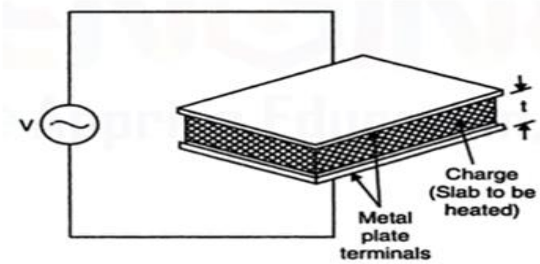
o The preparation of thermoplastic resins.

o The heating of bones and tissues.

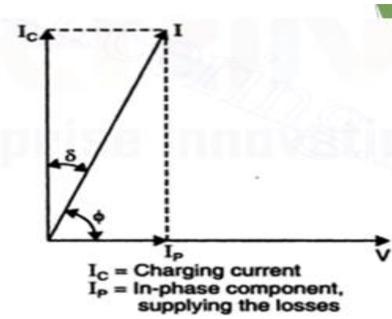
o Diathermy, i.e., the heat treatment for certain body pains and diseases, etc.

o The sterilization of cotton, bandages, etc.

o The processing of rubber, synthetic materials, chemicals, etc.



Parallel-plate capacitor
-Dielectric heating.



Vector diagram

Power drawn from supply = $VI \cos \phi$

Now, $$I_C = I = \frac{V}{X_C} = \frac{V}{1/2\pi fC} = 2\pi fCV.$$

$$\therefore \quad P = V(2\pi fCV) \cos \phi = 2\pi fCV^2 \cos \phi$$

Here, $$C = \frac{\varepsilon_0 \varepsilon_r A}{t},$$

t and A are the thickness and area of the dielectric slab respectively

ε_r is the relative permittivity of dielectric

ε_0 is the absolute permittivity of vaccum (= 8.854×10^{-12} F/m).

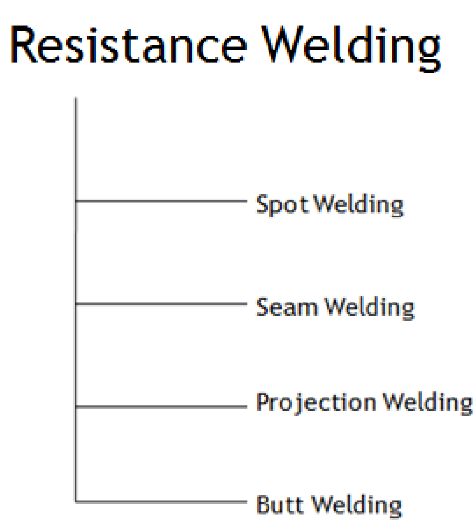
for a given insulation material C and δ are constant the *dielectric loss* $\alpha\, V^2 f$.

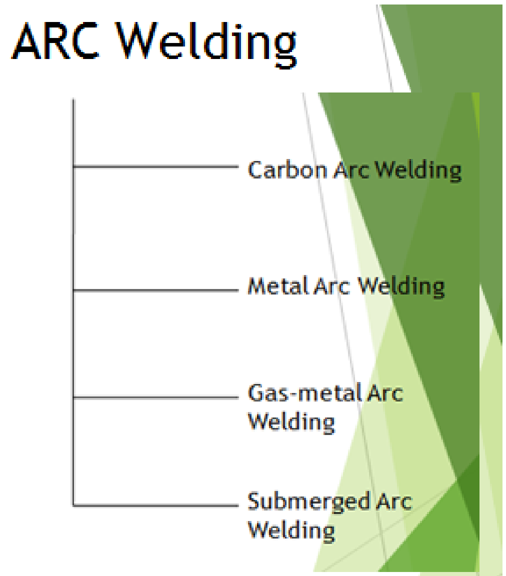
$$\text{Heat produced} \propto V^2 f$$

$$\therefore \quad V_2^2 f_2 = V_1^2 f_1$$

9) List out Different Methods of Electric Welding?

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





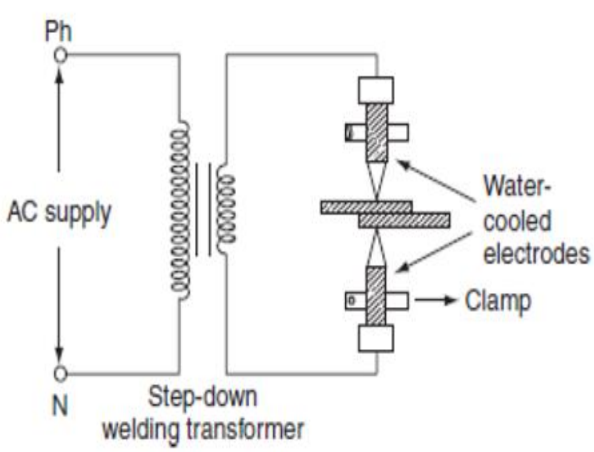
10) Explain about Resistane Welding and their types?

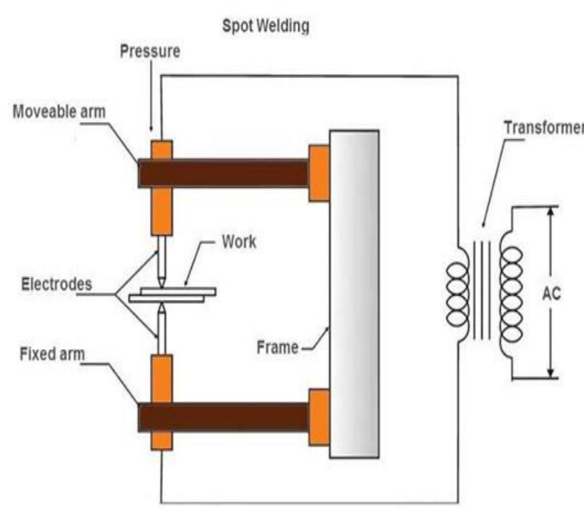
Definition: Resistance welding is the process of joining two metals together by the heat produced due to the resistance offered to the flow of electric current at the junctions of two metals. The heat produced by the resistance to the flow of current is given by:

$$H = I^2Rt,$$

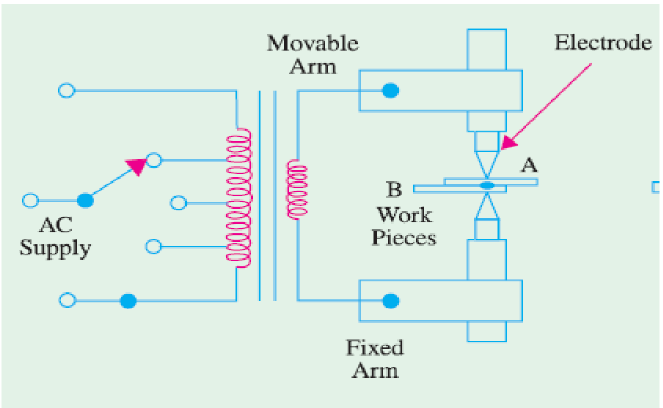
(i) Spot Welding

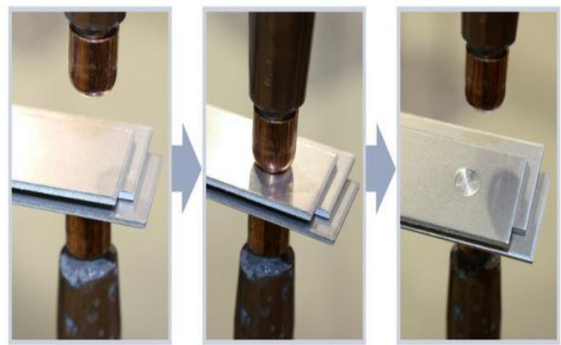
Spot welding means the joining of two metal sheets and fusing them together between copper electrode tips at suitably spaced intervals by means of heavy electric current passed through the electrodes as shown in Fig.





- It consists of a step-down transformer which can supply huge currents (upto 5,000 A) for short duration of time.
- The lower arm is fixed whereas the upper one is movable.
- As the movable electrode comes down and presses the two workpieces *A and B together*, *current is* passed through the assembly.
- The metals under the pressure zone get heated upto about 950°C and fuse together.



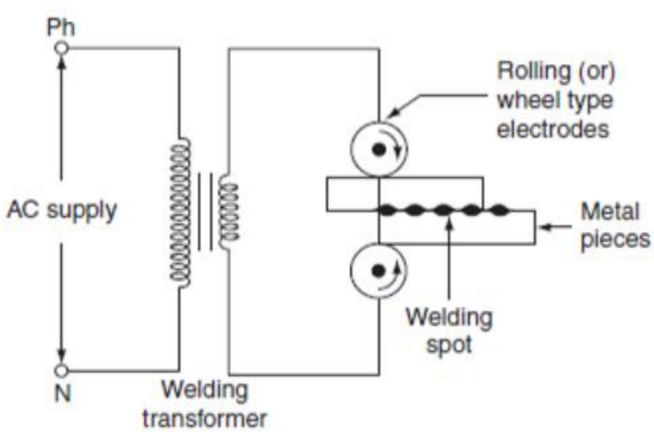


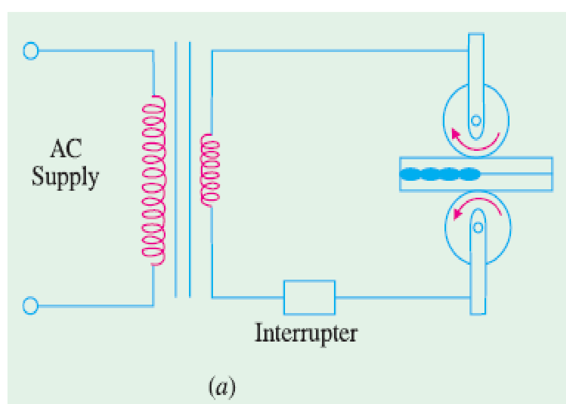
Applications

- Spot welding is used for galvanized, tinned and lead coated sheets and mild steel sheet work. This technique is also applied to non-ferrous materials such as brass, aluminum, nickel and bronze etc.

(ii) Seam welding

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

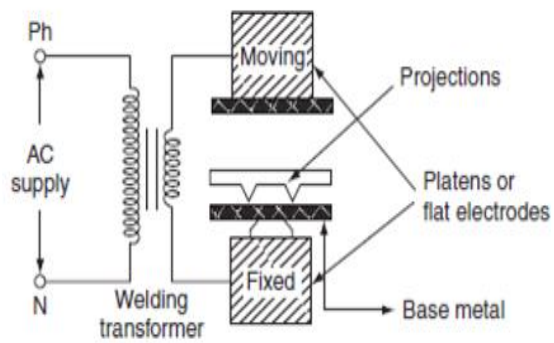


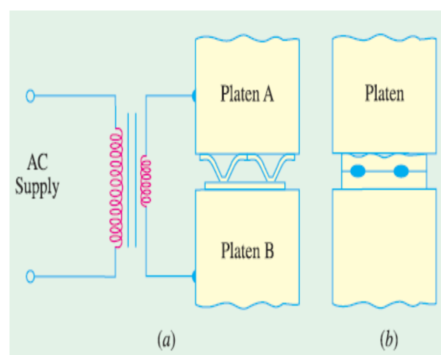


- The seam welder differs from ordinary spot welder only in respect of its electrodes which are of disc or roller shape.
- The current is so applied through the wheels that the weld spots as overlap.
- Seam welding is confined to welding of thin materials ranging in thickness from 2 mm to 5 mm. It is also restricted to metals having low hardenability rating such as hot-rolled grades of low alloy steels.

(iii) Projection welding

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





- Projection welding is an electric resistance welding process that uses small projections, embossments, or intersections on one or both components of the weld to localize the heat and pressure.
- By doing so, weld current and force is focused into the small area of the projection, and heat is obtained from the resistance to the flow of the welding current.
- Due to this heat, the projections collapse and the parts are weld together.

(iv)Butt welding

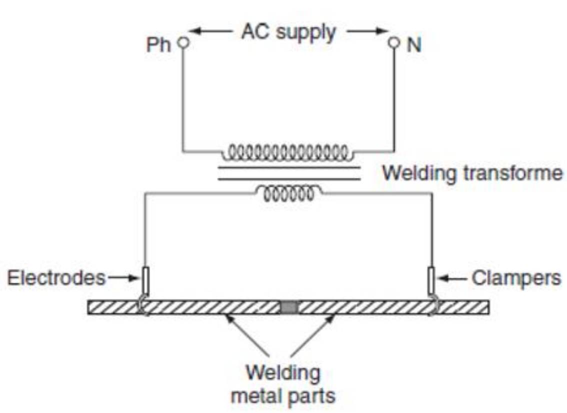
Butt welding is similar to the spot welding; however, the only difference is, in butt welding, instead of electrodes the metal parts that are to be joined or butted together are connected to the supply.

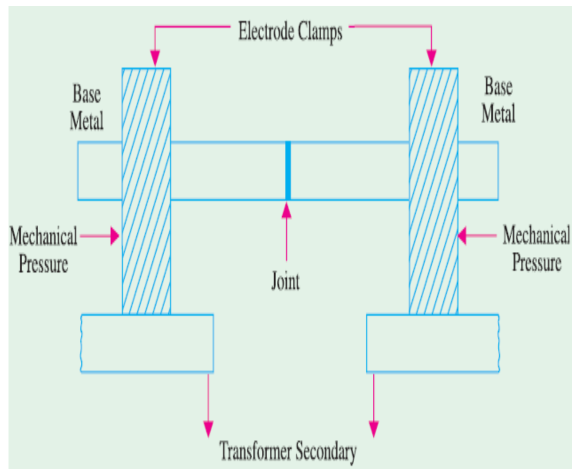
The two basic types of the butt welding process are:

1. Upset butt welding.
2. Flash butt welding.

Upset butt welding

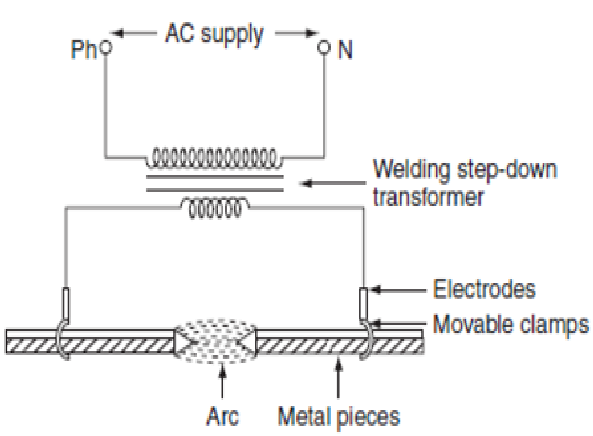
- In upset welding, the two metal parts to be welded are joined end to end and are connected across the secondary of a welding transformer as shown in Fig.
- When current is made to flow through the two electrodes, heat will develop due to the contact resistance of the two pieces and then melts.
- By applying high mechanical pressure either manually or by toggle mechanism, the two metal pieces are pressed.
- This type of welding is usually employed for welding of rods, pipes, and wires and for joining metal parts end to end.

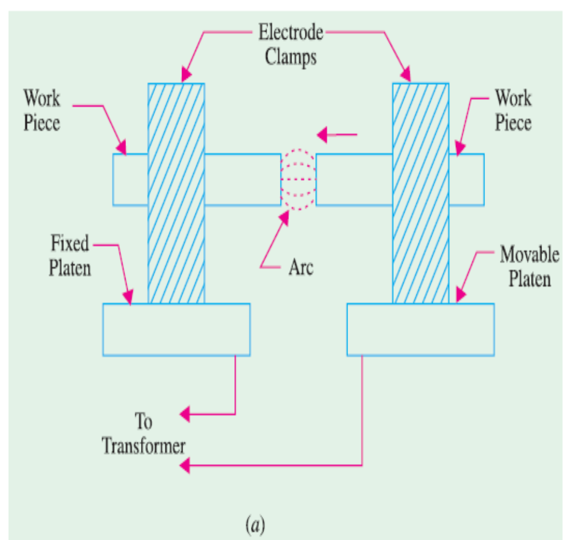




Flash butt welding

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





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

<u>Advantages:</u>

1. Even rough or irregular ends can be flash-welded. There is no need to level them by machining and grinding because all irregularities are burnt away during flashing period.
2. It is much quicker than upset butt welding.
3. It uses considerably less current than upset butt welding.
4. One of its major advantages is that dissimilar metals with different welding temperatures can be flash-welded.

<u>Applications:</u>

1. To assemble rods, bars, tubings, sheets and most ferrous metals.
2. In the production of wheel rims for automobiles and bicycles.
3. For welding tubular parts such as automobile break cross-shafts.
4. For welding tube coils for refrigeration plants etc.

11) Explain about Arc Welding and their types?

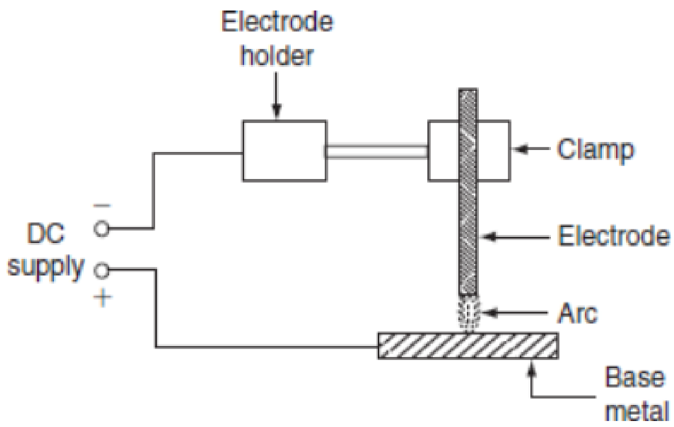
In this process, an electric arc is produced by bringing two conductors (electrode and metal piece) connected to a suitable source of electric current, momentarily in contact and then separated by a small gap, arc blows due to the ionization and give intense heat.

(i) 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.
- 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.
- Due to high temperature, there is a tendency of the particles of carbon will fuse and mix up with the base metal.
- In the carbon arc welding, carbon or graphite rods are used as electrode. Due to longer life and low resistance, graphite electrodes are used, and thus capable of conducting more current.

Advantages

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



Disadvantages

o Input current required in this welding, for the workpiece to rise its temperature to melting/welding temperature, is approximately double the metal arc welding.

o A separate filler rod has to be used if any filler metal is required

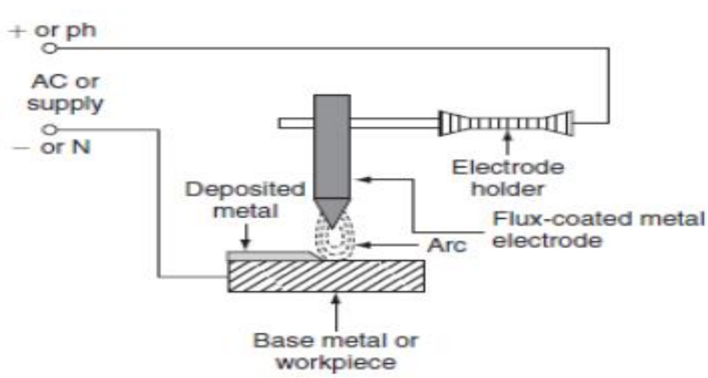
Applications

o It can be employed for the welding of stainless steel with thinner gauges.

o Useful for the welding of thin high-grade nickel alloys and for galvanized sheets using copper silicon manganese alloy as a filler metal.

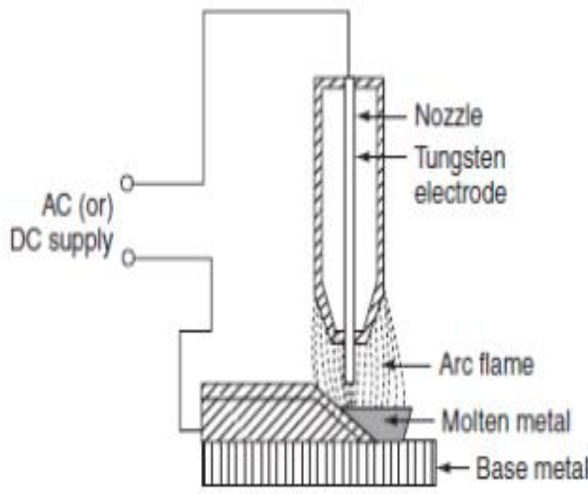
(ii) Metal arc welding

- In metal arc welding, the electrodes used must be of the same metal as that of the work - piece to be welded. The electrode itself forms the filler metal.
- An electric arc is stuck by bringing the electrode connected to a suitable source of electric current, momentarily in contract with the work pieces to be welded and withdrawn apart.
- This high temperature of the arc melts the metal as well as the tip of the electrode, then the electrode melts and deposited over the surface of the work piece, forms complete weld.
- 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.



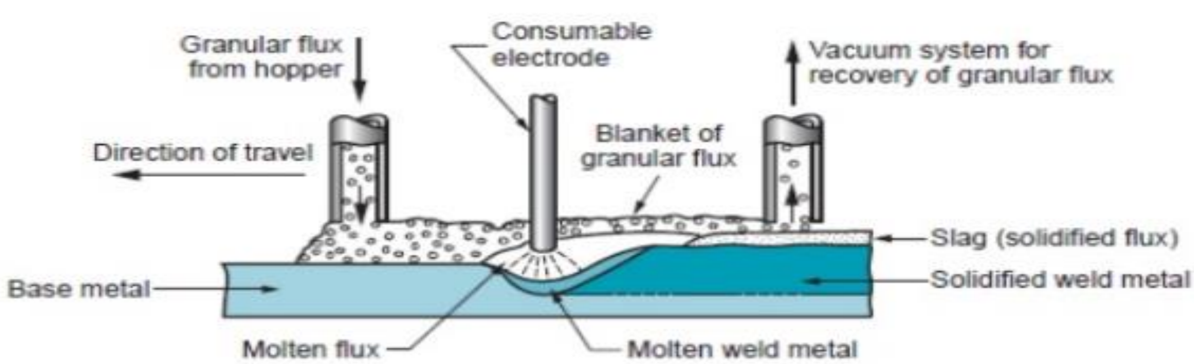
(iii)Gas-Metal arc welding (Inert Gas welding)

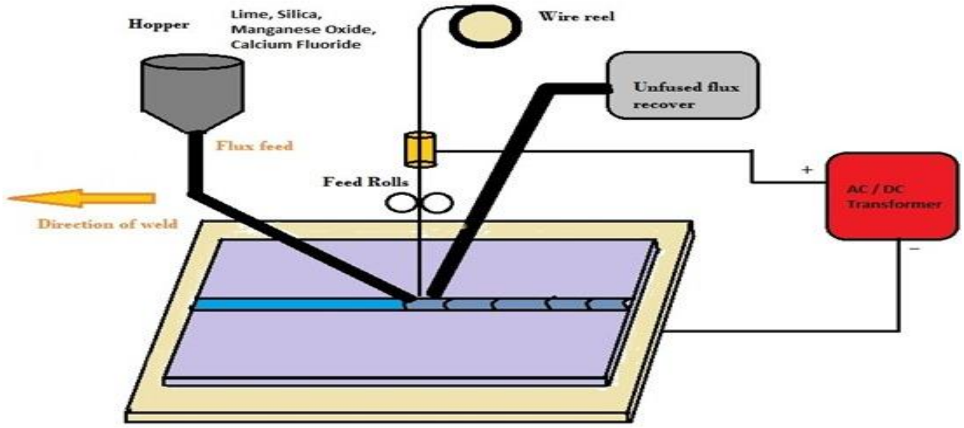
- It is a gas-shielded metal arc welding, in which an electric arc is stuck between tungsten electrode and work piece to be welded. Filler metal may be introduced separately into the arc if required.
- A welding gun, which carries a nozzle, through this nozzle, inert gas such as beryllium or argon is blown around the arc and onto the weld, as shown in Fig.
- As both beryllium and argon are chemically inert, so the molten metal is protected from the action of the atmosphere by an envelope of chemically reducing or inert gas.
- As molten metal has an affinity for oxygen and nitrogen, if exposed to the atmosphere, thereby forming their oxides and nitrides, which make weld leaky and brittle.



(iv)Submerged arc welding

- Submerged-arc welding (SAW) involves the formation of an arc between a continuously fed electrode and the work piece.
- A blanket of powdered flux, which generates a protective gas shield and a slag (and may also be used to add alloying elements to the weld pool), protects the weld zone. A shielding gas is not required.





12) Differentiate AC and Dc Welding?

COMPARISON BETWEEN AC AND DC 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.
2 The cost of the equipment is high.	The cost of the equipment is cheap.
3 Arc stability is more.	Arc stability is less.
4 The heat produced is uniform.	The heat produced is not uniform.
5 Both bare and coated electrodes can be used.	Only coated electrodes should be used.
6 The operating power factor is high.	The power factor is low. So, the capacitors are necessary to improve the power factor.
7 It is safer since no load voltage is low.	It is dangerous since no load voltage is high.
8 The electric energy consumption is 5–10 kWh/kg of deposited metal.	The electrical energy consumption is 3–4 kWh/kg of deposited metal
9 Arc blow occurs due to the presence of non-uniform magnetic field.	Arc blow will not occur due to the uniform magnetic field.
10 The efficiency is low due to the rotating parts.	The efficiency is high due to the absence of rotating parts.

13) Differentiate Resistance and Arc Welding?

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 head 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 more simple and easy 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.
7 The power consumption is low.	The power consumption is high.
8 The operating power factor is low.	The operating power factor is high.
9 Bar, roller, or flat type electrodes are used (not consumable).	Bare or coated electrodes are used (consumable or non-consumable).

14)

Example *. A slab of insulating material 130 cm² in area and 1 cm thick is to be heated by dielectric heating. The power required is 380 W at 30 MHz. Material has a relative permittivity of 5 and p.f. of 0.05. Absolute permittivity = 8.854 × 10⁻¹² F/m. Determine the necessary voltage.*

Solution. *Given* : $A = 130\ \text{cm}^2 = 130 \times 10^{-4}\ \text{m}^2$; $t = 1\ \text{cm} = 0.01\ \text{m}$; $P = 380\ \text{W}$; $f = 30\ \text{MHz}$; $\varepsilon_r = 5$; p.f. $= 0.05$; $\varepsilon_0 = 8.854 \times 10^{-12}\ \text{F/m}$

Voltage, V :

$$\text{Capacitance, } C = \frac{\varepsilon_0 \varepsilon_r A}{t} = \frac{8.854 \times 10^{-12} \times 5 \times 130 \times 10^{-4}}{0.01} = 57.55 \times 10^{-12}\ \text{F}$$

$$P = 2\pi f C V^2 \cos\phi$$

$$380 = 2\pi \times 30 \times 10^6 \times 57.55 \times 10^{-12}\ V^2 \times 0.05$$

$$V^2 = \frac{380}{2\pi \times 30 \times 10^6 \times 57.55 \times 10^{-12} \times 0.05} = 700595$$

$V = 837$ **V. (Ans.)**

15)

Example *A piece of an insulating material is to be heated by dielectric heating. The size of the piece is 12 cm × 12 cm × 3 cm. A frequency of 20 MHz is used and the power absorbed is 450 W. If the material has a relative permittivity of 5 and a power factor of 0.05, calculate the voltage necessary for heating and current that follows in the material.*

If the voltage were limited to 1700 V, what will be the frequency to get the same loss ?

Solution. *Given* : $A = 12 \times 12 = 144\ cm^2 = 144 \times 10^{-4}\ m^2$; $t = 3\ cm = 0.03\ m$;

$f = 20$ MHz ; $P = 450$ W ; $\varepsilon_r = 5$; $\cos \phi = 0.05$.

Voltage and current :

The capacitance of the parallel plate condenser that the material forms is given by,

$$C = \frac{\varepsilon_0 \cdot \varepsilon_r A}{t} = \frac{8.854 \times 10^{-12} \times 5 \times 144 \times 10^{-4}}{0.03} = 21.25 \times 10^{-12}\ F$$

Power, $P = 2\pi fCV^2 \cos \phi$

$$450 = 2\pi \times 20 \times 10^6 \times 21.25 \times 10^{-12} \times V^2 \times 0.05$$

$$V^2 = \frac{450}{2\pi \times 20 \times 10^6 \times 21.25 \times 10^{-12} \times 0.05} = 3370340$$

Voltage, **V = 1836 V. (Ans.)**

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 20 \times 10^6 \times 21.25 \times 10^{-12}} = 374.5\ \Omega$$

Current, $I \simeq I_C = \frac{V}{X_C}$

Current, $I \simeq I_C = \frac{V}{X_C} = \frac{1836}{374.5} = 4.9$ **A. (Ans.)**

Heat produced $\propto V^2 f$

$\therefore \quad V_2^2 f_2 = V_1^2 f_1$

$$f_2 = f_1 \times \left(\frac{V_1}{V_2}\right)^2 = 20 \left(\frac{1836}{1700}\right)^2 = 23.33\ \text{MHz.} \quad \textbf{(Ans.)}$$

16)

Example . *Calculate the efficiency of a high frequency induction furnace which takes 10 minutes to melt 1.8 kg of aluminium. The input to the furnace being 4.8 kW and initial temperature 15°C. Specific heat of aluminium = 0.88 kJ/kg°C; melting point of aluminium = 660°C ; latent heat of fusion of aluminium = 32 kJ/kg ; 1 kJ = 2.78 × 10^-4 kWh.*

Solution. *Given* : m = 1.8 kg ; Input to the furance = 4.8 kW ; t_1 = 15°C ; t_2 = 660°C, c = 0.88 kJ/kg°C ; L = 32 kJ/kg ; 1 kJ = 2.78×10^{-4} kWh.

Heat required to melt 1.8 kg of aluminium

$$= m \times c \times (t_2 - t_1) + m \times L$$

$$= m\,[c \times (t_2 - t_1) + L] = 1.8\,[0.88\,(660 - 15) + 32] = 1079.28 \text{ kJ}$$

$$= 1079.28 \times 2.78 \times 10^{-4} = 0.3 \text{ kWh}$$

Energy input $= 4.8 \times \dfrac{10}{60} = 0.8$ kWh

$$\therefore \quad \eta = \frac{\text{Output}}{\text{Input}} = \frac{0.3}{0.8} = 0.375 \quad \text{or} \quad \textbf{37.5\%}. \quad \textbf{(Ans.)}$$

17)

Example : A high-frequency induction furnace that takes 20 min to melt 1.9 kg of aluminum, the input to the furnace being 3 kW, and the initial temperature is 25°C. Then, determine the efficiency of the furnace. The specific heat of aluminum = 0.212. Melting point = 660°C. The latent heat of the fusion of aluminum = 76.8 kcal/kg.

Solution:

m= weight of the metal to be heated up = 1.9 Kg;
c= Specific heat of metal = 0.212
t1= Initial Temperature of metal = 25°C;
t2= Final melting point of metal = 660°C
L= Latent Heat of metal = 76.8 Kcal/kg

Total heat required (output) $= m[c \times (t_2 - t_1) + L]$

$= 1.9[0.212 \times (660 - 25) + 76.8]$

$= 401.698$ kcal

1 Kcal = 0.001163 kwh

∴ 401.698 KCal = 0.467174 Kwh = Energy output

Energy Input = $3 \times \frac{20}{60} = 1$ Kwh

$$\% \eta = \frac{\text{output}}{\text{Input}} \times 100 = \frac{0.467174}{1} = 46.7174\ \%$$

18)

Example . *A resistance oven employing nichrome wire is to be operated from 220 V single-phase supply and is to be rated at 16 kW. If the temperature of the element is to be limited to 1170°C and average temperature of the charge is 500°C find the diameter and length of the element wire.*

Radiating efficiency = 0.57, Emissivity = 0.9, Specific resistance of nichrome = 109 × 10^{-8} Ωm.

Solution. *Given* : $V = 220$ V ; $P = 16$ kW ; $T_1 = 273 + 1170 = 1443$ K ;

$T_2 = 273 + 500 = 773$ K ; $\eta_{rad} = 0.57$; $e = 0.9$; $\rho = 109 \times 10^{-8}$ Ωm.

***l, d* :**

We know that,
$$\frac{l}{d^2} = \frac{\pi V^2}{4\rho P} = \frac{\pi \times 220^2}{4 \times 109 \times 10^{-8} \times (16 \times 10^3)} = 2179660 \qquad ...(i)$$

Now,
$$H = 5.67\, \eta_{rad}\, e \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{W/m}^2$$

$$= 5.67 \times 0.57 \times 0.9 \left[\left(\frac{1443}{100}\right)^4 - \left(\frac{773}{100}\right)^4\right] = 115729 \text{ W/m}^2$$

If H is the heat dissipated by radiation per second per unit surface area of the wire, then, Heat radiated per second = $(\pi d) \times l \times H$

Now, total heat dissipated/sec. =Electrical power input

$\therefore \quad (\pi d) \times l \times 115729 = 16000 \qquad \therefore \quad dl = 0.044$

$$d^2 l^2 = 0.001936 \qquad ...(ii)$$

Multiplying (*i*) and (*ii*), we have

$$l^3 = 2179660 \times 0.001936 = 4219.8$$

$\therefore$ **l = 16.16 m. (Ans.)**

and,
$$\mathbf{d} = \frac{0.044}{16.16} = 2.723 \times 10^{-3} \text{ m} = \mathbf{2.723 \text{ mm.}} \quad \textbf{(Ans.)}$$

UNIT-3

Fundamentals of Illumination

1) Define the following terms?

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

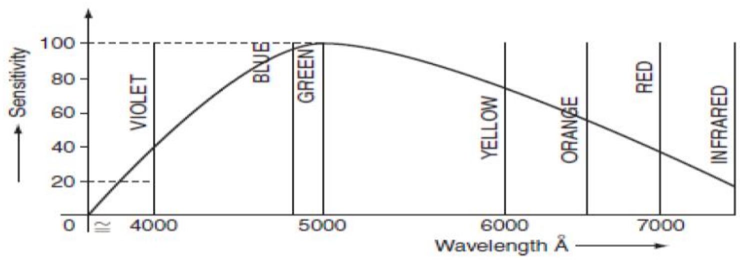


Fig. Wavelength

Relative sensitivity:

The reacting power of the human eye to the light waves of different wavelengths varies from person to person, and also varies with age. The eye is most sensitive for a wavelength of 5,500 Å. So that the relative sensitivity according to this wavelength is taken as unity. The relative sensitivity at any particular wavelength (λ) is known as relative luminous factor ($K\lambda$).

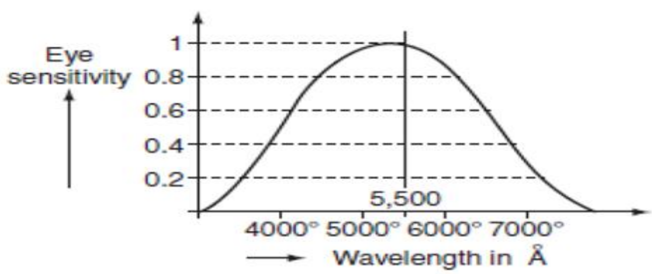


Fig. (b) The average relative sensitivity

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

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

Radiant efficiency:-

When an electric current is passed through a conductor, some heat is produced (*I2R* loss), which increases the temperature of the conductor. At low temperature, conductor radiates energy in the form of heat waves, but at very high temperatures, radiated energy will be in the form of light as well as heat waves.

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

$$\text{Radiant efficiency} = \frac{\text{energy radiated in the form of light}}{\text{total energy radiated by the body}}.$$

Plane angle:-

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

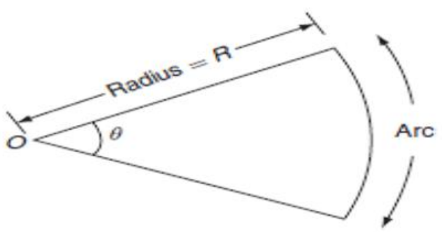


Fig. Plane angle

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

Solid angle:-

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

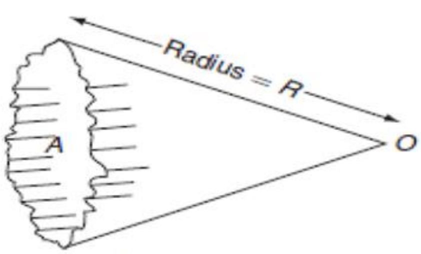


Fig. Solid angle

$$\therefore \text{Solid angle } (\omega) = \frac{\text{area}}{\text{radius}^2}.$$

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

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

Luminous intensity:-

Luminous intensity in a given direction is defined as the luminous flux emitted by the source per unit solid angle

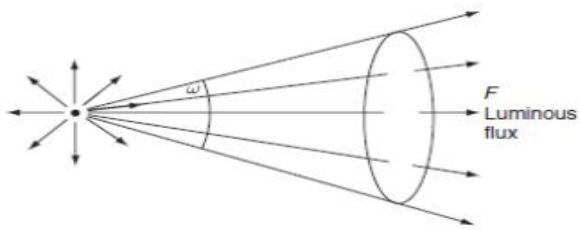


Fig. Luminous flux emitting from the source

It is denoted by the symbol 'I' and is usually measured in 'candela'.

Let 'F' be the luminous flux crossing a spherical segment of solid angle 'ω'. Then luminous intensity $(I) = \frac{\phi}{\omega}$ lumen/steradian or candela.

Lumen:-

It is the unit of luminous flux.

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

Lumen = candle power of source × solid angle.

Lumen = CP × ω

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

Candle power (CP)

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

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

Illumination

Illumination is defined as the luminous flux received by the surface per unit area.

It is usually denoted by the symbol 'E' and is measured in lux or lumen/m2 or meter candle or foot candle.

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

$$= \frac{\phi}{A} = \frac{CP \times \omega}{A} \text{ lux.}$$

Lux or meter candle

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

Foot candle

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

We know that 1 lux = 1 foot candle = 1 lumen/$(\text{ft})^2$

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

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

Brightness

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

If the luminous intensity of source be '*I*' candela on an *area A*, then the projected area is $A\cos\theta$.

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

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

Mean horizontal candle power (MHCP)

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

Mean spherical candle power (MSCP)

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

Mean hemispherical candle power (MHSCP)

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

Reduction factor

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

$$\text{i.e., reduction factor} = \frac{MSCP}{MHCP}.$$

Lamp efficiency

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

$$\therefore \text{Lamp efficiency} = \frac{\text{luminous flux}}{\text{power input}}.$$

Specific consumption

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

Space to height ratio

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

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

Coefficient of utilization or utilization factor

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

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

Maintenance factor

It is defined as the ratio of illumination under normal working conditions to the illumination when everything is clean. Its value is always less than 1, and it will be around 0.8.

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

Depreciation factor

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

$$\therefore \text{Depreciation factor} = \frac{1}{\text{maintenance factor}}.$$

Waste light factor

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

Absorption factor

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

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

Beam factor

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

Reflection factor or coefficient of reflection

When light rays impinge on a surface, it is reflected from the surface at an angle of incidence shown in Fig. A portion of incident light is absorbed by the surface.

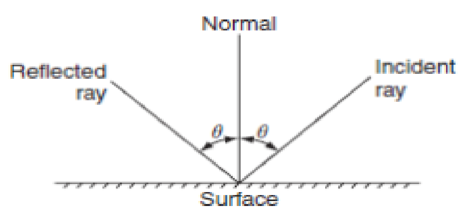


Fig. Reflected ray

$$\text{Reflection factor} = \frac{\text{reflected light}}{\text{incident light}}.$$

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.

2) Derive relationship between Plane angle and Solid angle?

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

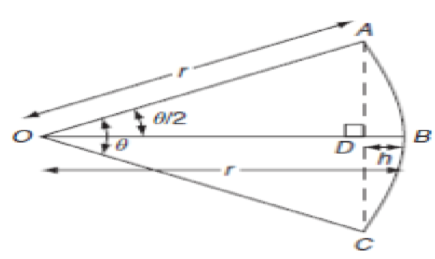


Fig. Sectional view for solid angle

From the Fig.:

$$BD = OB - OD$$

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

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

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

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

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

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

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

The curve shows the variation of solid angle with plane angle is shown in Fig.

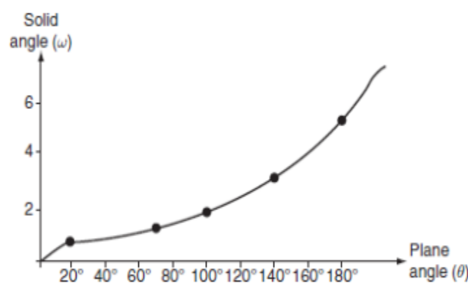


Fig. Relation between solid angle and plane angle

3) Derive the Relation between I, E, and L (Luminous Intensity, Illumination and Brightness)

Consider a uniform diffuse Spherical source with radius r metres and Luminous Intensity I candela Then

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

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

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

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

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

4) Explain the different laws of Illumination.

Mainly there are two laws of illumination.

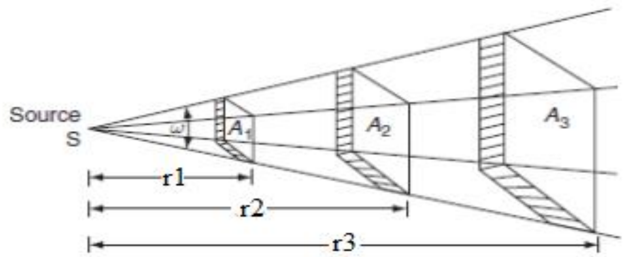
1. Inverse square law.
2. Lambert's cosine law.

Inverse square law:-

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

Proof:-

Let, '*S*' be a point source of luminous intensity '*I*' candela, the luminous flux emitting from source crossing the three parallel plates having areas *A*1 *A*2, and *A*3 square meters, which are separated by a distances of *r1*, *r*2, and *r3* from the point source respectively as shown in Fig.



For area A1, Solid angle is given by $\omega = \frac{A_1}{r_1^2}$

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

$$= I \times \omega = I \times \frac{A_1}{r_1^2}$$

∴ Illumination *'E*1*'* on the surface area *'A*1*'* is:

$$E_1 = \frac{flux}{area} = \frac{IA_1}{r_1^2} \times \frac{1}{A_1} = \frac{I}{r_1^2}$$

Therefore, $E_1 = \frac{I}{r_1^2}$

Similarly, illumination *'E*2*'* on the surface *area A*2 is: $E_2 = \frac{I}{r_2^2}$

and illumination '*E*3' on the surface area *A*3 is: $E_3 = \frac{I}{r_3^2}$

From the above equations $E_1 : E_2 : E_3 = \frac{I}{r_1^2} : \frac{I}{r_2^2} : \frac{I}{r_3^2}$

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

Lambert's cosine law:-

This law states that 'illumination, *E* at any point on a surface is directly proportional to the cosine of the angle made by the normal to the illuminated surface with the direction of incident flux'.

Proof:

As shown in the figure, let F be the luminous flux incident on the surface of area A when in position 1. When this surface is turned back through an angle θ, then luminous flux incident on it is F$\cos\theta$.

Hence illumination of the surface when in position 1 is $E_1 = \frac{F}{A}$

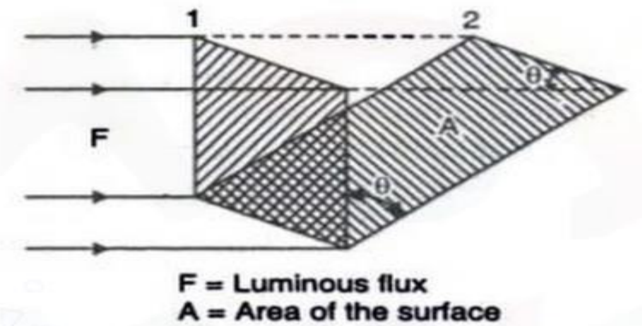


Fig. Lambert's cosine law.

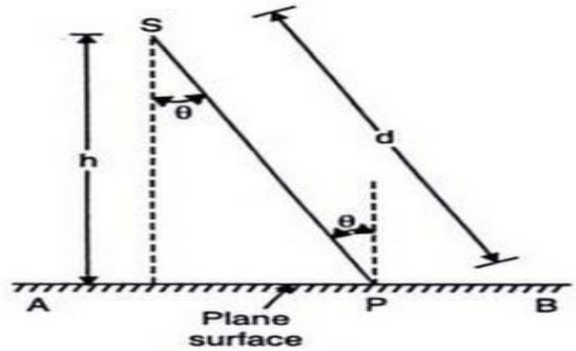
But, when in position 2 $E_2 = \frac{F\cos\theta}{A}$

Therefore, $E_2 = E_1 \cos\theta$

Combining all these factors together, we get $E = \frac{I\cos\theta}{r^2}$

The illumination at any point on the plane surface due to the light source suspended at a height 'h' from the plane surface as shown in fig.

From the diagram, Consider a point 'P' on the plane surface 'AB' where the illumination due to the light source 'S' of luminous intensity 'I' at a height 'h' from the surface 'AB' is to be determined. Let'd' be the distance source 'S' and point 'P'.



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

Illumination at point 'P', by laws of illumination is given by

$$\frac{I}{d^2}\cos\theta = \frac{I}{(h/\cos\theta)^2}\cos\theta = \frac{I}{h^2}\cos^3\theta$$

Illumination at point 'O' vertically below the source of light is given by $\frac{I}{h^2}$

Hence, illumination at any point on a plane is $\cos^3\theta$ times of illumination at a point just vertically below the light source, where θ is the angle between the normal to the surface at the point and rays of light.

5) What are Polar curves and what is their significance?

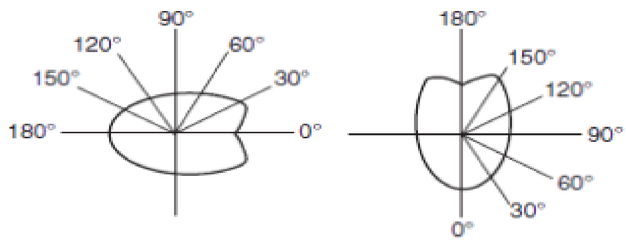
- ❖ The luminous flux emitted by a source can be determined using the intensity distribution curve. Till now we assumed that the luminous intensity or the candle power from a source is distributed uniformly over the surrounding surface. But it is not uniform in all directions.
- ❖ The luminous intensity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

Accordingly, there are two different types of polar curves and they are:

1. If the luminous intensity, i.e., candle power is measured in the horizontal plane about the vertical axis and a curve is plotted between the candle power and the angular position, 'a ***horizontal polar curve***' is obtained.

2. If the candle power is measured at angular positions in the vertical plane and a curve is plotted between the candle power and the angular position, a ***'vertical polar curve***' is obtained.

The typical polar curves for an ordinary lamp are shown in figure below



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

Depression at 180° in the vertical polar curve is due to the lamp holder.

Slight depression at 0° in horizontal polar curve is because of coiled coil filament.

- Polar curves are used to determine the actual illumination of a surface by employing the candle power in that particular direction. These are also used to determine mean horizontal candle power (MHCP) and mean spherical candle power (MSCP).
- The mean horizontal candle power of a lamp can be determined from the horizontal polar curve by considering the mean value of all the candle powers in a horizontal direction.
- The mean spherical candle power of a symmetrical source of a light can be found out from the polar curve by means of a Rousseau's construction.

Rousseau's construction

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

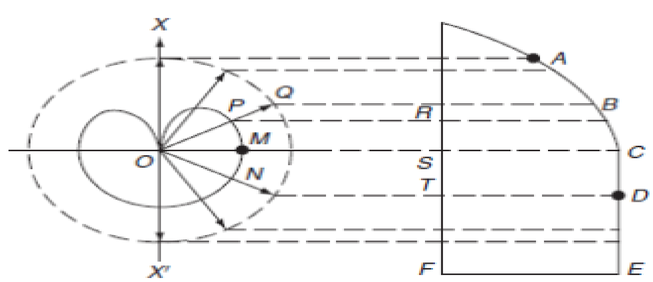


Fig. Rousseau's curve

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

1. Draw a circle with any convenient radius and with '*O*' as center.
2. Draw a line *'AF*' parallel to the axis *XOX*1 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*.

5. 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 *ABC DEFA* so obtained by joining these ordinates is known as Rousseau's curve.

The mean ordinate of this curve gives the mean spherical candle power (MSCP) of the lamp.

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

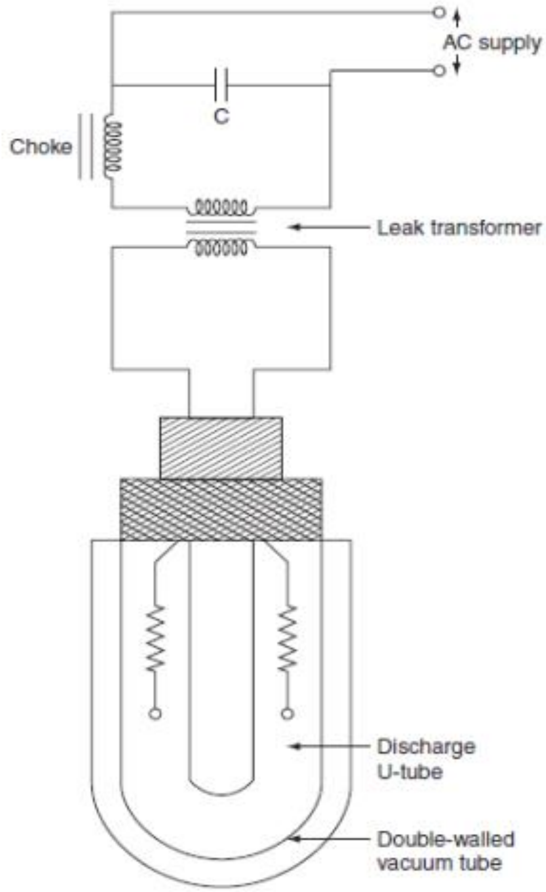
6) Explain the construction and working of Sodium vapour lamp.

SODIUM VAPOR LAMP

- A sodium vapor lamp is a cold cathode and low-pressure lamp.
- A sodium vapor discharge lamp consists of a *U*-shaped tube enclosed in a double-walled vacuum flask, to keep the temperature of the tube within the working region.
- The inner *U*-tube consists of two oxide-coated electrodes, which are sealed with the ends.
- These electrodes are connected to a pin type base construction of sodium vapor lamp is shown in Fig.
- This sodium vapor lamp is low luminosity lamp, so that the length of the lamp should be more.
- This long *U*-tube consists of a small amount of neon gas and metallic sodium.
- At the time of start, the neon gas vaporizes and develops sufficient heat to vaporize metallic sodium in the *U*-shaped tube.

Working

- Initially, the sodium is in the form of a solid, deposited on the walls of inner tube.
- When sufficient voltage is impressed across the electrodes, the discharge starts in the inert gas, i.e., neon; it operates as a low-pressure neon lamp with pink color.
- The temperature of the lamp increases gradually and the metallic sodium vaporizes and then ionizes thereby producing the monochromatic yellow light.
- This lamp takes 10–15 min to give its full light output. The yellowish output of the lamp makes the object appears gray.
- In order to start the lamp, 380 – 450 V of striking voltage required for 40- and 100-W lamps.
- These voltages can be obtained from a high reactance transformer or an auto transformer.
- The operating power factor of the lamp is very poor, so that a capacitor is placed to improve the power factor to above 0.8.
- More care should be taken while replacing the inner tube, if it is broken, then sodium comes in contact with the moisture; therefore, fire will result.



- The lamp must be operated horizontally or nearly so, to spread out the sodium well along the tube.
- The efficiency of sodium vapor lamp is lies between 40 and 50 lumens/W.
- Normally, these lamps are manufactured in 45-, 60-, 85- and 140-W ratings.
- The normal operating temperatures of these lamps are 300°C.
- In general, the average life of the sodium vapor lamp is 3,000 hr and such bulbs are not affected by voltage variations.
- The average light output of the lamp is reduced by 15% due to aging.
- These lamps are mainly used for highway and street lighting, parks, railway yards, general outdoor lighting, etc.

Following are the causes of failure to operate the lamp, when:
o The cathode fails to emit the electrons.
o The filament breaks or burns out.
o All the particles of sodium are concentrated on one side of the inner tube.
o The life of the lamp increases due to aging.

7) Explain the construction and working of High pressure mercury vapour lamp.

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.

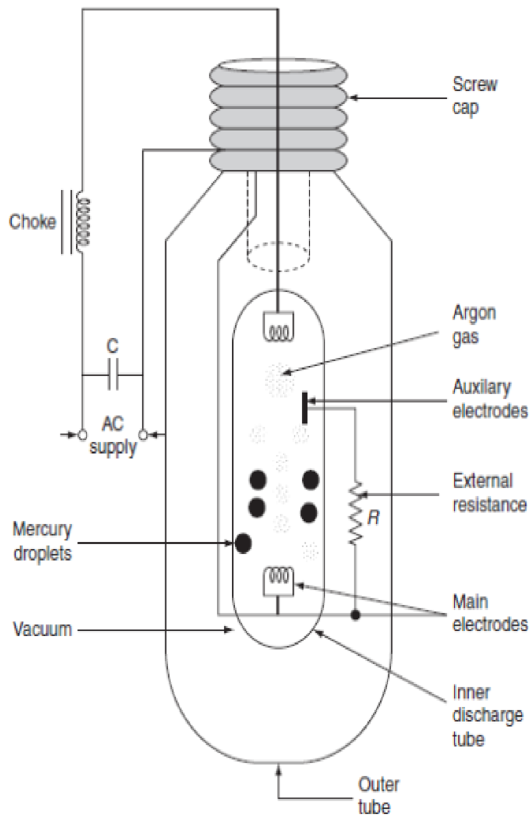
3. MB type: Preferred for 80- and 125-W rating bulbs and they are working at very high pressures.

MA type lamp

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

Working

- Initially, the tube is cold and hence the mercury is in condensed form.
- Initially, when supply is given to the lamp, argon gas present between the main and the auxiliary electrodes gets ionized, and an arc is established, and then discharge takes place through argon for few minutes between the main and the auxiliary electrodes.
- As a result, discharge takes place through argon for few minutes in between the main and the auxiliary electrodes.



- The discharge can be controlled by using high resistance that is inserted in-series with the auxiliary electrode.
- After few minutes, the argon gas, as a whole, gets ionized between the two main electrodes. Hence, the discharge shifts from the auxiliary electrode to the two main electrodes.
- During the discharge process, heat is produced and this heat is sufficient to vaporize the mercury.
- As a result, the pressure inside the discharge tube becomes high and the voltage drop across the two main
electrodes will increases from 20 to 150 V. After 5–7 min, the lamp starts and gives its full output.
- Initially, the discharge through the argon is pale blue glow and the discharge through the mercury vapors is greenish blue light; here, choke is provided to limit high currents and capacitor is to improve the power factor of the lamp.
- If the supply is interrupted, the lamp must cool down and the vapor pressure be reduced before it will start. It takes approximately 3 – 4 min.
- The operating temperature of the inner discharge tube is about 600°C. The efficiency of this type of lamp is 30–40 lumens/W.

- These lamps are manufactured in 250 and 400 W ratings for use on 200–250 V on AC supply.
- Generally, the MA type lamps are used for general industrial lighting, ports, shopping centers, railway yards, etc.

8)

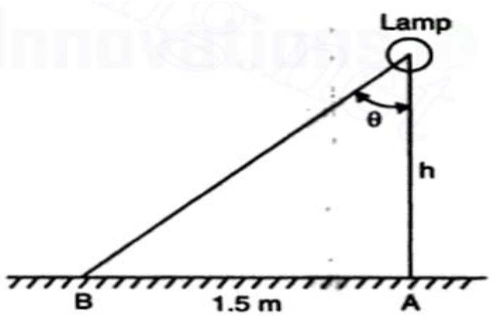
Example *The illumination at a point on a working plane directly below the lamp is to be 80 lumens / m^2. The lamp gives 180 C.P. uniformly below the horizontal plane. Determine :*

(i) The height at which the lamp is suspended.

(ii) The illumination at a point on the working plane 1.5 m away from the vertical axis of the lamp.

Solution. Luminous intensity of the lamp, $I = 180$ C.P.

Illumination directly below the lamp, $E = 80$ lumens/m^2.



(i) The height at which the lamp is suspended, h :

We know that,

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

∴ $$80 = \frac{180}{h^2}$$

or $$h = \sqrt{\frac{180}{80}} = 1.5 \text{ m.} \quad \text{(Ans.)}$$

(ii) The illumination at a point 1.5 m away :

The illumination at a point on the working plane 1.5 m away from the vertical axis of the lamp,

$$E_B = \frac{I}{h^2}\cos^3\theta = \frac{180}{(1.5)^2} \times \left[\frac{1.5}{\sqrt{1.5^2 + 1.5^2}}\right]^3$$

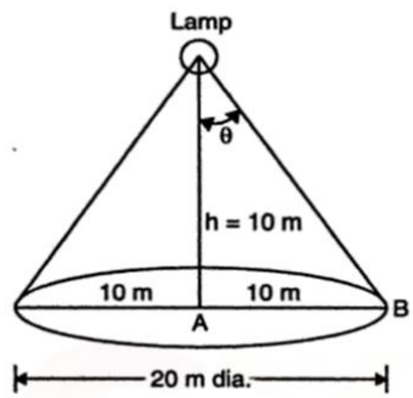
$$= 2.96 \text{ lux.} \quad \text{(Ans.)}$$

9) **Example** *A lamp with reflector is mounted 10 m above the centre of a circular area of 20 m diameter. If the combination of the lamp and reflector gives a uniform C.P. of 800 over the circular area, determine the maximum and minimum illumination produced on the area.*

Solution. Candle power of the lamp, C.P. = 800

Height of the lamp, $h = 10$ m

Diameter of the circular area = 20 m



The *maximum illumination* will occur *directly below the lamp* *i.e.*, at point *A* and

$$= \frac{\text{C.P.}}{h^2} = \frac{800}{10^2} = 8 \text{ lux.} \quad \textbf{(Ans.)}$$

The minimum illumination will occur at the periphery of the circular area *i.e.*, at point *B* and

$$= \frac{\text{C.P.}}{h^2} \cos^3 \theta$$

$$= \frac{800}{10^2} \times \left(\frac{10}{\sqrt{10^2 + 10^2}} \right)^3 = 2.83 \text{ lux.} \quad \textbf{(Ans.)}$$

Example *Two lamp posts are 14 m apart and are fitted with 200 C.P. lamp each at a height of 5 m above the ground. Calculate :*

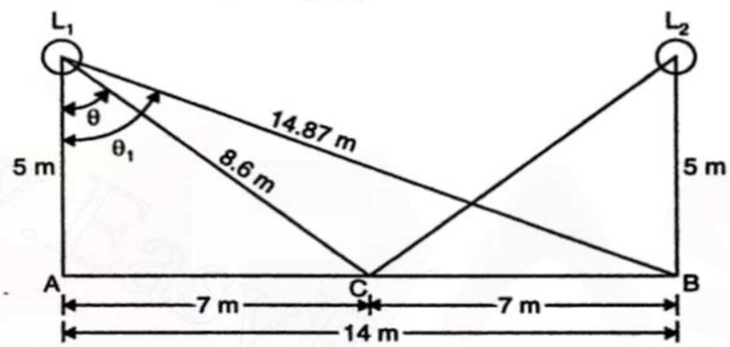
10) *(i) Illumination mid-way between them.*

(ii) Illumination under each lamp.

Solution. Candle power of each lamp = 200 C.P.

Height of each lamp from the ground = 5 m

Distance between the two lamps = 14 m



(*i*) **Illumination midway between the lamps :**

Illumination midway between the lamps,

$$E_C = \text{Illumination due to lamp } L_1 + \text{Illumination due to lamp } L_2$$

$$= \frac{200}{5^2} \times \cos^3\theta + \frac{200}{5^2} \times \cos^3\theta$$

$$= 2 \times \frac{200}{5^2} \times \left(\frac{5}{8.6}\right)^3 = 3.144 \text{ lux.} \quad \textbf{(Ans.)}$$

(*ii*) **Illumination under each lamp :**

Illumination under either of the lamps, say under lamp L_2,

$$E_B = \text{Illumination due to lamp } L_1 + \text{Illumination due to lamp } L_2$$

$$= \frac{200}{5^2}\cos^3\theta_1 + \frac{200}{5^2} = \frac{200}{5^2}(\cos^3\theta_1 + 1)$$

$$= 8\left[\left(\frac{5}{14.87}\right)^3 + 1\right] = 8.3 \text{ lux.} \quad \textbf{(Ans.)}$$

11)

Example *A 500 W lamp having M.S.C.P. of 800 is suspended 3 m above the working plane :*

(i) Illumination directly below the lamp at the working plane.

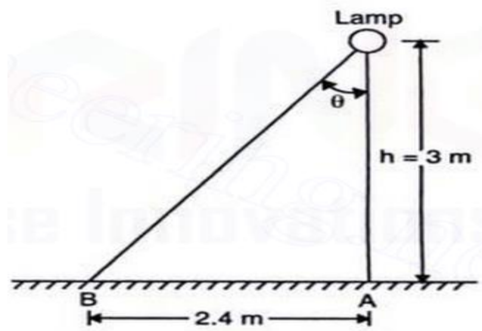
(ii) Lamp efficiency.

(iii) Illumination at a point 2.4 m away on the horizontal plane from vertically below the lamp.

Solution. Wattage of the lamp = 500 W

M.S.C.P. of the lamp, $I = 800$

Height of the lamp, $h = 3$ m



(i) Illumination directly below the lamp at the working plane :

Illumination directly below the lamp,

$$E_A = \frac{I}{h^2} = \frac{800}{3^2} = 88.9 \text{ lux. (Ans.)}$$

(ii) Lamp efficiency :

Lamp efficiency

$$= \frac{\text{Luminous flux}}{\text{Power input}}$$

$$= \frac{4\pi \times \text{M.S.C.P.}}{500}$$

$$= \frac{4\pi \times 800}{500}$$

= **20.1 lumens/watt. (Ans.)**

(*iii*) **Illumination at a point 2.4 m away :**

Illumination at a point 2.4 m away on the horizontal plane from vertically below the lamp,

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

Here, $$\cos\theta = \frac{3}{\sqrt{3^2 + 2.4^2}} = 0.7808$$

∴ $$E_B = \frac{800}{3^2} \times (0.7808)^3 = 42.3 \text{ lux.} \quad \textbf{(Ans.)}$$

12)

Example : Two sources of candle power or luminous intensity 200 candela and 250 candela are mounted at 8 and 10 m, respectively. The horizontal distance between the lamp posts is 40 m, calculate the illumination in the middle of the posts.

Solution:-

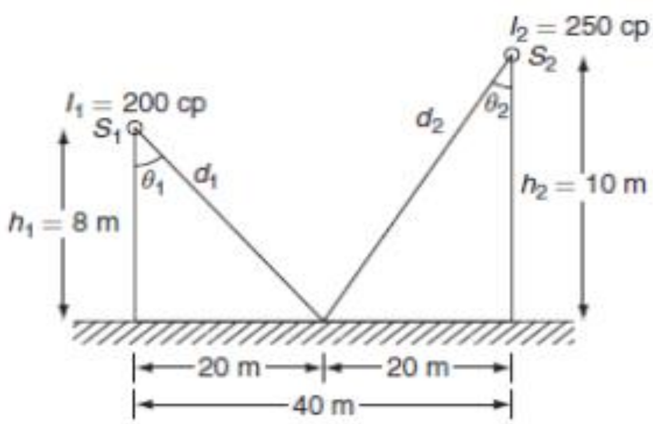
Candle Power of lamp S1= 200 C.P

Candle Power of lamp S2= 250 C.P

Height of lamp S1 from ground= 8m

Height of lamp S2 from ground= 10m

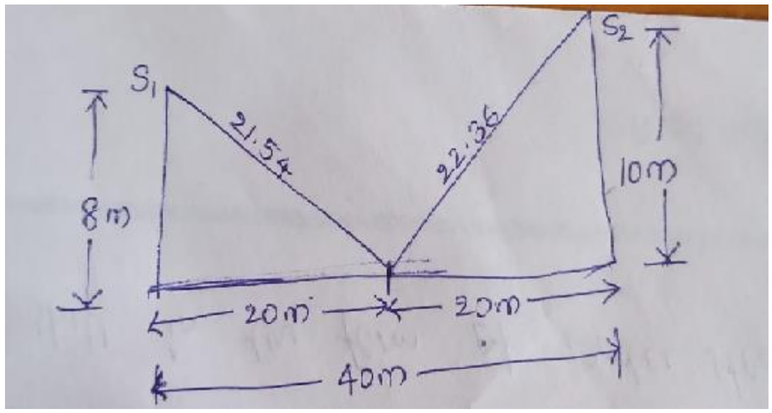
Distance between the lamps = 40m



Illumination midway between the lamps :

Illumination midway between the lamps,

$$E_C = \text{Illumination due to lamp } L_1 + \text{Illumination due to lamp } L_2$$



$$\frac{200}{8^2}\left[\left(\frac{8}{21.54}\right)^3\right] + \frac{250}{10^2}\left[\left(\frac{10}{22.36}\right)^3\right]$$

$$3.125(0.0512) + 2.5(0.0894)$$

$$0.16 + 0.2236$$

$$= 0.3836$$

UNIT-4

Various Illumination Methods

1) **Explain the construction and working of Tungsten filament lamp (or) Incandescent lamp.**

Incandescent Lamp

- These lamps are temperature-dependent sources. When electric current is made to flow through a fine metallic wire, which is known as *filament*, its temperature increases.
- At low temperatures, it emits only heat energy, but at very high temperature, the metallic wire emits both heat and light energy. These incandescent lamps are also known as *temperature radiators.*

Choice of material for filament

The materials commonly used as filament for incandescent lamps are carbon, tantalum, tungsten, and osmium.

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

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

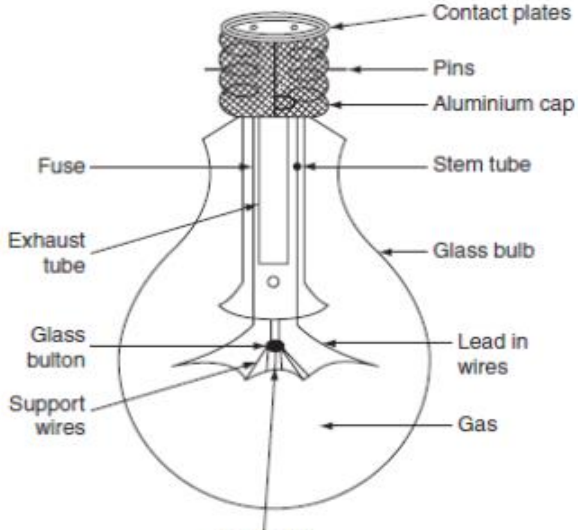
Construction

- 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.
- The inner side of the bulb consists of a tungsten filament and the support wires are made of molybdenum to hold the filament in proper position.

A glass button is provided in which the support wires are inserted. A stem tube forms an air-tight seal around the filament whenever the glass is melted.

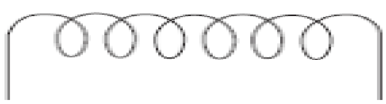
Operation

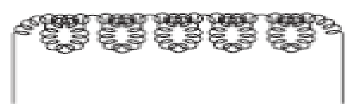
- When electric current is made to flow through the fine metallic tungsten filament, its temperature increases. At very high temperature, the filament emits both heat and light radiations, which fall in the visible region.
- The maximum temperature at which the filament can be worked without oxidization is 2,000°C, i.e., beyond this temperature, the tungsten filament blackens the inside of the bulb.
- The tungsten filament lamps can be operated efficiently beyond 2,000°C, it can be attained by inserting a small quantity of inert gas nitrogen with small quantity of organ.



❖ But if gas is inserted instead of vacuum in the inner side of the bulb, the heat of the lamp is conducted away and it reduces the efficiency of the lamp.

❖ To reduce this loss of heat by conduction and convection, as far as possible, the filament should be so wound that it takes very little space. This is achieved by using a single-coil filament instead of a straight wire filament as shown in Fig(a). below. This single-coil filament is used in vacuum bulbs up to 25 W and gas filled bulbs from 300 to 1,000 W.


(a) Single coil filament


(b) Coiled coil filament

❖ On further development of the incandescent lamps, the shortening of the length of the filament was achieved by adopting a coiled coil or a double coil filament as shown in Fig. (b).

❖ The use of coiled coil filament not only improves the efficiency of the lamp but also reduces the number of filament supports and thus simplified interior construction because the double coil reduces the filament mounting length in the ratio of 1:25 as compared to the straight wire filaments.

Usually, the tungsten filament lamp suffers from 'aging effect', the output of the light an incandescent lamp decreases as the lamp ages. The output of the light of the lamp decreases due to two reasons.

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

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

The effects of voltage variations

The variations in normal supply voltages will effect the operating characteristics of incandescent lamps. The performance characteristic of an incandescent lamp, when it is subjected to voltage other than normal voltage, is shown in Fig. The depreciation in the light output is around 15% over the useful life of the lamp.

Advantages of the incandescent lamps

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

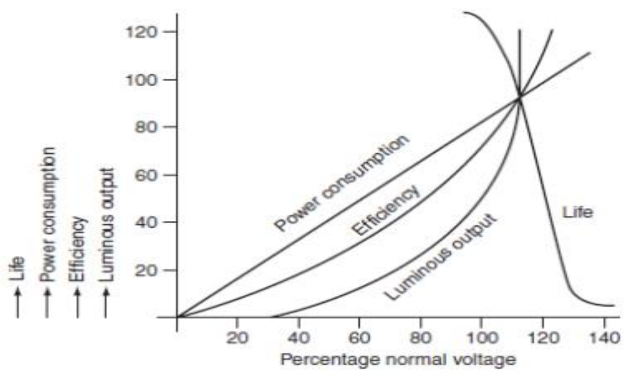


Fig Performance characteristics of incandescent lamp

Filament dimensions

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

The input wattage to the lamp is expressed as:

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

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

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

where I is the current taken by the lamp A,
a is the filament cross-section, sq. m,
ρ is the resistivity of the filament at working temperature Ω-m,
l is the length of the filament m, and
d is the diameter of the filament.

Let the emissivity of the material be '*e*'. Total heat dissipated will depend upon the surface area and the emissivity of the material.

∴ Heat dissipated ∝ surface area × emissivity:

$$\propto \pi d l \times e.$$

At the steady state condition, the power input should be equal to the heat dissipated.

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

$$I^2 \propto d^3 \quad \text{or} \quad I \propto d^{3/2}.$$

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

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

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

$$\therefore \text{Lumen output} \propto l_1 d_1 \propto l_2\, d_2$$

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

Limitations

The incandescent lamp suffers from the following drawbacks:

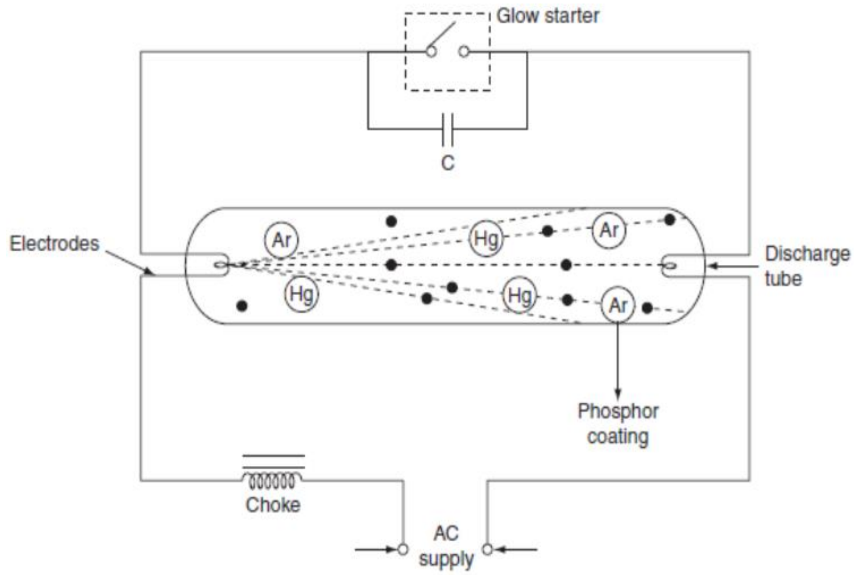
- Low efficiency.
- Colored light can be obtained by using different colored glass enclosures only.

2) Explain the construction and working of Low pressure mercury vapour lamp (or) Fluorescent lamp.

Fluorescent Lamp (Low-Pressure Mercury Vapor Lamp)

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

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



Working

- At the time of starting, when both the lamp and the glow starters are cold, the mercury is in the form of bubbles.
- When supply is switched on, the glow starter terminals are open circuited and full supply voltage appeared across these terminals, due to low resistance of electrodes and choke coil.
- The small quantity of argon gas gets ionized, which establishes an arc with a starting glow. This glow warms up the bimetallic strip thus glow starts gets short circuited.
- Hence, the two electrodes come in series and are connected across the supply voltage.
- Now, the two electrodes get heated and start emitting electrons due to the flow of current through them.
- These electrons collide with the argon atoms present in the long tube discharge that takes place through the argon gas.
- So, in the beginning, the lamp starts conduction with argon gas as the temperature increases, the mercury changes into vapor form and takes over the conduction of current.
- In the mean time, the starter potential reaches to zero and the bimetallic strip gets cooling down.
- As a result, the starter terminals will open. This results breaking of the series circuit.
- A very high voltage around 1,000 V is induced, because of the sudden opening of starter terminals in the series circuit. But in the long tube, electrons are already present; this induced voltage is quite sufficient to break down the long gap.

- Thus, more number of electrons collide with argon and mercury vapor atoms. The excited atom of mercury gives UV radiation, which will not fall in the visible region. Meanwhile, these UV rays are made to strike phosphor material; it causes the re-emission of light of different wavelengths producing illumination. The phenomenon of the emission is called as *luminescence.*

  This luminescence is classified into two ways. They are:

  1. **Fluorescence:** In this case, the excitation presents for the excited periods only.
  2. **Phosphorescence:** In this case, even after the exciting source is removed, the excitation will present.

3) What are the different types of Sources of Illumination (or) Light?

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

Electric arc lamps

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

Incandescent lamps

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

Gaseous discharge lamps

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

Fluorescent lamps

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

Arc Lamps

In arc lamps, the electrodes are in contact with each other and are separated by some distance apart; the electric current is made to flow through these two electrodes. The discharge is allowed to take place in the atmosphere where there are the production of a very intense light and a considerable amount of UV radiation, when an arc is struck between two electrodes.

The arcs maintain current and is very efficient source of light. They are used in search lights, projection lamps, and other special purpose lamps such as those in flash cameras. Generally, used arc lamps are:

1. Carbon arc lamp,
2. Flame arc lamp, and
3. Magnetic arc lamp.

4) Define stroboscopic effect.

- We all know that because of ‘the alternating nature of supply, it crosses zero two times in a cycle’.
- For 50-Hz frequency supply of the alternating current, a discharge lamp will be extinguished twice in a cycle and 100 times per second (for 50-Hz supply).
- A human eye cannot identify this extinguish phenomenon, because of the persistence of vision.
- If this light falls upon a moving object, the object appearing like slow moving or fast moving or moving in reverse direction, sometimes stationary.
- This effect is due to the extinguishing nature of the light of the lamp. This effect is called as **‘*stroboscopic effect*’**.

5) Compare between Fluorescent tube and filament lamp.

COMPARISON BETWEEN TUNGSTEN FILAMENT LAMPS AND FLUORESCENT LAMPS

Incandescent lamp	***Fluorescent lamp***
1. Initial cost is less.	1. Initial cost is more.
2. Fluctuation in supply voltage has less effect on light output, as the variations in voltage are absorbed in choke.	2. Fluctuations in supply voltage has comparatively more effect on the light output.
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 high that is about 8 – 40 lumens/W.	5. The luminous efficiency is poor, which is about 8–10 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.
7. Brightness of the lamp is more.	7. Brightness of the lamp is less.
8. The reduction in light output of the lamp is comparatively high, with the time.	8. The reduction in light output of the lamp is comparatively low, with the lamp.
9. The working temperature is about 2,000°C.	9. The working temperature is about 50°C.
10. The normal working life is 1,000 hr.	10. The normal working life is 5,000–7,500 hr.
11. No stroboscopic effect.	11. Stroboscopic effect is present.
12. These lamps are widely used for domestic, industrial, and street lighting.	12. They find wide application in domestic, industrial, and floodlighting.
13. The luminous efficiency increases with the increase in the voltage of the lamp.	13. The luminous efficiency increase with the increase in voltage and the increase in the length of tube.

6) Describe the basic principles of Light control.

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

1. Reflection,
2. Refraction,
3. Diffusion, and
4. Absorption.

Reflection

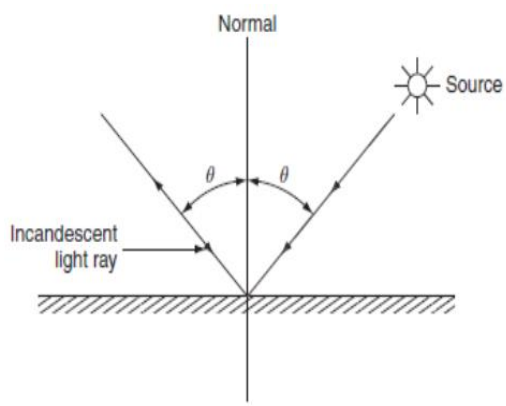
- The light falling on the surface, whole of the light will not absorbed or transmitted through the surface, but some of the light is reflected back, at an angle equals to the angle of incidence.
- The ratio of reflected light energy to the incident light energy is known as reflection factor.

The two basic types of reflection are:

1. Mirror or Specular reflection and
2. Diffuse reflection.

Specular reflection

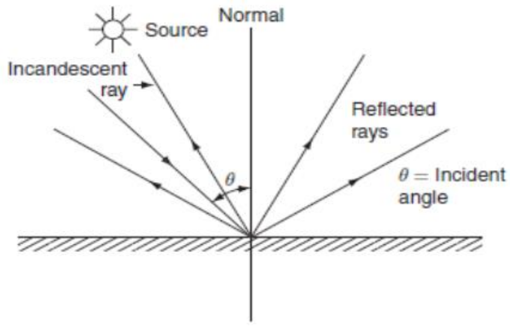
- When whole of the light falling on a smooth surfaces will be reflected back at an angle equal to
  the angle of incidence. Such a reflection is known as ***Specular reflection.***
- With such reflection, observer will be able to see the light source but not the illuminated surface.
- Most of the surfaces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



Specular reflection

Diffuse reflection

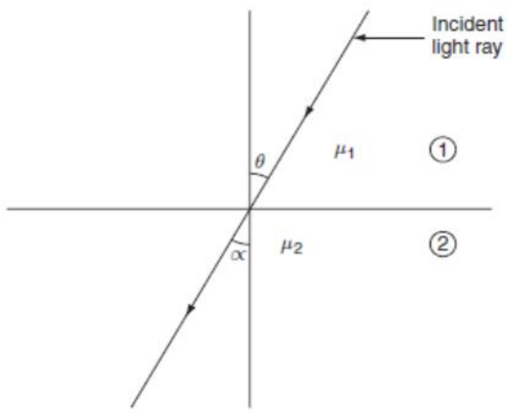
- When the light ray falling on any surface, it is scattered in all directions irrespective of the angle of incidence. Such type of reflector is known as ***diffuse reflection.***
- Most of the surfaces causing the diffuse reflection are rough or matt surfaces such as blotting paper, frosted glass, plaster,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



Diffuse reflection

Refraction

- When a beam of light passes through two different mediums having different densities, the light ray will be reflected. This phenomenon is known as ***refraction.*** Figure shows the refraction of light ray from dense medium to rare medium where $\mu 1$ and $\mu 2$ are the refractive indices of two medium, θ is the angle of incidence, and α is the angle of reflection.



Refraction

Diffusion

- When a ray of light falling on a surface is reflected in all possible directions, so that such surface appears luminous from all possible directions.
- This can be achieved with a diffusing glass screen introduced between the observer and the light source. The normally employed diffusing glasses are opal glass and frosted glass.
- Both are ordinary glasses, but frosted glass is an ordinary glass coated with crystalline substance.

- Although frosted glass is cheaper than opal glass, the disadvantage of frosted glass is, it collects more dust particles and it is difficult to clean.

Absorption

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

7) Explain the different types of Lighting Schemes.

Usually, with the reflector and some special diffusing screens, it is possible to control the distribution of light emitted from lamps up to some extent. A good lighting scheme results in an attractive and commanding presence of objects and enhances the architectural style of the interior of a building.

Depending upon the requirements and the way of light reaching the surface, lighting schemes are classified as follows:

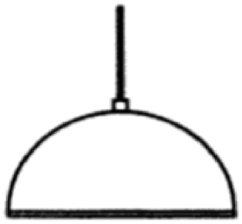
1. Direct lighting,
2. Semi direct lighting,
3. Indirect lighting,
4. Semi-indirect lighting, and
5. General lighting.

Direct lighting schemes

- Direct lighting scheme is most widely used for interior lighting scheme. In this scheme, by using deep reflectors, it is possible to make 90% of light falls just below the lamp.
- This scheme is more efficient but it suffers from hard shadows and glare. Hence, while designing such schemes, all the possibilities that will cause glare on the eye have to be eliminated. It is mainly used for industrial and general outdoor lighting.

Semi-direct lighting schemes

- In semi direct lighting scheme, about 60–90% of lamps luminous flux is made to fall downward directly by using some reflectors and the rest of the light is used to illuminate the walls and ceiling.
- This type of light scheme is employed in rooms with high ceiling. Glare can be avoided by employing diffusing globes. This scheme will improve not only the brightness but also the efficiency.



(a) Direct lighting

(b) Semi-direct lighting

Indirect lighting schemes

- In this lighting scheme, 90% of total light is thrown upwards to the ceiling. In such scheme, the ceiling acts as the lighting source and glare is reduced to minimum.
- This system provides shadow less illumination, which is very useful for drawing offices and in workshops where large machines and other difficulties would cause trouble some shadows if direct lighting schemes were used.

Semi-indirect lighting schemes

- In semi-indirect lighting scheme, about 60–90% of light from the lamp is thrown upwards to the ceiling and the remaining luminous flux reaches the working surface.
- Glare will be completely eliminated with such type of lighting scheme. This scheme is widely preferred for indoor lighting decoration purpose.

(c) Semi-indirect lighting

(d) Indirect lighting

(e) General diffusing lighting

General lighting scheme

- This scheme of lighting use diffusing glasses to produce the equal illumination in all directions.
- Mounting height of the source should be much above eye level to avoid glare. Lamp fittings of various lighting schemes are shown in Fig.

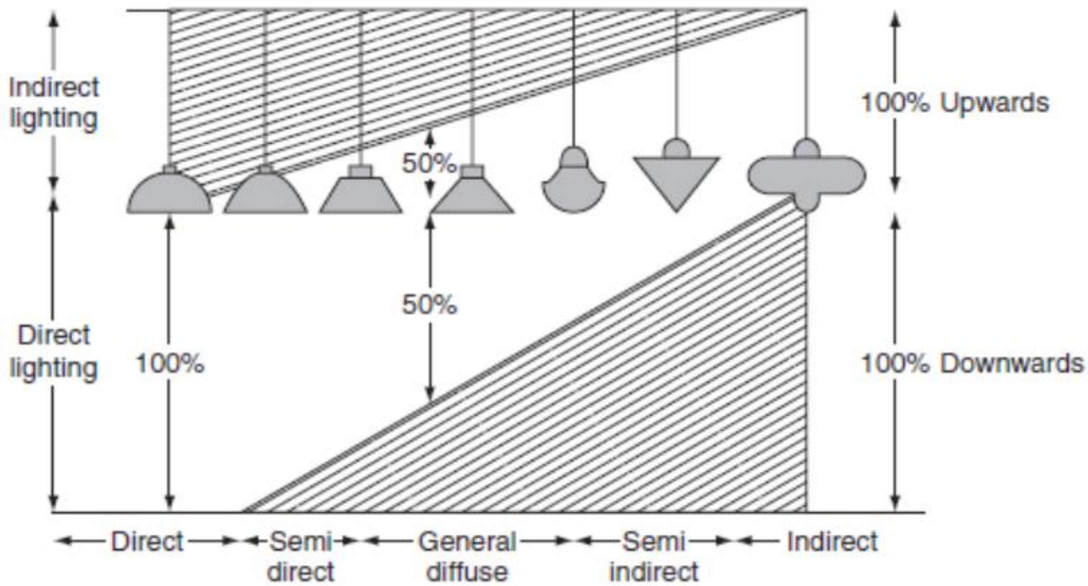


Fig: Lighting schemes

8) Explain the main objectives of Street Lighting.

Street lighting will be used for the following.

o In order to make the street more attractive, so that obstructions on the road clearly visible to the drivers of vehicles.

o To increase the community value of the street.

o To clear the traffic easily in order to promote safety and convenience.

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

1. Diffusion principle.
2. The Specular reflection principle.

Diffusion principle

- In this method, light is directed downwards from the lamp by the suitably designed reflectors.
- The design of these reflectors are in such a way that they may reflect total light over the road surface uniformly as much as possible.
- The reflectors are made to have a cutoff between 30° and 45°, so that the filament of the lamp is not visible expect just below the source, which results in eliminating glare.
- Illumination at any point on the road surface is calculated by applying inverse square low or point-by-point method.

Specular reflection principle

- The Specular reflection principle enables a motorist to see an object about 30 m ahead.
- In this case, the reflectors are curved upwards, so that the light is thrown on the road at a very large angle of incidence. This can be explained with the help of Fig.
- An object resides over the road at ‘P’ in between the lamps *S*1, *S*2, and *S*3 and the observer at ‘*Q*’.

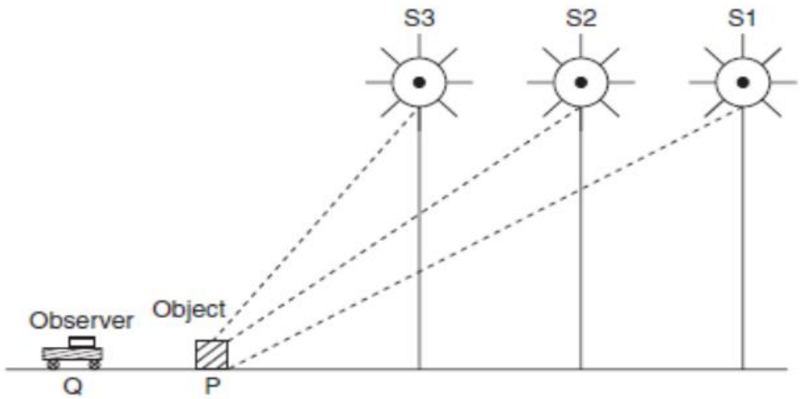


Fig: Specular reflection for street lighting

- Thus, the object will appear immediately against the bright road surface due to the lamps at a longer distance.
- This method of lighting is only suitable for straight sections along the road.
- In this method, it is observed that the objects on the roadway can be seen by a smaller expenditure of power than by the diffusion method of lighting.

9) Explain in detail about Flood lighting and how projectors are classified based on beam spread?

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

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

The flooding of large surfaces with light from powerful projectors is called flood lighting. **It may be employed for the following *purposes* :**

(*i*) To enhance the beauty of ancient monuments by night.

(*ii*) To illuminate advertisement boards and show-cases.

(*iii*) To illuminate railway yards, sports stadiums, car parks, construction sites, quarries etc.

For small buildings, rather uniform flood lighting is used. Flood lights can be placed on other buildings nearby or on suitable posts at distances of not more than about 60 metres. Light should fall nearly perpendicular to the building.

Large or tall buildings are illuminated non-uniformly. Flood lights should be so located that contours and features of the building are well defined. If any shadows are cast, they should enhance the beauty of the building or movement.

According to the beam spread, the projectors are *classified* as follows :

(*i*) ***Narrow beam projectors***—Beam spread between 12-25°. These are used for distance beyond 70 m.

(*ii*) ***Medium angle projector***—Beam spread between 25-40°. These are employed for distance between 30-70 m.

(*iii*) ***Wide angle projectors***—Beam spread between 40-90°. These are used for distance below 30 m.

10) List out different methods of lighting calculations.

There are so many methods have been employed for lighting calculation, some of those methods are as follows.

1. Watts-per-square-meter method.
2. Lumen or light flux method
3. Point-to-point method

1. Watt per square method :

- This method is *very handy for rough calculation or checking.*
- It consists in making an allowance of watts per square metre of area to be illuminated according to the illumination desired on the assumption of an average figure of overall efficiency of the system.

2. Lumen or light flux method. This method is applicable to those cases where the sources of light are such as to produce an approximate uniform illumination over the working plane or where an average value is required.

Total lumens received on working plane

= No. of lamps × wattage of each lamp × efficiency of each lamp (in terms of lumens/watt) × coefficient of utilisation × maintenance factor.

3. Point-to-point or inverse-square law method :

- *This method is applicable where the illumination at a point due to one or more sources of light is required, the candle power of the sources in the particular direction under consideration being known.*
- When a polar curve of lamp and its reflector giving candle powers of the lamp in different directions is known, the illumination at any point within the range of the lamp can be calculated from the inverse square law. If two and more than two lamps are illuminating the same working plane, the illumination due to each can be calculated and added.
- This method is not much used (because of its complicated and cumbersome applications) ; it is employed only in some special problems, such as *flood lighting, yard lighting etc.*

Calculation of Illumination

The following empirical formula can be used to calculate the illumination :

$$N = \frac{E \times A}{O \times UF \times MF}$$

where, N = Number of fittings needed,
E = Required illumination (lux),
A = Working area (square metres),
O = Luminous flux produced per lamp (lumens),
UF = Utilisation factor (or co-efficient of utilisation), and
MF = Maintenance factor.

11)

Example *A small assembly shop 16 m long, 10 m wide, and 3 m upto trusses is to be illuminated to a level of 200 lux. The utilization and maintenance factors are 0.74 and 0.8 respectively. Calculate the number of lamps required to illuminate the whole area if the lumen output of the lamp selected is 3000 lumens.*

Solution. Working area, $A = 16 \text{ m} \times 10 \text{ m} = 160 \text{ m}^2$
Required illumination, $E = 200$ lux
Lumens output of one lamp, $O = 3000$ lumens
Utilization factor, $UF = 0.74$
Maintenance factor, $MF = 0.8$.

Number of lamps required, N :

$$N = \frac{E \times A}{O \times UF \times MF}$$

$$= \frac{200 \times 160}{3000 \times 0.74 \times 0.8} = 18. \quad \textbf{(Ans.)}$$

12)

Example *An office 25 m × 12 m is illuminated by 40 W incandescent lamps of lumen output 2700 lumens. The average illumination required at the work place is 200 lux. Calculate the number of lamps required to be fitted in the office. Assume utilization and depreciation factors as 0.65 and 1.25 respectively.*

Solution. Working area, $A = 25 \text{ m} \times 12 \text{ m} = 300 \text{ m}^2$
Required illumination, $E = 200$ lux
Lumens output of the lamp, $O = 2700$ lumens
Utilization factor, $UF = 0.65$
Depreciation factor, $= 1.25$

∴ Maintenance factor, $MF = \frac{1}{1.25} = 0.8$

Number of lamps required, N :

$$N = \frac{E \times A}{O \times UF \times MF} = \frac{200 \times 300}{2700 \times 0.65 \times 0.8} = 4.3. \quad \textbf{(Ans.)}$$

UNIT-5 & 6

Electric Traction I & II

1) What do you mean by Electric Traction?

The system that causes the propulsion of a vehicle in which that driving force or tractive force is obtained from various devices such as electric motors, steam engine drives, diesel engine drives, etc. is known as traction system.

Traction system may be broadly classified into two types. They are

(1) Electric traction systems, which use electrical energy, and
(2) Non-electric traction system, which does not use electrical energy for the propulsion of vehicle.

2) What are the requirements of an ideal traction system? How are they met in an electric traction System?

The requirements of ideal traction systems are:
o Ideal traction system should have the capability of developing high tractive effort in order to have rapid acceleration.
o The speed control of the traction motors should be easy.
o Vehicles should be able to run on any route, without interruption.
o Equipment required for traction system should be minimum with high efficiency.
o It must be free from smoke, ash, durt, etc.
o Regenerative braking should be possible and braking should be in such a way to cause minimum wear on the break shoe.
o Locomotive should be self-contained and it must be capable of withstanding overloads.
o Interference to the communication lines should be eliminated while the locomotive running along the track.

3) State the advantages of electric traction over other non-electrical systems of traction including steam traction?

The following are the **advantages** of electric traction:

o Electric traction system is more clean and easy to handle.
o No need of storage of coal and water that in turn reduces the maintenance cost as well as the saving of high-grade coal.

o Electric energy drawn from the supply distribution system is sufficient to maintain the common necessities of locomotives such as fans and lights; therefore, there is no need of providing additional generators.
o The maintenance and running costs are comparatively low.
o The speed control of the electric motor is easy.
o Regenerative braking is possible so that the energy can be fed back to the supply system during the braking period.
o In electric traction system, in addition to the mechanical braking, electrical braking can also be used that reduces the wear on the brake shoes, wheels, etc.
o Electrically operated vehicles can withstand for overloads, as the system is capable of drawing more energy from the system.

The electric traction system suffers from the following **drawbacks:**
o Electric traction system involves high erection cost of power system.
o Interference causes to the communication lines due to the overhead distribution networks.
o The failure of power supply brings whole traction system to stand still.
o In an electric traction system, the electrically operated vehicles have to move only on the electrified routes.
o Additional equipment should be needed for the provision of regenerative braking, it will increase the overall cost of installation.

4) Explain in detail about System of Traction?

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

1. Non-electric traction system

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

Self-contained locomotives

In this type, the locomotives or vehicles themselves having a capability of generating electrical energy for traction purpose. Examples for such type of locomotives are:

1. Steam electric drive

In steam electric locomotives, the steam turbine is employed for driving a generator used to feed the electric motors. Such types of locomotives are not generally used for traction because of some mechanical difficulties and maintenance problems.

2. Diesel electric trains

A few locomotives employing diesel engine coupled to DC generator used to feed the electric motors producing necessary propelling torque. Diesel engine is a variable high-speed type that feeds the self- or separately excited DC generator. The excitation for generator can be supplied from any auxiliary devices and battery.

1. **Petrol electric traction**

This system of traction is used in road vehicles such as heavy lorries and buses. These vehicles are capable of handling overloads. At the same time, this system provides fine and smooth control so that they can run along roads without any jerking.

4. Battery drives

In this drive, the locomotive consists of batteries used to supply power to DC motors employed for driving the vehicle. This type of drives can be preferred for frequently operated services such as local delivery goods traction in industrial works and mines, etc. This is due to the unreliability of supply source to feed the electric motors.

Electric vehicles fed from distribution network

Vehicles in electrical traction system that receives power from over head distribution network fed or substations with suitable spacing. Based on the available supply, these groups of vehicles are further subdivided into:

1. System operating with DC supply. Ex: tramways, trolley buses, and railways.
2. System operating with AC supply. Ex: railways.

5) Explain in detail about System of Track Electrification?

Now a days, based on the available supply, the track electrification system are categorized into.

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

DC system

- In this system of traction, the electric motors employed for getting necessary propelling torque should be selected in such a way that they should be able to operate on DC supply.

- Examples for such vehicles operating based on DC system are tramways and trolley buses.
- Usually, DC series motors are preferred for tramways and trolley buses even though DC compound motors are available where regenerative braking is desired.
- The operating voltages of vehicles for DC track electrification system are 600, 750, 1,500, and 3,000 V.
- Direct current at 600–750 V is universally employed for tramways in the urban areas and for many suburban and main line railways, 1,500–3,000 V is used.
- In some cases, DC supply for traction motor can be obtained from substations equipped with rotary converters to convert AC power to DC.
- These substations receive AC power from 3-φ high voltage line or single-phase overhead distribution network.
- The operating voltage for traction purpose can be justified by the spacing between stations and the type of traction motors available.
- These substations are usually automatic and remote controlled and they are so costlier since they involve rotary converting equipment.
- The DC system is preferred for suburban services and road transport where stops are frequent and distance between the stops is small.

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 163⅔ Hz or 25 Hz.
- The main reason of operating at reduced frequencies is AC series motors that are more efficient and show better performance at low frequency.
- These high voltages are stepped down to suitable low voltage of 300–400 V by means of step-down transformer.
- Low frequency can be obtained from normal supply frequency with the help of frequency converter.
- Low-frequency operation of overhead transmission line reduces the line reactance and hence the voltage drops directly and single-phase AC system is mainly preferred for main line services where the cost of overhead structure is not much importance moreover rapid acceleration and retardation is not required for suburban services.

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, and better performance at both normal and reduced frequencies.

- In addition to the above advantages, the induction motors suffer from some drawbacks; they are low-starting torque, high-starting current, and the absence of speed control.
- The main disadvantage of such track electrification system is high cost of overhead distribution structure.
- This distribution system consists of two overhead wires and track rail for the third phase and receives power either directly from the generating station or through transformer substation.
- Three-phase AC system is mainly adopted for the services where the output power required is high and regeneration of electrical energy is possible.

Composite system

- As the above track electrification system have their own merits and demerits, 1-φ AC system is preferable in the view of distribution cost and distribution voltage can be stepped up to high voltage with the use of transformers, which reduces the transmission losses.
- Whereas in DC system, DC series motors have most desirable features and for 3-φ system, 3-φ induction motor has the advantage of automatic regenerative braking.
- So, it is necessary to combine the advantages of the DC/AC and 3-φ/1-φ systems. The above cause leads to the evolution of composite system.
- Composite systems are of two types.
  1. Single-phase to DC system.
  2. Single-phase to three-phase system or kando system.

Single-phase to DC system

- In this system, the advantages of both 1-φ and DC systems are combined to get high voltage for distribution in order to reduce the losses that can be achieved with 1-φ distribution networks, and DC series motor is employed for producing the necessary propelling torque.
- Finally, 1-φ AC distribution network results minimum cost with high transmission efficiency and DC series motor is ideally suited for traction purpose.
- Normal operating voltage employed of distribution is 25 kV at normal frequency of 50 Hz. This track electrification is employed in India.

Single-phase to 3-φ system or kando system

- In this system, 1-φ AC system is preferred for distribution network.
- Since single phase overhead distribution system is cheap and 3-φ induction motors are employed as traction motor because of their simple, robust construction, and the provision of automatic regenerative braking.
- The voltage used for the distribution network is about 15–25 kV at 50 Hz.
- This 1-φ supply is converted to 3-φ supply through the help of the phase converters and high voltage is stepped down transformers to feed the 3-φ induction motors.
- Frequency converters are also employed to get high-starting torque and to achieve better speed control with the variable supply frequency.

6) List out the special features of Traction motors?

The general features of the electric motors used for traction purpose are:
1. Mechanical features.
2. Electrical features.

Mechanical features

1. A traction motor must be mechanically strong and robust and it should be capable of withstanding severe mechanical vibrations.
2. The traction motor should be completely enclosed type when placed beneath the locomotive to protect against dirt, dust, mud, etc.
3. In overall dimensions, the traction motor must have small diameter, to arrange easily beneath the motor coach.
4. A traction motor must have minimum weight so the weight of locomotive will decrease. Hence, the load carrying capability of the motor will increase.

Electrical features

High-starting torque

A traction motor must have high-starting torque, which is required to start the motor on load during the starting conditions in urban and suburban services.

Speed control

The speed control of the traction motor must be simple and easy. This is necessary for the frequent starting and stopping of the motor in traction purpose.

Dynamic and regenerative braking

Traction motors should be able to provide easy simple rheostatic and regenerative braking subjected to higher voltages so that system must have the capability of withstanding voltage fluctuations.

Temperature

The traction motor should have the capability of withstanding high temperatures during transient conditions.

Overload capacity

The traction motor should have the capability of handling excessive overloads.

Parallel running

In traction work, more number of motors need to run in parallel to carry more load. Therefore, the traction motor should have such speed–torque and current–torque characteristics and those motors may share the total load almost equally.

Commutation

Traction motor should have the feature of better commutation, to avoid the sparking at the brushes and commutator segments.

7) Explain the typical speed – time curve for electric train operating on (i) Mail line Servies (ii) Sub-urban (passenger) services (iii) Urban Services?

Speed–time curve for main line service

Typical speed–time curve of a train running on main line service is shown in Fig.. It mainly consists of the following time periods:

1. Constant accelerating period.
2. Acceleration on speed curve.
3. Free-running period.
4. Coasting period.
5. Braking period.

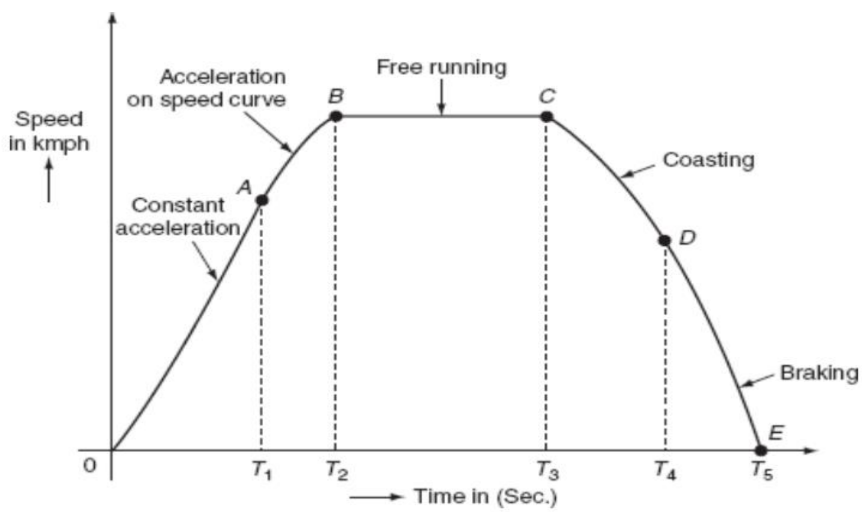


Fig. Speed–time curve for mainline service

Constant acceleration

During this period, the traction motor accelerate from rest. The curve 'OA' represents the constant accelerating period. During the instant 0 to $T1$, the current is maintained approximately constant and the voltage across the motor is gradually increased by cutting out the starting resistance slowly moving from one notch to the other. Thus, current taken by the motor and the tractive efforts are practically constant and therefore acceleration remains constant during this period. Hence, this period is also called as notch up accelerating period or rheostatic accelerating period. Typical value of acceleration lies between 0.5 and 1 kmph. Acceleration is denoted with the symbol 'α'.

Acceleration on speed-curve

During the running period from $T1$ to $T2$, the voltage across the motor remains constant and the current starts decreasing, this is because cut out at the instant '*T*1'. According to the characteristics of motor, its speed increases with the decrease in the current and finally the current taken by the motor remains constant. But, at the same time, even though train accelerates, the acceleration decreases with the increase in speed. Finally, the acceleration reaches to zero for certain speed, at which the tractive effort excreted by the motor is exactly equals to the train resistance. This is also known as decreasing accelerating period. This period is shown by the curve '*AB*'.

Free-running or constant-speed period

The train runs freely during the period *T*2 to *T*3 at the speed attained by the train at the instant '*T*2'. During this speed, the motor draws constant power from the supply lines. This period is shown by the curve *BC*.

Coasting period

This period is from *T*3 to *T*4, i.e., from C to D. At the instant '*T*3' power supply to the traction, the motor will be cut off and the speed falls on account of friction, windage resistance, etc. During this period, the train runs due to the momentum attained at that particular instant. The rate of the decrease of the speed during coasting period is known as coasting retardation. Usually, it is denoted with the symbol 'βc'.

Braking period

Braking period is from *T*4 to *T*5, i.e., from *D* to *E*. At the end of the coasting period, i.e., at '*T*4' brakes are applied to bring the train to rest. During this period, the speed of the train decreases rapidly and finally reduces to zero. In main line service, the free-running period will be more, the starting and braking periods are very negligible, since the distance between the stops for the main line service is more than 10 km.

Speed–time curve for suburban service

In suburban service, the distance between two adjacent stops for electric train is lying between 1 and 8 km. In this service, the distance between stops is more than the urban service and smaller than the main line service. The typical speed–time curve for suburban service is shown in Fig.

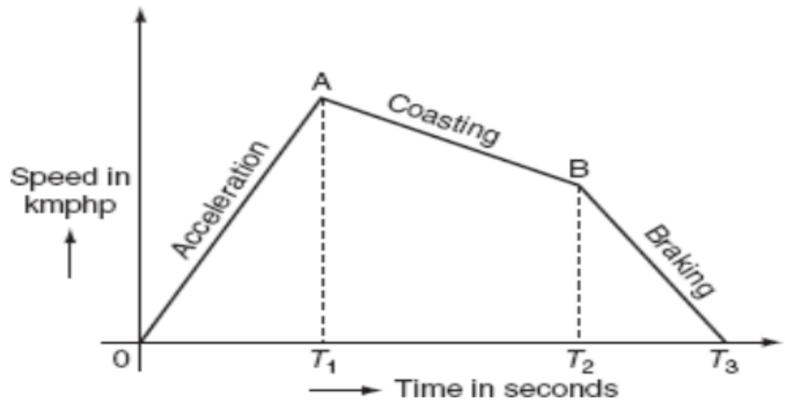


Fig. Typical speed–time curve for suburban service

The speed–time curve for urban service consists of three distinct periods. They are:

1. Acceleration.
2. Coasting.
3. Retardation.

- For this service, there is no free-running period. The coasting period is comparatively longer since the distance between two stops is more.
- Braking or retardation period is comparatively small. It requires relatively high values of acceleration and retardation.
- Typical acceleration and retardation values are lying between 1.5 and 4 kmph and 3 and 4 kmph, respectively.

Speed–time curve for urban or city service

The speed–time curve urban or city service is almost similar to suburban service and is shown in Fig.

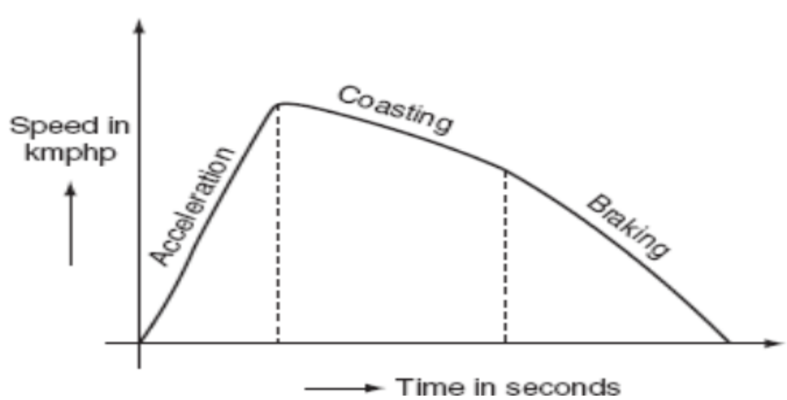


Fig. Typical speed–time curve for urban service

In this service also, there is no free-running period. The distance between two stop is less about 1 km. Hence, relatively short coasting and longer braking period is required. The relative values of acceleration and retardation are high to achieve moderately high average between the stops. Here, the small coasting period is included to save the energy consumption. The acceleration for the urban service lies between 1.6 and 4 kmph. The coasting retardation is about 0.15 kmph and the braking retardation is lying between 3 and 5 kmph.

8) Describe the analysis of Trapezoidal Speed time curve?

Trapezoidal speed–time curve can be approximated from the actual speed–time curves of different services by assuming that:

o The acceleration and retardation periods of the simplified curve is kept same as to that of the actual curve.

o The running and coasting periods of the actual speed–time curve are replaced by the constant periods.

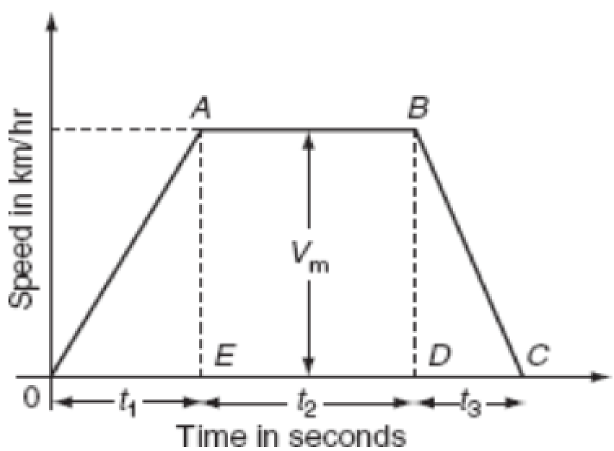


Fig. Trapezoidal speed–time curve

Calculations from the trapezoidal speed–time curve

Let *D* be the distance between the stops in km,

T be the actual running time of train in second,

α be the acceleration in km/h/sec,

β be the retardation in km/h/sec,

*V*m be the maximum or the crest speed of train in km/h, and

*V*a be the average speed of train in km/h.

Actual running time of train, $T = t_1 + t_2 + t_3$.

we have

$$\alpha = \frac{V_m}{t_1} \quad \text{or} \quad t_1 = \frac{V_m}{\alpha} \qquad \text{...}(i)$$

$$\beta = \frac{V_m}{t_3} \quad \text{or} \quad t_3 = \frac{V_m}{\beta} \qquad \text{...}(ii)$$

$$t2 = T - \left[\frac{V_m}{\alpha} + \frac{V_m}{\beta}\right].$$

Since the total distance *D* between the stops is given by the area of trapezium *OABC*, therefore,

$$D = \text{Area } OABC$$

Area under the trapezoidal speed–time curve gives the total distance between the two stops (*D*).

∴ The distance between the stops (*D*) = area under triangle *OAE* + area of rectangle *ABDE* + area of triangle *DBC*

= The distance travelled during acceleration + distance travelled during free running period + distance travelled during retardation.

The distance travelled during acceleration = average speed during accelerating period × time for acceleration

$$= \frac{0 + V_m}{2} \times t_1 \text{ km/h} \times \text{sec}$$

$$= \frac{0 + V_m}{2} \times \frac{t_1}{3,600} \text{ km.}$$

The distance travelled during free-running period = average speed × time of free running

$$= V_m \times t_2 \text{ km/h} \times \text{sec}$$

$$= V_m \times \frac{t_2}{3,600} \text{ km.}$$

The distance travelled during retardation period = average speed × time for retardation

$$= \frac{V_m + 0}{2} \times t_3 \text{ km/h} \times \text{sec}$$

$$= \frac{0 + Vm}{2} \times \frac{t_3}{3,600} \text{ km.}$$

The distance between the two stops is:

$$D = \frac{V_m}{2} \times \frac{t_1}{3,600} + V_m \times \frac{t_2}{3,600} + \frac{V_m}{2} \times \frac{t_3}{3,600}$$

$$D = \frac{V_m t_1}{7,200} + \frac{V_m}{3,600}[T - V_m(t_1 + t_2)] + \frac{V_m t_3}{7,200}$$

$$D = \frac{V_m^2}{7,200\alpha} + \frac{V_m}{3,600}\left[T - V_m\left(\frac{1}{\alpha} + \frac{1}{\beta}\right)\right] + \frac{V_m^2}{7,200\beta}$$

$$3,600 \times D = \frac{V_m^2}{2\alpha} + \frac{V_m^2}{\beta} - V_m^2\left(\frac{1}{\alpha} + \frac{1}{\beta}\right) + V_m T$$

$$3,600\ D = V_m^2\left(\frac{1}{2\alpha} - \frac{1}{\alpha}\right) + V_m^2\left(\frac{1}{2\beta} - \frac{1}{\beta}\right) + V_m T$$

$$3,600\ D = \frac{-V_m^2}{2\alpha} - \frac{V_m^2}{2\beta} + V_m T$$

$$\therefore V_m^2\left[\frac{1}{2\alpha} + \frac{1}{2\beta}\right] - V_m T + 3,600D = 0.$$

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

$$\therefore V_m^2 X - V_m T + 3,600D = 0.$$

Solving quadratic Equation , we get:

$$V_m = \frac{T + \sqrt{T^2 - 4 \times X \times 3,600D}}{2 \times X.}$$

$$= \frac{T}{2X} \pm \sqrt{\frac{T^2}{4X^2} - \frac{3,600D}{X}}.$$

By considering positive sign, we will get high values of crest speed, which is practically not possible, so negative sign should be considered

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

$$\text{Or,} \quad V_m = \frac{\alpha\beta}{\alpha + \beta}T - \sqrt{\left(\frac{\alpha\beta}{\alpha + \beta}\right)^2 T^2 - 7,200\left(\frac{\alpha\beta}{\alpha + \beta}\right)D}.$$

9) Describe the analysis of Quadrilateral Speed time curve?

Quadrilateral speed–time curve for urban and suburban services for which the distance between two stops is less. The assumption for simplified quadrilateral speed–time curve is the initial acceleration and coasting retardation periods are extended, and there is no free-running period. Simplified quadrilateral speed–time curve is shown in Fig.

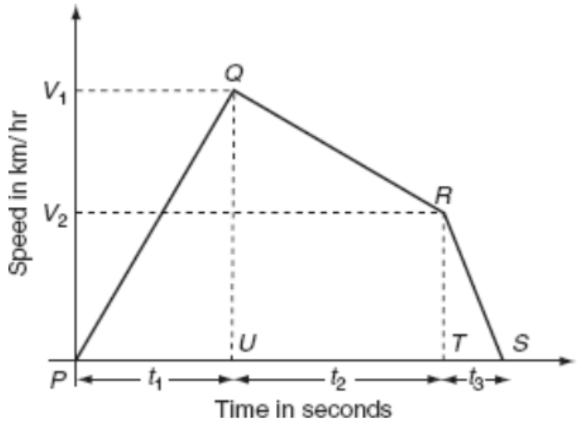


Fig. Quadrilateral speed–time curve

Let *V*1 be the speed at the end of accelerating period in km/h,
*V*2 be the speed at the end of coasting retardation period in km/h, and
*β*c be the coasting retardation in km/h/sec.
Time for acceleration,

$$t_1 = \frac{V_1 - 0}{\alpha} = \frac{V_1}{\alpha}.$$

Time for coasting period,

$$t_2 = \frac{V_2 - V_1}{\beta}.$$

Time period for braking retardation period,

$$t_3 = \frac{V_2 - 0}{\beta} = \frac{V_2}{\beta}.$$

Total distance travelled during the running period *D*:
= the area of triangle *PQU* + the area of rectangle *UQRT* + the area of triangle *TRS*.
= the distance travelled during acceleration + the distance travelled during coasting retardation + the distance travelled during breaking retardation.

But, the distance travelled during acceleration = average speed × time for acceleration

$$= \frac{0 + V_1}{2} \times t_1 \text{ km/h} \times \text{sec}$$

$$= \frac{V_1}{2} \times \frac{t_1}{3,600} \text{km.}$$

The distance travelled during coasting retardation

$$= \frac{V_2 + V_1}{2} \times t_2 \text{ km/h} \times \text{sec}$$

$$= \frac{V_2 + V_1}{2} \times \frac{t_2}{3,600} \text{km.}$$

The distance travelled during breaking retardation = average speed × time for breaking retardation

$$= \frac{0+V_2}{2} \times t_3 \text{km/h} \times \text{sec}$$

$$= \frac{V_2}{2} \times \frac{t_3}{3,600} \text{km.}$$

∴ Total distance travelled:

$$D = \frac{V_1}{2} \times \frac{t_1}{3,600} + \frac{(V_1+V_2)}{2} \frac{(t_2)}{3,600} + \frac{V_2}{2} \times \frac{t_3}{3,600}$$

$$= \frac{V_1 t_1}{7,200} + \frac{(V_1+V_2)t_2}{7,200} + \frac{V_2 t_3}{7,200}$$

$$= \frac{V_1}{7,200}(t_1+t_2) + \frac{V_2}{7,200}(t_2+t_3)$$

$$= \frac{V_1}{7,200}(T-t_3) + \frac{V_2}{7,200}(T-t_1)$$

$$= \frac{(V_1+V_2)T}{7,200} - \frac{V_1 t_3}{7,200} - \frac{V_2 t_1}{7,200}$$

$$= \frac{(V_1+V_2)T}{7,200} - \frac{V_1 V_2}{7,200\beta} - \frac{V_1 V_2}{7,200\alpha}$$

$$= \frac{\mathrm{T}}{7,200}(V_1+V_2) - \frac{V_1 V_2}{7,200}\left(\frac{1}{\alpha}+\frac{1}{\beta}\right)$$

$$7,200D = (V_1+V_2)\mathrm{T} - V_1 V_2\left(\frac{1}{\alpha}+\frac{1}{\beta}\right).$$

Where β_c = Retardation in KMPHPS during coasting

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

$$\Rightarrow V_2 = V_1 - \beta_c t_2$$

$$= V_1 - \beta_c\left[T - (t_1 + t_3)\right] = V_1 - \beta_c\left[T - \left(\frac{V_1}{\alpha} + \frac{V_2}{\beta}\right)\right]$$

$$\Rightarrow V_2 = V_1 - \beta_c T - \beta_c \cdot \frac{V_1}{\alpha} + \beta_c \cdot \frac{V_2}{\beta}$$

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

$$\text{(or)} \quad V_2 \left[1 - \frac{\beta_c}{\beta}\right] = V_1 - \beta_c \left[T - \frac{V_1}{\alpha}\right]$$

$$\text{(or)} \quad V_2 = \frac{V_1 - \beta_c \left[T - \frac{V_1}{\alpha}\right]}{\left[1 - \frac{\beta_c}{\beta}\right]}$$

Using above equations, V_1, V_2, and D can be obtained

10) Write short notes on Mechanics of Train movement?

- The essential driving mechanism of an electric locomotive is shown in Fig..
- 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.
- Fig illustrates the transfer of power from traction motor to the driving wheel.
- The Traction motor drives the pinion which meshes with gear wheel keyed to the driving axle.
- The torque developed by the traction motor will be transmitted to the driving wheel through the gear.

Let T is the torque exerted by the motor in N-m,
F_p is tractive effort at the edge of the pinion in Newton,
F_t is the tractive effort at the wheel,
D is the diameter of the driving wheel,
d_1 and d_2 are the diameter of pinion and gear wheel, respectively, and
η is the efficiency of the power transmission for the motor to the driving axle.

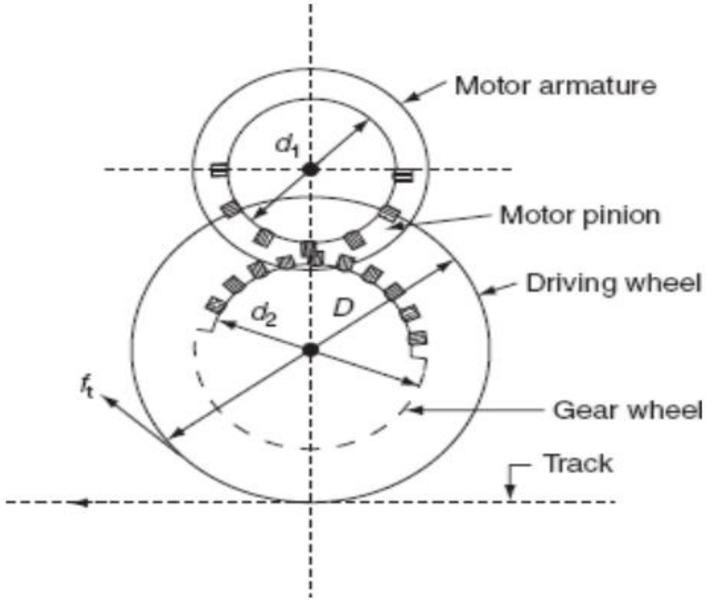


Fig. Driving mechanism of electric locomotives

Now, the torque developed by the motor $T = F_p \times \frac{d_1}{2}$ N-m.

$$\therefore F_p = \frac{2T}{d_1}$$

The tractive effort at the edge of the pinion transferred to the wheel of locomotive is:

$$F_t = \eta\, F_p \times \frac{d_2}{D}$$

From Equations

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

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

$$= \eta T \cdot \frac{2}{D} \cdot r,$$

where 'r'= $\left(\frac{d_2}{d_1}\right)$ is known as gear ratio.

$$\therefore F_t = 2\eta r \frac{T}{D}$$

11) Explain the Tractive effort of the train for the following (i) Acceleration (ii) Train resistance (iii) gravitational pull (up and down the gradient)

Def: It is the effective force acting on the wheel of locomotive, necessary to propel the train is known as '*tractive effort*'.

(or)

Def: Tractive Effort is the force developed by the traction motors at the wheel rims to move the train.

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.

Tractive effort during acceleration (Fa) :

Let W = mass of the train (or dead weight) in ton (metric)

F_a = tractive force/effort for accelerating the train in newton

α = acceleration in kmphps

According to Newton's second law of motion

Accelerating force = mass of the body × acceleration

$$F_a = (1000W) \times \frac{\alpha \times 1000}{3600}$$

$$= 277.8\ W\alpha \text{ newton.}$$

∴ The effective or accelerating mass* of the train, $We = W + W^1$

where W^1 = effect of rotational inertia

Hence.

$$F_a = 277.8\ We\,\alpha \text{ newton.}$$

This force is sufficient to give linear motion to the train with stationary parts. But force is also needed to give rotational motion or angular acceleration to its wheels, axles, armatures of electric motors and gears. For angular acceleration, the moment of inertia of the rotating parts will be considered. This will increase the accelerating mass of the train by 8 to 15% of W.

Tractive effort to overcome train resistance (F_r) :

Tractive effort is needed to balance the resistance to motion of the train. The train resistance depends upon various factors and is difficult to analyse. Train resistance is due to

(a) friction at the track } mechanical resistance

(b) friction at various parts of rolling stock } mechanical resistance

(c) air resistance.

Let r = train resistance in newton/tonne

$F_r = W r$ newton.

Tractive effort to overcome the gravitational pull (F_g) :

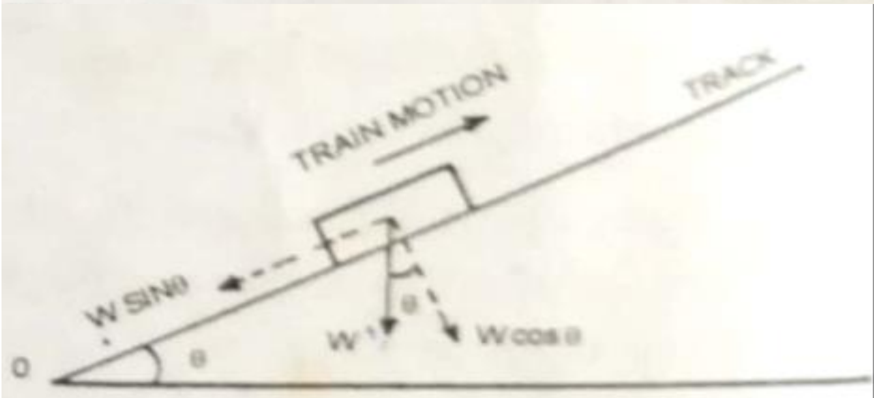


Fig. 6.9 GRAVITATIONAL FORCE

When the train is moving on an up-gradiant

θ = inclination of gradient

W = train mass (tonne)

as shown in Fig. 6.9, the train mass W can be resolved into W cosθ and W sinθ. The W cosθ is perpendicular to direction of motion of the train and it has no effect on its motion. But W sinθ opposes the motion of the train.

In order to overcome this opposition, an additional tractive effort required is given by

$$F_g = 1000\ W \times 9.81 \sin\theta \text{ newton}$$

In railway department, gradient is expressed in terms of track distance corresponding to a rise of 1 metre OR in terms of rise per 100 m of track.

Let G = percent gradient of the track.

From Fig. 6.9

$$\sin\theta = \frac{\text{Elevation}}{\text{Distance along track}} = \frac{G}{100}$$

$$\therefore G = 100 \sin\theta$$

$$\text{Hence, } F_g = 1000W \times 9.81 \times \frac{G}{100}$$

$$= 98.1 \text{ WG newton.}$$

Net tractive effort (F_t)

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

$$\boxed{F_t = 277.8\, W_e \alpha + W\gamma \pm 98.1\, WG} \text{ newton.}$$

+ve sign should be considered for up gradients motion and −ve sign for down gradients motion.

12) Derive the equation for the Power output from the driving Axles.

Power Output from Driving Wheels :

Let F_t = tractive effort (newton)

v = speed (metre/second)

P = power output (watt or kW).

By definition

Power output = Rate of doing work

$$P = \frac{\text{Work done}}{\text{time taken}}$$

$$= \frac{\text{Force} \times \text{distance}}{\text{time taken}}$$

$$= \text{Force} \times \text{speed}$$

$$\boxed{P = F_t \times v} \text{ N-m/S or watt}$$

If 'v' is given in kmph then,

$$\boxed{P = \frac{F_t \times v}{3600}} \text{ kW}$$

If η_1 = efficiency of power transmission system

η_2 = efficiency of the traction motors

Then power input to motors 'P_i'

$$\boxed{P_i = \frac{F_t \times v}{\eta \times 3600}} \text{ kW.}$$

13) Describe about the terms Energy consumption and Specific Energy Consumption in detail.

- 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.

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

Energy output is the energy required for the propulsion of a train or vehicle is mainly for

(1) *Energy required for accelerating the train from rest to its crest speed 'Vm'*

(2) *Energy required for overcoming the gradient and tracking 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

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

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

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

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

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

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

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

Energy required for overcoming the gradient and tracking resistance to motion

Energy required for overcoming the gradient and tracking resistance:

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

$$= F_t' \times \frac{V_m}{3,600} \times \frac{t_2}{3,600} \text{kW-hr}$$

$$= \frac{V_m t_2}{(3,600)^2}\left[Wr + 98.1\,WG\right]\text{kW-hr,}$$

where *Ft′* 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.

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

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

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

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

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

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

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

14) Write short notes on Factors affecting energy consumption in propelling a train.

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

(1) 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.

(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. 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.

15) Define the following terms

Dead weight

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

Accelerating weight

It is the effective weight of train that has angular acceleration due to the rotational inertia including the dead weight of the train. It is denoted by 'W_e'.

This effective train is also known as accelerating weight. The effective weight of the train will be more than the dead weight. Normally, it is taken as 5–10% of more than the dead weight.

Adhesive weight

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

Coefficient of adhesion

It is defined as the ratio of the tractive effort required to propel the wheel of a locomotive to its adhesive weight.

$$Ft \propto W$$
$$= \mu W,$$

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

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

Crest speed

The maximum speed attained by the train during run is known as crest speed. It is denoted with 'V_m'.

Average speed

It is the mean of the speeds attained by the train from start to stop, i.e., it is defined as the ratio of the distance covered by the train between two stops to the total time of run. It is denoted with 'Va'.

$$\therefore \text{Average speed} = \frac{\text{distance between stops}}{\text{actual time of run}}$$

$$V_a = \frac{D}{T},$$

where Va is the average speed of train in kmph, D is the distance between stops in km, and T is the actual time of run in hours.

Schedule speed

The ratio of the distance covered between two stops to the total time of the run including the time for stop is known as schedule speed. It is denoted with the symbol 'Vs'.

$$\therefore \text{Schedule speed} = \frac{\text{distance between stops}}{\text{total time of run} + \text{time for stop}}$$

$$= \frac{\text{distance between stops}}{\text{shedule time}}$$

$$V_s = \frac{D}{T_s},$$

where Ts is the schedule time in hours.

Schedule time

It is defined as the sum of time required for actual run and the time required for stop.

i.e., Ts = Trun + Tstop.

16) **A suburban electric train has a maximum speed of 75 kmph. The schedule speed including a station stop of 25 s is 48 kmph. If the acceleration is 2 kmphps, the average distance between two stops is 4 km. Determine the value of retardation.**

Solution:

Maximum speed Vm = 75 kmph.

The distance of run (D) = 4 km.

Schedule speed (Vs) = 48 kmph.

Acceleration (α) = 2 kmphps.

The duration of stop = 25 s.

$$\text{Schedule time } (T_s) = \frac{D}{V_s}$$

$$= \frac{4}{48} \times 60 \times 60 = 300 \text{ s}.$$

$$\therefore V_m^2\left(\frac{1}{2\alpha}+\frac{1}{2\beta}\right)-V_mT+3,600\times D=0$$

$$\therefore V_m^2\left(\frac{1}{2\alpha}+\frac{1}{2\beta}\right)-V_mT+3,600\times D=0$$

$$\frac{1}{2\alpha}+\frac{1}{2\beta}=\frac{V_mT-3,600D}{V_m^2}$$

$$\frac{1}{2\times 2}+\frac{1}{2\beta}=\frac{75\times 275-3,600\times 4}{(75)^2}$$

$$0.25+\frac{1}{2\beta}=1.1066$$

$$\beta=0.5836 \text{ kmphps.}$$

17) An electric train is to have the acceleration and braking retardation of 0.6 km/hr/sec and 3 km/hr/sec, respectively. If the ratio of the maximum speed to the average speed is 1.3 and time for stop is 25 s. Then determine the schedule speed for a run of 1.6 km. Assume the simplified trapezoidal speed–time curve.

Solution:

Acceleration $\alpha = 0.6$ km/hr/s.

Retardation $\beta = 3$ km/hr/s.

Distance of run $D = 1.6$ km.

$$\text{Average speed } V_a=\frac{3,600D}{T}=\frac{3,600\times 1.6}{T}=\frac{5,760}{T}\text{ kmph.}$$

$$\text{Maximum speed}=1.3V_a=1.3\times\frac{5,760}{T}=\frac{7,488}{T}\text{ km/hr}$$

$$\therefore V_m^2\left[\frac{1}{2\alpha}+\frac{1}{2\beta}\right]-V_mT+3,600D=0.$$

$$V_m^2 = \frac{V_m T - 3,600D}{\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right)}$$

$$= \frac{\frac{7,488}{T} \times T - 3,600 \times 1.6}{\left(\frac{1}{2 \times 0.6} + \frac{1}{2 \times 3}\right)}$$

$$= \frac{7,488 - 5,760}{0.833 + 0.166}$$

$$= 1,729.729$$

$$\therefore V_m = 41.59 \text{ km/hr.}$$

$$\text{Average speed, } (V_a) = \frac{V_m}{1.3} = \frac{41.59}{1.3}$$

$$(V_a) = 31.9923 \text{ kmph.}$$

$$\text{Actual time of run } T = \frac{3,600D}{V_a}$$

$$= \frac{3,600 \times 1.6}{31.9923}$$

$$T = 180.0433 \text{ s.}$$

$$\text{Schedule time } T_s = \text{Actual time of run} + \text{time of stop}$$

$$= 180.0433 + 25$$

$$= 205.0433 \text{ s.}$$

$$\text{Schedule speed } V_s = \frac{D \times 3,600}{T_s}$$

$$= \frac{1.6 \times 3,600}{205.0433}$$

$$= 28.0916 \text{ kmph.}$$

18) 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 $V_m = \alpha t_1$

$= 6.5 \times 20 = 130$ kmph.

Free-running time (t_2) = 12 × 60

= 720 s.

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

$= \frac{130}{6.5} = 20$ 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 km.

The distance between the two stations:

$D = D1 + D2 + D3$

$= 0.36 + 26 + 0.362$

$= 26.724$ km.

$$\text{Average distance } (V_{avg}) = \frac{D \times 3600}{T} = \frac{26.724 \times 3600}{20 + 720 + 20} = 126.58 \text{ kmph.}$$

$$\text{Schedule speed } (V_s) = \frac{D \times 3600}{T + \text{stoptime}} = \frac{26.724 \times 3,600}{20 + 720 + 20 + 70 \times 60} = 81.53 \text{ kmph.}$$

19) 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 kmphps and 3 kmphps, 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.

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

$$\text{Actual run time, } T = T_s - \text{stop duration} = 108 - 18 = 90 \text{ s.}$$

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

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

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

$$= 0.416.$$

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

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

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

20) An electric train has an average speed of 40 kmph on a level track between stops 1,500 m apart. It is accelerated at 2 kmphps and is braked at 3 kmphps. Draw the speed–time curve for the run.

Solution:

Average speed *V*a = 40 kmph.

The distance of run (*D*) = 1,500 m = 1.5 km.

Acceleration (*α*) = 2 kmphps.

Retardation (*β*) = 3 kmphps.

$$\text{The time of run } T = \frac{D}{V_a}$$

$$= \frac{1.5}{40} \times 60 \times 60 = 135 \text{ s.}$$

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

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

$$= \frac{1}{2\times 2} + \frac{1}{2\times 3} = 0.416.$$

$$\therefore V_m = \frac{135}{2\times 0.416} - \sqrt{\frac{(135)^2}{4\times(0.416)^2} - \frac{3600\times 1.5}{0.416}}$$

$$= 162.25 - \sqrt{(2,632 - 8.182) - (12,980.769)}$$

$$= 46.718 \text{ kmph.}$$

Acceleration period, $t_1 = \frac{V_m}{\alpha}$

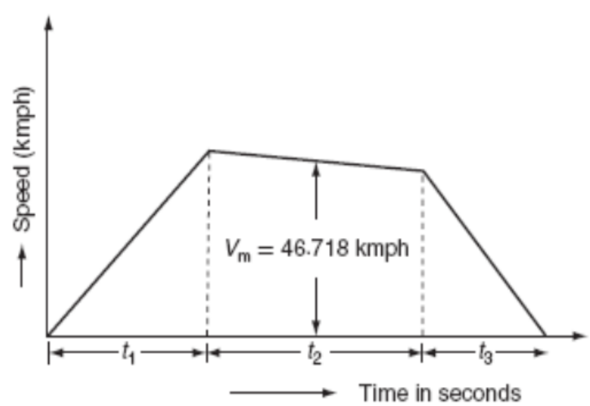
$$= \frac{46.718}{2}$$

$$t_1 = 23.359 \text{ s.}$$

Braking period, $t_3 = \frac{V_m}{\beta}$

$$= \frac{46.718}{3} = 15.572.$$

Free-running period, $t_2 = T - (t_1 + t_3)$
$= 135 - (23.359 + 15.572)$
$= 96.069.$



21) **Example 6.9 :** An electric train weights 250 tonne is to be accelerated up a gradient of 1 in 80 at an acceleration of 1.2 kmphps. The effect of rotational inertia and train resistance are 10% of dead weight and 40 newton per tonne respectively. Find the tractive effort.

Solution :

Given Data :

$W = 250\ T$ $G = \frac{1}{80} \times 100 = 1.25$ $\alpha = 1.2$ kmphps $W_e = 1.1\ W = 275\ T$ $r = 40$ N/tonne	$F_t = ?$

$$F_t = 277.8\ W_e \alpha + W_r + 98.1\ WG$$

$$= 277.8 \times 275 \times 1.2 + 250 \times 40 + 98.1 \times 250 \times 1.25$$

$$= \mathbf{132330.25\ newton\ \ Ans.}$$

22) **Example 6.10 :** A train with an electric locomotive weight 300 tonne. The train attains a maximum speed of 50 kmph in 25 second up a gradient of 1 in 150. The frictional resistance and rotational inertia are 50 newton/tonne and 10% of train weight respectively. Find the tractive effort required.

Given Data :

$W = 300\ T$ $V_m = 50$ kmph $t_1 = 25\ S$ $G = \frac{1}{150} \times 100 = \frac{2}{3}$ $r = 50$ N/T $W_e = 1.1\ W$	$F_t = ?$

$$\alpha = \frac{V_m}{t} = \frac{50}{25} = 2 \text{ kmphps.}$$

$$F_t = 277.8\, W_e \alpha + W\gamma \pm 98.1\, WG$$

$$= 277.8 \times 1.1 \times 300 \times 2 + 300 \times 50 + 98.1 \times 300 \times \left(\frac{2}{3}\right)$$

$$= \mathbf{217968\ newton\ \ Ans.}$$

23) An electric train of weight 250 ton has eight motors geared to driving wheels, each is 85 cm diameter. The tractive resistance is of 50/ton. The effect of rotational inertia is 10% of the train weight, the gear ratio is 4–1, and the gearing efficiency is 85% determine. The torque developed by each motor to accelerate the train to a speed of 50 kmph in 30 s up a gradient of 1 in 200.

Solution:

The weight of train W = 250 ton.

The diameter of driving wheel D =0.85 m.

Tractive resistance, r = 50N/ton.

Gear ratio r = 4.

Gearing efficiency η = 0.85.

Accelerating weight of the train:

$W_e = 1.10 \times W = 1.10 \times 250 = 275$ ton.

Maximum speed V_m = 50 kmph.

$$\text{Acceleration } \alpha = \frac{V_m}{t_1} = \frac{50}{30} = 1.66 \text{ kmpmph.}$$

$$\text{Tractive effort } F_t = 277.8\, W_e \alpha + 98.1\, WG + Wr$$

$$= 126{,}815.7 + 12{,}262.5 + 12{,}500$$

$$= 151{,}578.2 \text{ N.}$$

$$\text{Total torque developed } T = \frac{F_t \times D}{\eta \times 2\gamma}$$

$$= \frac{151{,}578.2 \times 0.85}{0.85 \times 2 \times 4}$$

$$= 18.947.25 \text{ N-m.}$$

$$\text{Torque developed by each motor} = \frac{18{,}947.25}{8}$$

$$= 2{,}368.409 \text{ N-m.}$$

24) Example 6.12 : A 500 tonne goods train is to be hauled by a locomotive up a gradient of 2 percent with an acceleration of 1.2 kmphps. Coefficient of adhesion is 25%, track resistance 40 N/tonne and effect of rotating masses 10% of dead weight. Find the weight of locomotive and the number of axles if axle load is not to exceed 21 tonnes. [June 1994]

Given Data :

Given	Find
$W = (500 + W_L)$	$W_L = ?$
$G = 2$	axles = ?
$\alpha = 1.2$ kmphps	
$\mu = 0.25$	
$r = 40$ N/T	
$W_e = 1.1\,(500 + W_L)$	
load/axle = 21 T	

$$F_t = 277.8\, W_e \alpha + W_r + 98.1\, WG$$

$$= 277.8 \times 1.1\,(500 + W_L) + (500 + W_L) \times 40 + 98.1\,(500 + W_L) \times 2$$

$$= (500 + W_L)\,(277.8 \times 1.1 + 40 + 98.1 \times 2)$$

$$= 541.78\,(500 + W_L) \text{ newton}$$

$$= \frac{541.78\,(500 + W_L)}{9.81 \times 1000}$$

$$= 0.055227\,(500 + W_L) \text{ tonne}$$

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

$$0.25 = \frac{0.05522\,(500 + W_L)}{W_L}$$

$$0.25\, W_L - 0.055227\, W_L = 27.614$$

$$\therefore \; W_L = \frac{27.614}{0.194773} = \mathbf{141.77 \text{ tonne}} \quad \textbf{Ans.}$$

$$\text{Number of Axles} = \frac{W_L}{21} = \frac{141.77}{21} = \mathbf{7} \quad \textbf{Ans.}$$