

Electric Traction IIIntroduction:-

Electric traction means a locomotion in which the driving force is obtained from electric motors, one of the practical applications of electricity which enters into the everyday life of many of us, is its use in the service of transport. - The electric propulsion of vehicles - electric trains, trolley buses, tram cars, and in the latest development such as diesel-electric traction over other forms of locomotion. If the electrical energy could be generated cheaply and initial cost, which is enormous, could be born, then this system of locomotion would replace steam locomotion entirely for electrification.

Calculations of tractive effort :-

The effective force, necessary to propel the train, at the wheels of vehicle is called the tractive effort. It is tangential to the driving wheels and measured in Newton. It is a vector quantity.

Tractive effort is the force developed by the traction unit at the wheel rims for moving the traction unit and its train.

Draw bar pull is the force exerted by the traction unit through the draw bar for moving the train.

Thus draw bar pull is less than the tractive effort by the force required to move the traction unit.

Tractive effort exerted by the traction unit has to perform the following functions.

- (a) To give necessary linear and angular acceleration to the train mass
- (b) To overcome the gravity component of the train
- (c) To overcome the wind and frictional resistance of the train
- (d) To overcome curve resistance.

Traction Effort for propelling a train

The total tractive effort required to run a train on track
= Tractive effort during acceleration + Tractive effort to overcome the effect of gravity + Tractive effort used in overcoming functional resistance.

i.e., $F_t = F_a + F_g + F_r$

(a) Tractive effort for acceleration, (F_a):- Let the weight of the train, be W tonnes. If it is to be accelerated at a rate of α km/hr/sec. then the accelerating force or tractive effort required for linear acceleration, F_a will be given by,

$$F_a = m \alpha (\text{mass} \times \text{Acceleration})$$

where weight of train = $1000 W$ kgf.

mass of train, $m = 1000 W$ kg

Acceleration, α in km.p.h.p.s = $\alpha \times \frac{1000}{3600}$ m/sec².

putting the values, we get

i.e., $F_a = m \alpha = 1000 W \times 0.2778 \alpha$

$$= 277.8 W \alpha \text{ Newtons.}$$

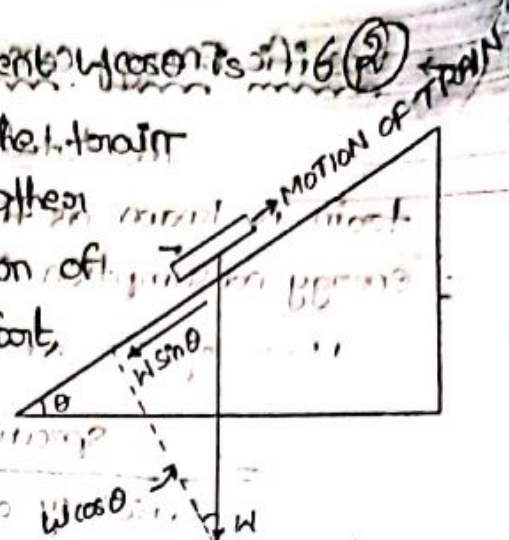
when a train is accelerated in a linear direction, its rotating parts like the wheels and the armatures of motors have to be accelerated in an angular direction. Therefore, the accelerating mass of the train is greater than the dead mass of the train by 8 to 15 percent. For most of the trains the effective or accelerating weight W_e is 1.1 times their dead weight W .

Hence, $F_d = 277.8 W_e \alpha$ Newtons

(b) Tractive effort, to overcome the effect of gravity on to move the

train up a gradient, (F_g):- The dead weight of the train W tonnes can be assumed to be made up of two parts viz, $W \cos \theta$ and $W \sin \theta$, where θ is the angle of inclination of the track to

The horizontal (from fig) since the component $W \cos \theta$ is perpendicular to the direction of motion of the train it has no effect on its motion but the other component $W \sin \theta$ tries to oppose the motion of the train. Hence an additional tractive effort, $F_g = W \sin \theta$ tonnes must be provided for running the train on the inclined track.



If, $G =$ percent gradient of the track
 then $G = 100 \sin \theta$.

The tractive effort F_g (in Newtons) becomes

$$\begin{aligned} F_g &= \pm 1000 W \sin \theta \times 9.81 \text{ Newtons} \\ &= \pm (100 \sin \theta) \times 98.1 W \text{ Newtons} \\ &= \pm G \times 98.1 W \text{ Newtons} = \pm 98.1 W G \text{ Newtons.} \end{aligned}$$

If the train is moving down the gradient then the component of dead weight along the track, i.e. $W \sin \theta$ will help the motion of the train

c) Tractive effort to overcome the frictional resistance (F_r):

If r is the specific train resistance in Newtons per tonne of the dead weight, then the tractive effort required to overcome this resistance

i.e., $F_r = W \times r$ Newtons

where r is a function of velocity for a given train

For a normal train the value of specific resistance has been 40 to 70 Newtons/tonne.

Hence the total tractive effort required

$$F_t = F_a \pm F_f + F_r$$

$$= 277.8 W \alpha + 98.1 W G + W r$$

The +ve sign is used when the train is going up the gradient and the -ve sign is used when it is going down the gradient.

→ Specific Energy Consumption is the (or may) be defined as
 The total energy input to all the traction motors in a train is known as the "energy consumption" of the train. The specific energy consumption is the energy consumption in watt-hr, per tonne-km.

Hence, specific energy consumption

$$= \frac{\text{specific energy output}}{\text{Efficiency of gear} \times \text{Efficiency of motor}}$$

$$= \frac{\text{Energy output in watt-hours}}{\eta_{\text{gear}} \times \eta_{\text{motor}} (\text{Wt. of train in tonnes} \times \text{distance of run in km})}$$

Determination of specific Energy output

Consider the simplified speed-time curves.

Let the track have a gradient of G , percent through out its run

(a) Energy output for accelerating the train from rest to V_m ,

$$= \frac{1}{2} \frac{F_t V_m}{3600} \times \frac{t_1}{3600} \text{ kWh}$$

$$= \frac{1}{2} \frac{F_t V_m}{3600} \times \frac{V_m}{3600} \left[\because t_1 = \frac{V_m}{a} \right]$$

$$= \frac{1}{2} \frac{V_m^2}{(3600)^2} \times (271.8 W_R + 98.1 W_G + W \cdot \pi) \text{ kWh}$$

$$\left[\because F_t = 271.8 W_R + 98.1 W_G + W \cdot \pi \right]$$

(b) Energy output to run the train at the speed V_m against the gradient and resistance to motion.

$$= \frac{F_t \times V_m}{3600} \times \frac{t_2}{3600} \text{ kWh}$$

$$= \frac{F_t \times D'}{3600} \text{ kWh}$$

[since $\frac{V_m t_2}{3600} = D'$, the distance travelled during free run]

$$= (W \cdot \pi + 98.1 W_G) \times \frac{D'}{3600} \text{ kWh}$$

Total energy output for the run, (3)

$$= \frac{V_m^2}{2 \times (3600)^2} [277.8 W_e + 98.1 W_G + W_a]$$

$$+ [W_r + 98.1 W_G] \times \frac{D'}{3600} \text{ kWh}$$

$$= \frac{V_m^2 \times 1000}{2 \times (3600)^2} [277.8 W_e + 98.1 W_G + W_a]$$

$$+ [W_r + 98.1 W_G] \times \frac{D' \times 1000}{3600} \text{ Wh}$$

$$= \frac{V_m^2}{2} \times \frac{1000}{(3600)^2} \times 277.8 W_e + \frac{V_m^2}{2} \times \frac{1000}{(3600)^2} [98.1 W_G + W_a]$$

$$+ \frac{1000 D'}{3600} [W_r + 98.1 W_G]$$

$$= 0.01072 V_m^2 W_e + (98.1 W_G + W_a) \left[\frac{V_m^2}{2 \times 3600} + D' \right] \times \frac{1000}{3600}$$

$$= 0.01072 V_m^2 W_e + \frac{1000}{3600} [98.1 W_G + W_a] (D' + D'')$$

Where, $\frac{V_m^2}{2 \times 3600} = D''$, distance moved during accelerating period.

$$= 0.01072 V_m^2 W_e + 0.2778 (98.1 W_G + W_a) \times D$$

($D = D'' + D'$ = distance travelled during acceleration and free run in km)

specific energy output,

$$= \frac{\text{Energy output for the run in watt-hr}}{\text{Wt. of train in tonnes} \times \text{distance of run in km.}}$$

$$= \frac{0.01072 V_m^2 W_e + 0.2778 (98.1 W_G + W_a) \times D}{W \cdot D}$$

$$= \frac{0.01072 V_m^2}{D} \times \frac{W_e}{W} + 0.2778 \times \frac{D'}{D} (98.1 G + R) \text{ watt-hr/tonne-km}$$

If the track is level one,

$G = 0$, then,

specific energy output

$$= \frac{0.01072 V_m^2}{D} \times \frac{W_e}{W} + 0.2778 \times \frac{D'}{D} \times \frac{1}{2} \text{ watt-hr/tonne-km}$$

Specific energy consumption

$$= \frac{\text{Specific energy output}}{\text{Efficiency of motor}}$$

$$= \frac{0.01072 \text{ Vm}}{0.2} \times \frac{1}{W} + 0.2178 \times \frac{1}{D} \times \frac{1}{2} \text{ watt-hr per tonne-km.}$$

Acceleration and retardation :-

D , which is the distance for coasting, for which the power remains on increasing with higher values of acceleration and retardation giving an increase in specific energy consumption.

Dead weight, Accelerating weight and Adhesion weight :-

(i) Dead weight :- The total weight of locomotive and train to be pulled by the locomotive is known as dead weight.

(ii) Accelerating weight :- The dead weight of the train, i.e., the weight of the locomotive and train can be considered to be divided into two parts viz.,

(a) The weight which requires angular acceleration such as weight of wheels, axles, gears etc., and

(b) The weight which requires linear acceleration.

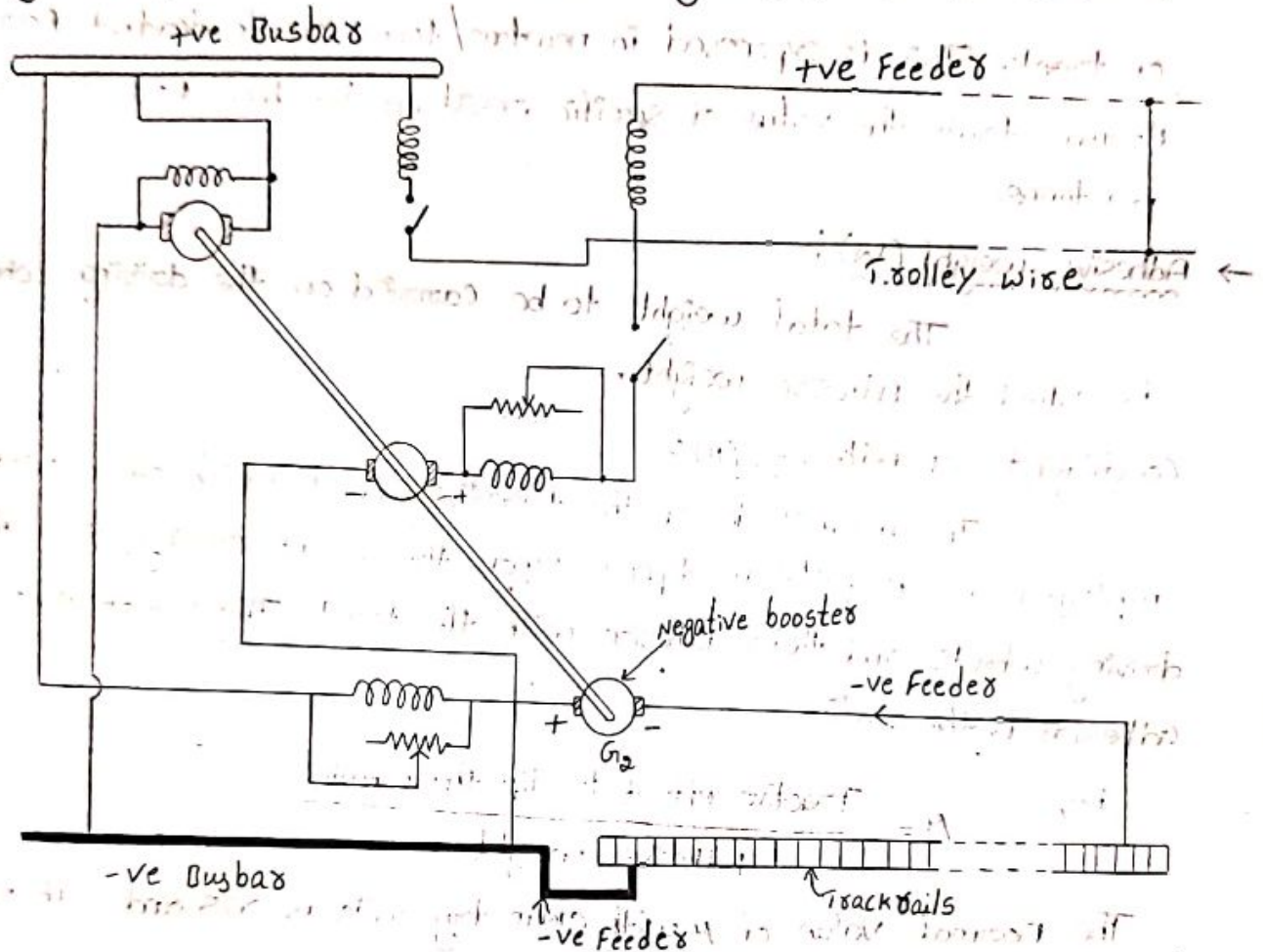
Hence the effective weight, which is greater than dead weight is called as accelerating weight. Accelerating weight is taken to be 10 percent more than dead weight.

(iii) Adhesive weight :-

The total weight to be carried on the driving wheels is known as "adhesive weight."

(b) Negative booster: all arrangements of rails of size 25mm x 10mm (4)

As the train car goes away from the substation, the (d) potential drop increases. The effect of this increased drop is to reduce the voltage of the trolley wire and to increase the voltage between any two points in the rail track being employed as return path.



As already said the potential of track rail is kept within the limit of 7 Watts by employing a negative booster.

The negative booster is a separately excited generator whose armature is connected in series with the negative booster feeder and field is connected in series with feeder supplying the corresponding sections of the trolley wire. It is driven by a d.c Motor - M. The "boost" on the feeder is adjusted by means of a diverter rheostat connected in parallel with the field winding.

Sometimes, a positive booster (a series excited generator) is also connected on the positive side in addition to negative booster

on negative side in order to compensate the voltage drop in the trolley wire.

b) Train Resistance:- and given as 20 N/t

When the train moves, there is a force opposing the motion on account of friction and wind etc. This force is known as friction force and depends upon various factors such as shape, size and condition of track. This is expressed in newtons/tonne of the dead wt. For a normal train the value of specific resistance has been 40 to 70 newtons per tonne.

Adhesive weight (W):-

The total weight to be carried on the driving wheels is called the Adhesive weight.

Coefficient of Adhesion, (μ):-

The magnitude of the tractive effort which can be usefully employed for propulsion, depends upon the weight coming over the driving wheels and their adhesion with the track. The co-efficient of adhesion is the ratio.

$$\text{i.e., } \mu = \frac{\text{Tractive effort to slip the wheels}}{\text{Adhesive weight}}$$

The normal value of μ with clean dry rails is 0.25 and with wet or greasy rails is 0.15 to 0.20 may be used.

On account of greater adhesive weight that electric traction possesses a great advantage over steam traction. In a motor each 100% of the weight is on the driving wheels, 70 percent in an electric locomotive and only 50 percent or less in a steam locomotive. The co-efficient of adhesion is also greater in electric traction than in a steam traction for the following two reasons.

(a) In electric traction the torque exerted is continuous whereas in steam traction the torque is pulsating which causes jolting and skidding.

(b) The driving wheels are distributed over much greater length in the case of electric traction where as in steam traction they are very close to each other. The tractive effort in electric traction is much greater, therefore, electric train can be made to accelerate at a faster rate. This results in saving of time, especially when the distance between stops is small e.g, in urban and suburban areas.

In order to increase the tractive effort of a locomotive it is not enough to increase the h.p. of the traction motors alone, but at the same time weight on the driving wheels has to be increased. Railway standards provide certain maximum axle load. As such adhesive weight can only be increased by increasing the number of driving axles. In steam locomotive this is done by using coupling rod to connect driving wheels.

As coefficient of friction is more at starting than at braking so also coefficient of adhesion at any speed will be less than that at lower speed or at standing. This is due to the cyclic variation of axle loads caused due to the acceleration and retardation to which unsprung masses are subjected as they have to follow track irregularities. Relationship between the coefficient of adhesion is given by eq (i) used by French National Railways.

$$M_{ar} = M_{as} \frac{8+0.1V}{8+0.2V} \longrightarrow \textcircled{1}$$

or by equation (ii) given by Curtius and Kniffelen

$$M_{ar} = \frac{7.5}{V+4} + 0.16 \longrightarrow \textcircled{2}$$

where, M_{ar} = coefficient of adhesion at running

M_{as} = coefficient of adhesion at standing

V = speed of locomotive in km.p.h

problems

(1) P.E.S.

407] A parallel plate capacitor has a dielectric material of thickness 2 cm and area 200 cm^2 . The material has a permittivity of 2.5 and power factor 0.05 . Power required is 400 watts and frequency of $40 \times 10^6 \text{ Hz}$ is to be used. Determine the voltage necessary and the current that will flow through the material. If the voltage were to be limited to 700 V , will be the frequency to get the same loss.

Since power absorbed is 400 watts and power factor $\cos \phi = 0.05$.
Supply frequency $f = 40 \times 10^6 \text{ Hz}$

Capacitance of the capacitor formed

$$C = \frac{\epsilon_0 \epsilon_r A}{d} = \frac{8.854 \times 10^{-12} \times 5 \times 200 \times 10^{-4}}{0.02}$$

$$= 44.27 \times 10^{-12} \text{ F}$$

$$P = 2\pi f C V^2 \cos \phi \Rightarrow V = \sqrt{\frac{P}{2\pi f C \cos \phi}}$$

$$V = \sqrt{\frac{400}{2\pi \times 40 \times 10^6 \times 44.27 \times 10^{-12} \times 0.05}} = 848 \text{ volts}$$

Current flowing through the material

$$I = \frac{P}{V \cos \phi} = \frac{400}{848 \times 0.05} = 9.434 \text{ Amp}$$

Since heat

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

$$f_2 V_2^2 = f_1 V_1^2 \Rightarrow f_2 = f_1 \left(\frac{V_1}{V_2} \right)^2$$

$$f_2 = 40 \times 10^6 \left(\frac{848}{700} \right)^2$$

$$= 58.7 \times 10^6 \text{ Hz}$$

A motor has to be selected for a load rising uniformly from zero speed to 200 ft/min in 10 minutes, after which it is constant at 200 ft/min for 10 minutes, followed by a no-load period of 15 minutes, before the cycle repeats itself. Estimate a suitable size of continuous rated motor.

$$\text{Size of motor} = \sqrt{\frac{(1/2 \times 200)^2 \times 10 + (200^2) \times 10 + 0}{10 + 10 + 15 \times 1/2}}$$

$$= \sqrt{\frac{(100)^2 \times 10 + (200)^2 \times 10}{25}} = 100\sqrt{2} = 140 \text{ H.P.}$$

Load drops down to half the value and remains constant at that for 40 sec. The motor is at no load for the next one minute after which the cycle of operation is repeated.

The load cycle of a motor operating at 11 H.P. for 9 min is as follows.

Loading period at the bottom — 4 min — 11 H.P.

Load going up — 1 min — 20 H.P.

Load period at the top — 3 min — 1 H.P.

Load going down — 1 min — 15 H.P.

Regenerative braking takes place when the load is descending. The cycle is repeated continuously. Estimate a suitable Horse power rating for the motor.

The load curve is shown by the full line and the $(\text{H.P.})^2$ curve is shown in dotted in Fig 2.87. Between the 8th and 9th min power is fed back into the lines. Still, however, heating of the motor takes place.

The total area under the $(\text{H.P.})^2$ curve

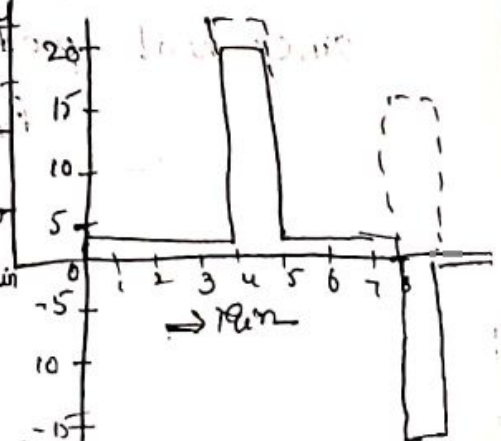
$$= 1^2 \times 4 + 20^2 \times 1 + 1^2 \times 3 + (-15)^2 \times 1$$

$$= 4 + 400 + 3 + 225 = 632 \text{ H.P. min}$$

The above area should be equal to $(\text{H.P.})^2 \times 9$ H.P. min

$$(\text{H.P.})^2 \times 9 = 632 \quad \text{H.P.} = 8.4 \text{ H.P.}$$

on the assumption that heat produced is proportional to the square of the load, the equivalent continuous rating of a motor works out as 8.4 H.P. The nearest standard rating of the motor



Q. A suburban electric train has a maximum speed of 65 kmph. The scheduled stop including acceleration and deceleration is 30 sec. in 43.5 kmph. If the acceleration is 1.3 kmph/s. Find the value of retardation when the avg distance between stops is 3 km.

Sol: $V_m = 65 \text{ kmph}$ Scheduled speed, $T_s = 43.5 \text{ kmph}$
Acceleration, $\alpha = 1.3 \text{ kmph/s}$

Distance of run $T_R = 3 \text{ km}$

Total time of run including stop

$$T_s = \frac{S}{V_s} \times 3600 = \frac{3}{43.5} \times 3600 = 248 \text{ sec}$$

Time for actual run

$$T = T_s - \text{Duration of stop} \\ = 248 - 30 = 218 \text{ sec}$$

Avg speed $V_{avg} = \frac{S}{T} \times 3600$

$$= \frac{3}{218} \times 3600 = 49.5 \text{ kmph}$$

Using the relation $\frac{1}{\alpha} + \frac{1}{\beta} = \frac{7200S}{V_m^2} \left[\frac{V_m}{V_{avg}} - 1 \right]$

$$\frac{1}{\alpha} + \frac{1}{\beta} = \frac{7200S}{V_m^2} \left[\frac{V_m}{V_{avg}} - 1 \right]$$

$$\frac{1}{1.3} + \frac{1}{\beta} = \frac{7200 \times 3}{(65)^2} \left[\frac{65}{49.5} - 1 \right]$$

$$\frac{1}{\beta} + \frac{1}{1.3} = \frac{6480}{4225}$$

$$\frac{1}{\beta} = \frac{6480}{4225} - \frac{1}{1.3} = \frac{15}{10} - \frac{10}{13}$$

$$= \frac{195 - 100}{130} = \frac{95}{130}$$

$$\beta = \frac{130}{95} = 1.3 \text{ kmph/s}$$

25) The illumination of drawing office $30 \times 10 \text{ m}$ is to have a value of 250 lux and is to be provided by a no of 300 W filament lamps. If the coefficient of utilisation is 0.4 and depreciation factor is 0.9 and luminous efficiency of each lamp is 14 lumens per watt, determine the number of lamps required.

if: Area of drawing office = $30 \times 10 = 300 \text{ sq. m}$

Illumination = 250 lux

Wattage of lamps = 300 watts

U.F = 0.4

D.F = 0.9

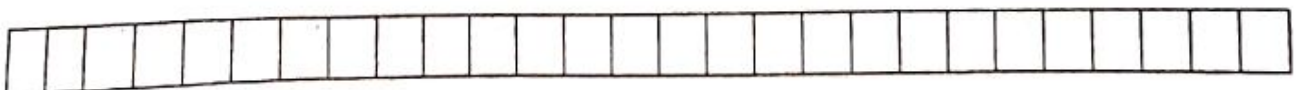
Luminous efficiency = 14 lumens/watt

Gross lumens output required from source

$$= \frac{E \times A}{U.F \times D.F} = \frac{300 \times 250}{0.4 \times 0.9} = 208333.33 \text{ lumens.}$$

$$\begin{aligned} \text{Flux emitted by per lamp} &= \text{Wattage} \times \text{efficiency} \\ &= 300 \times 14 = 4200 \text{ lumens.} \end{aligned}$$

$$\begin{aligned} \text{Total no of lamps required} &= \frac{\text{Gross lumens}}{\text{Lumens output of one lamp}} \\ &= \frac{208333.33}{4200} = 49.8 = \underline{\underline{50}} \end{aligned}$$

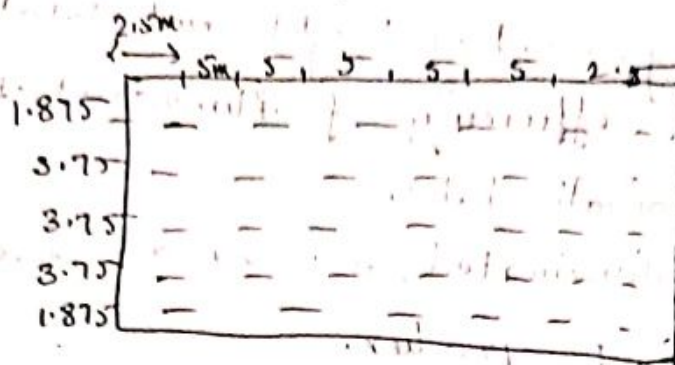


(3)
 ⇒ A drawing hall 30 m by 15 m with a ceiling height of 5 m is to be provided with a general illumination of 120 lux. Taking a coefficient of utilisation of 0.5 and depreciation factor of 1.4. Determine the number of fluorescent tubes required, their spacing, mounting height and total wattage.
 Taking luminous efficiency of fluorescent tube as 40 lumens/watt for 80 watt tubes.
 Sol: floor area to be illuminated, $A = 15 \times 30 = 450 \text{ m}^2$
 Illuminated required $E = 120 \text{ lux}$
 Total lumens required at floor level
 $\phi = A \times E = 450 \times 120 = 54000 \text{ lumen}$
 $U.F. = 0.5$
 Lumens required to be emitted by tubes or
 Gross lumen, $\phi = \frac{A \times E \times D.F.}{U.F.} = \frac{54000 \times D.F.}{U.F.}$
 $= \frac{54000 \times 1.4}{0.5} = 151200 \text{ lumens}$
 Lumens output of each tube
 $= 80 \times 40 = 3200 \text{ lumens}$
 Number of tubes required
 $= \frac{\text{Total lumens required}}{\text{lumens of each tube}}$
 $= \frac{151200}{3200} = 47.25 \text{ (48 say)}$
 Total wattage of tubes
 $= 48 \times 80 = 3840 \text{ watts}$

24 twin tube units, each containing 2 tubes of 80 watts each can be provided in the drawing hall in six rows having spacing of 5 metres each row will have four units spaced 3.75 metres as shown in figure.

Assuming mounting height as 3.5 metres

(Lengthwise) space height ratio $= \frac{3}{3.5} = 1.43$
 (Breadthwise) space height ratio $= \frac{3.75}{3.5} = 1.07$
 which is in between 1 and 1.5



An electric train weighing 200 tonne has eight motors, geared to driving wheels each wheel is 90cm diameter. determine the torque developed by each motor to accelerate the train to a speed of 48 kmph in 30 sec up a gradient of 1 in 200. The tractive resistance is of 50 newtons per tonne, the effect of rotational inertia is 10% of the train weight, the gear ratio is 4 to 1 and gearing efficiency is 80%.

weight of train, $w = 200$ tonne

Diameter of driving wheels, $D = 90\text{cm} = 0.9\text{m}$

percentage gradient, $G = \frac{1}{200} \times 100 = 0.5\%$

Tractive resistance, $r = 50$ newtons/tonne

Gear ratio, $\lambda = 4$

Gearing efficiency, $\eta = 0.80$

Equivalent accelerating weight of the train

$$w_e = 1.10w = 1.1 \times 200 = 220 \text{ tonne}$$

Max speed, $V_m = 48 \text{ kmph}$

Time taken in accelerating the train to a speed of 48 kmph

$$t_1 = 30 \text{ seconds}$$

Acceleration, $\alpha = \frac{v_m}{t_1} = \frac{1.5 \text{ kmph/s}}{30} = 0.05 \text{ kmph/s}$

Traction effort required $1.5 \times 1000 = 1500 \text{ N}$

$$F_t = 277.8 \times 220 \times 1.6 + 98.1 \times 200 \times 0.5 + 200 \times 50$$

$$= 277.8 \times 220 \times 1.6 + 98.1 \times 200 \times 0.5 + 200 \times 50$$

$$= 1,17,596 \text{ N}$$

Total torque developed

$$T = \frac{F_t \times D}{\eta \times 2} = \frac{1,17,596 \times 0.79}{0.8 \times 2} = 16,537 \text{ N-m}$$

Torque developed by each motor

$$= \frac{16537}{4} = 4134.25 \text{ N-m}$$

⇒ An electric train weighing 400 tonnes runs along an upgradient of 1% with following speed-time curve.

i. uniform acceleration of 1.5 kmph/s for 30 sec

ii. free-running for 36 sec. iii. coasting for 20 sec

iv. Braking at 2.6 kmph/s to rest.

If tractive resistance is 45 N/tonne, rotational inertia

effect 10%, overall efficiency of transmission and motor is

determine the specific energy consumption

∴ The maximum speed at the end of acceleration is $30 \times 1.5 = 45 \text{ kmph}$

$$\text{Distance covered during acceleration} = \frac{1}{2} \times 45 \times \frac{30}{3600} = \frac{3}{16} \text{ km}$$

Distance covered during free-running

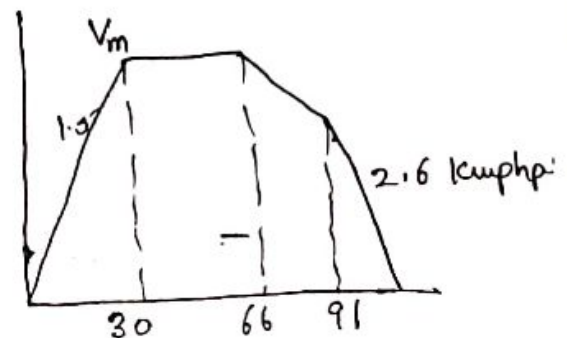
$$= \frac{36 \times 45}{3600} = \frac{9}{20} \text{ km} = 0.45 \text{ km}$$

Traction effort during free running

$$\text{period} = (W_r + 10 W G) \text{ Newton}$$

$$= 400 (45 + 10 \times 1 \times 9.81)$$

$$= 400 \times 143.1$$



During coasting $a = 0$, $\therefore F = 0$, $\therefore$ no force is exerted

$$= 400 \times 143.1 \text{ Newton}$$

$$\text{Retardation} = \frac{400 \times 143.1}{277.8 \times 440} = 0.468 \text{ m/s}^2$$

$$V_2 = 45 - 0.468 \times 25 = 33.3 \text{ kmph}$$

$$\text{time for braking} = \frac{33.3}{2.6} = 12.8 \text{ sec}$$

$$\text{Distance covered during coasting} = \frac{1}{2} (45 + 33.3) \times \frac{25}{3600} = 0.272 \text{ kms}$$

$$\text{Distance during braking} = \frac{1}{2} \times 33.3 \times \frac{12.8}{3600} = 0.059 \text{ km}$$

$$\text{Total distance travelled} = 0.1875 + 0.45 + 0.272 + 0.059 = 0.9685 \text{ kms}$$

Distance during acceleration and free-running when energy is being actually spent i.e.,

$$D = 0.1875 + 0.45 = 0.6375 \text{ km}$$

Therefore, Specific energy output using equation, we have

$$= 0.010726 \frac{\text{Nm}^2}{\text{D}} \times \frac{W_2}{\rho} + 27.25 \text{ G} \times \frac{\rho}{\rho} + 0.2778 \times \frac{\rho}{\rho}$$

$$= 0.010726 \times \frac{45^2}{0.9685} \times 1.1 + 27.25 \times 1 \times \frac{0.6375}{0.9685} + 0.2778 \times \frac{0.6375}{0.9685}$$

$$= 23.89 + 17.937 + 8.23$$

$$= 50.06 \text{ whr/Tonne-km}$$

$$\therefore \text{Specific energy consumption} = 66.75 \text{ whr/Tonne km.}$$



Two lamps of 36 and 16 c.p respectively are one meter apart, where should the screen be placed on a st. line passing through the lamps so as to have equal illumination on it.

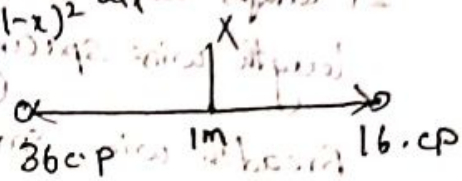
Say screen is placed at x metres from 36 c.p. lamp and

so distance from 16 c.p. lamp is $(1-x)$ metres

$$\text{Illumination due to } L_1 = \frac{36}{d_1^2} \cos \theta = \frac{1}{x^2} = \frac{36}{x^2} \text{ lux}$$

$$\text{Illumination due to } L_2 = \frac{16}{d_2^2} \cos \theta = \frac{16}{(1-x)^2} \text{ lux}$$

Since illumination of both lamps is same



$$\frac{36}{x^2} = \frac{16}{(1-x)^2}$$

$$\frac{36}{x^2} = \frac{16}{1+x^2-2x} \Rightarrow 36 + 36x^2 - 72x = 16x^2$$

$$20x^2 - 72x + 36 = 0 \Rightarrow 5x^2 - 18x + 9 = 0$$

$$x = \frac{18 \pm \sqrt{(18)^2 - 4 \times 5 \times 9}}{2 \times 5} = \frac{18 \pm \sqrt{324 - 180}}{10} = \frac{18 \pm \sqrt{144}}{10}$$

$$x = \frac{18 \pm 12}{10}$$

$$x = \frac{18+12}{10} = \frac{30}{10} = 3m$$

$$x = \frac{18-12}{10} = \frac{6}{10} = 0.6m$$

A hall measuring $15m \times 4.5m$ is to be illuminated by suitable lamps to give an average illumination of 45 lux. Assuming mounting height of lamp to be 3m above the working plane, utilisation factor of 0.65 and depreciation factor of 1.3. Estimate the number and installation position of lamps. The lamps are to be selected from the following

Wattage of lamps	75	100	150	200
Lumens output	880	1280	2120	2880

Q.1) The area to be illuminated = $15 \times 45 = 675 \text{ m}^2$
 Total lumens required = $675 \times 46 = 30375$ lumens
 From lumen required = $30375 \times \frac{1.3}{0.65} = 60750$ lumens

Since efficiency of higher wattage lamp is more and no. of lamps required will be less so let us first try for 200 watt lamp

o/p of a 200w lamp = 2880 lumens

No. of lamps required = $\frac{60750}{2880} = 21.1$ i.e. 21 lamps

21 lamps can be arranged in 7 rows of 3 lamps each.

length wise spacing = $\frac{45}{3} = 15 \text{ m}$

Breadth wise spacing = $\frac{15}{3} = 5 \text{ m}$

Since height ratio in length and breadth-wise be $\frac{15}{5} = 3$ and $\frac{6.43}{3} = 2.14$ and $\frac{5}{3} = 1.66$, which is more than 1.5 and this arrangement can not provide uniform illumination.

Next trying 150 watt lamp size

o/p of a 150 watt lamp = 2120 lumens

No. of lamps required = $\frac{60750}{2120} = 28.7$ (say 30)

Arranging 30 lamps in 10 rows of 3 lamps each

length-wise spacing = $\frac{45}{3} = 15 \text{ m}$

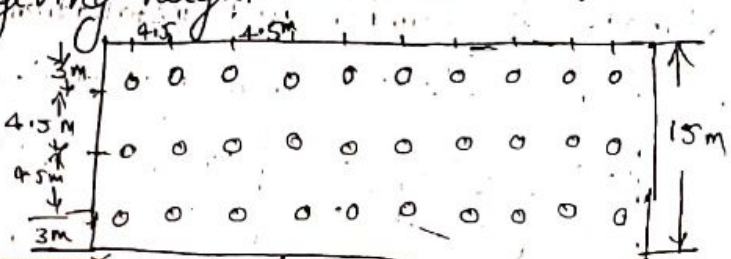
Breadth-wise spacing = $\frac{15}{3} = 5 \text{ m}$

space height ratio length-wise = $\frac{15}{3} = 5$

space height ratio breadth-wise = $\frac{5}{3} = 1.66$

Instead of keeping 2.5m distance b/w the lamp and wall on breadth side, let it be 3m and then the distance b/w two consecutive lamps will be 4.5m, thus giving height ratio as $\frac{4.5}{3} = 1.5$

A suitable arrangement with 150watts lamps can be as shown in figure.



$\Rightarrow$ A 30 kW , 3ϕ , 400 V resistive oven is employed which contains
 strip 0.025 m thick for the 3 -phase star-connected heating
 elements. If the wire temperature is to be 1100°C and that
 of charge is to be 200°C , estimate a suitable width for the
 strip. Assume radiating efficiency as 0.6 and emissivity as
 0.9 . The specific resistance of the nichrome-alloy is $1.03 \times 10^{-6} \Omega/\text{m}$
 state any assumption made.

$\therefore$ power per phase, $P = \frac{30 \times 1000}{3} = 10,000 \text{ W}$

phase voltage, $V_p = \frac{400}{\sqrt{3}} = 230.94 \text{ V}$

Resistance of strip, $R = \frac{(V_p)^2}{P} = \frac{(230.94)^2}{10,000} = 5.333 \Omega$

If l is the length of the strip and w is the width of the
 strip then resistance of strip,

$R = \frac{\rho l}{wt} = \frac{1.03 \times 10^{-6} \times l}{w \times 0.025 \times 10^{-2}} \Rightarrow \frac{l}{w} = \frac{0.00025 R}{1.03 \times 10^{-6}}$

$\frac{0.00025 \times 5.333}{1.03 \times 10^{-6}} = 1295 \quad \text{--- (1)}$

Heat dissipated from the surface,

$$H = 5.72 \times 0.6 \times 0.9 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \text{ W/m}^2$$

$$= 5.72 \times 0.6 \times 0.9 \left[\left(\frac{273+1100}{100} \right)^4 - \left(\frac{273+200}{100} \right)^4 \right] \text{ W/m}^2$$

$$= 82,082 \text{ W/m}^2$$

Surface area available for heat radiation = $2wl$ metres

heat dissipated = power $\Rightarrow$

$82,082 \times 2wl = 10,000 \Rightarrow wl = \frac{10000}{2 \times 82082} = 0.060915 \text{ m}^2$

Dividing the expression (2) and (1)

$\frac{(2)}{(1)} \Rightarrow w^2 = \frac{0.060915}{1295} = 0.000047 \text{ m}^2$

$w = \sqrt{0.000047} = 0.00686 \text{ m} = 6.86 \text{ mm}$

A motor with flywheel has to supply the load of 200 kg-m for 10 sec followed by a no-load period. During the no-load period, the motor regains its speed. If it is desired to limit the motor torque to 100 kg-m, what should be the moment of inertia of the flywheel? The no-load speed of the motor is 500 r.p.m and has a slip of 10% at a torque of 100 kg-m.

if $T_m = 100 \text{ kg-m}$ $T_L = 200 \text{ kg-m}$, $T_0 = 0 \text{ kg-m}$

Load period, $t = 10 \text{ sec}$

slip, $s = 0.1 \times 500 = 50 \text{ rpm} = \frac{2\pi \times 50}{60} = \frac{10\pi}{60} \text{ rad/sec}$

Now, $\frac{1}{K} \frac{dT}{dt} = \frac{s}{T_m} = \frac{\frac{10\pi}{60}}{200} = \frac{\pi}{1200}$

$T_m = T_L - (T_L - T_0) e^{-g/KJ \cdot t}$

$(T_L - T_0) e^{-g/KJ \cdot t} = T_L - T_m$

$-\frac{g}{KJ} \cdot t = \log_e \frac{T_L - T_m}{T_L - T_0}$

$t = \frac{KJ \log_e \frac{T_L - T_0}{T_L - T_m}}{-g}$

$J = \frac{g \cdot t}{K \log_e \frac{T_L - T_0}{T_L - T_m}} = \frac{9.81 \times 10}{60 \log_e \frac{200}{100}}$

$J = \frac{9.81 \times 10 \times 60}{9.81 \times 60 \log_e \frac{200}{100}} = 2.704 \text{ kg m}^2$

$J = \frac{9.81 \times 600}{3.14 \times 2.3 \times 0.3010} = 2.704 \text{ kg m}^2$

Since the motor has a no-load speed of 500 rpm, the synchronous speed is 500 rpm.

$\omega_s = \frac{2\pi \times 500}{60} = 52.36 \text{ rad/sec}$

$J = \frac{2.704}{52.36^2} = 0.001 \text{ kg m}^2$

$J = 0.001 \text{ kg m}^2$

$J = 0.001 \text{ kg m}^2$