1 a). Definition: Act of drawing or state of being drawn: propulsion of vehicle is called the traction and the system of traction involving the use of electricity is called electric traction system. 2M

Types of traction:

1. Direct steam Engine Drive

2. Direct Internal Combustion Engine

3. Steam Electric Drive

4. Battery Electric Drive

5. Electric Drive 3M

1b).

Each system of traction has got its own merits, demerits and fields of applications and no single system fulfills the requirements of an ideal traction system which are given below:

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

2).

... in series for running at full maximum speed.

7. Electric Drive. The drive of this type is most widely used. In this system of traction the vehicle draws electrical energy from the distribution system (from a contact wire suspended above the track or from an additional rail laid along side it) fed at suitable points from either a central power station or substations. The advantages and disadvantages of electric drive are as follows:

Advantages. 1. It is the cleanest of all other types of systems of traction. Due to this only it is ideally suitable for the underground and tube railways.

2. No water and coaling depots are required in electric drive.
3. Ancilliary equipment, such as coaling cranes, ash and fire cleaning pits, water supply plants, is not required. Size of running sheds and workshops is comparatively smaller.
4. The electrical energy required for lights and fans of the train can be drawn from the lines directly and, therefore, there is no need of providing Rosenberg generators.
5. Owing to better speed control in electric drive locomotion on steep gradients at slow speed is possible.
6. It has got another advantage of rapid acceleration and braking retardation. An electric locomotive has an acceleration of 1.5 to 3.5 kmphps for urban service. Trolley buses have acceleration of 4 to 6 kmphps. The steam locomotive has an acceleration of only 0.8 kmphps. Hence the schedule speed may be from 50 to 100 per cent higher than that corresponding to steam operation over short runs and with frequent stops.
7. Because of *larger* passenger carrying capacity and higher schedule speed the electric railway can handle the traffic of any amount—up to double the amount possible with steam railway.
8. The electric train can be divided and run in sections during the periods of light traffic, thereby enabling a frequent service to be maintained.
9. Less terminal space is required on account of speedy movement and lesser number of units required for operating a given service.
10. An electric locomotive requires much less time for ... and repairs than a steam locomotive and

13. There is no damage to the plant, equipment and building due to corrosive smoke fumes because of absence of unwanted gases and fire hazards.
14. This system is healthier from the hygienic point of view owing to complete absence of smoke and fumes.
15. Electric traction is most economical in areas of high traffic density particularly if electrical energy is cheap.
16. Centre of gravity of electric locomotive is lower than that of steam locomotive and, therefore, electric locomotive is able to negotiate curves at comparatively higher speeds.
17. The vibrations in electrically operated vehicles are less as the torque exerted by the electric motors is continuous.
18. In electric traction it is possible to instal power units in two or more power cars in the train and to control them from one point whereas in steam traction each locomotive is to be manned by its own crew.
19. The coefficient of adhesion is better in electric traction than that in steam traction. This is due to continuous torque of electric motors and distribution of driving wheels along the length of the train. Higher coefficients of adhesion not only reduces the ratio of weight to output kW of the locomotive but also results in improvement in riding qualities and reduction in wear and tear of the track.
20. Electric equipment can withstand large temporary overloads and can draw relatively large power from the distributing system.
21. Electric traction helps in saving of high grade coal which is limited in quantity in our country.
22. Power requirement for railway electrification has been of the order of 50 kW/track km. This is a sizeable load which tends to increase power development schemes. Traction load has high load factor of the order of 60 to 70%. Electric traction, therefore, provides a most important base load. This, therefore, enables the use of large generator units having high thermal efficiency possible in thermal stations. High base load also affords economic development of hydroelectric potential.

3).

stop has less conspicuous effect on the schedule speed.

11.5. SIMPLIFIED SPEED-TIME CURVES (4)

In order to study the performance of a service at different schedule speeds the speed-time curves are replaced by simple geometric shaped curves. From these simplified curves the relationships between acceleration, retardation, average speed and distance can be easily worked out. These can have either quadrilateral or trapezoidal shape.

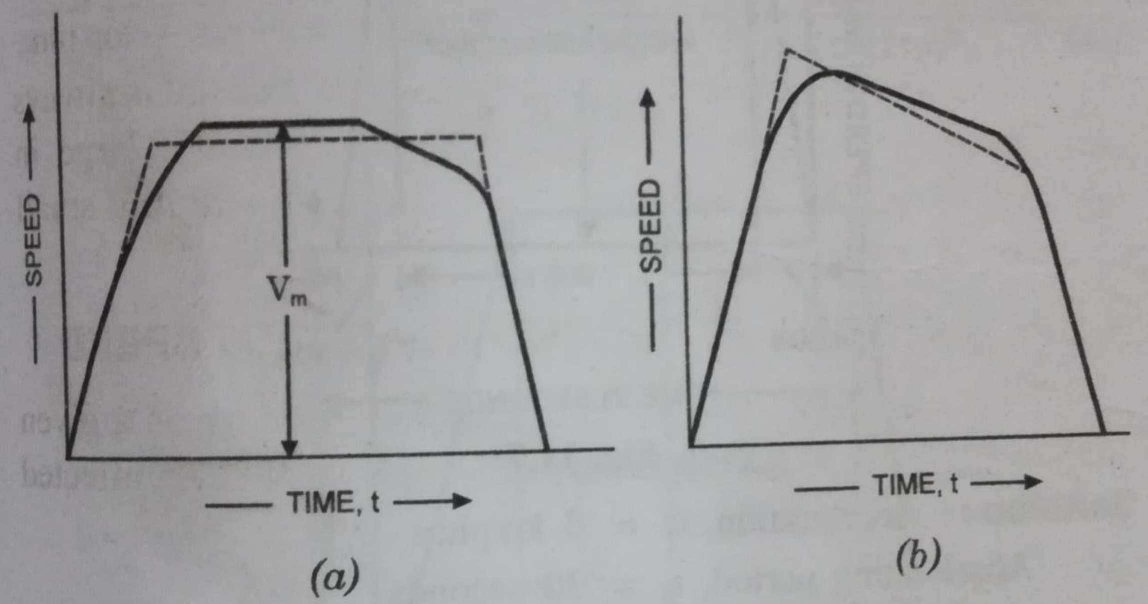


Fig. 11.4. ***Approximate Speed-Time Curves***

The speed-time curve of an urban service can be replaced by an equivalent speed-time curve of simple quadrilateral shape. The speed-time curve of a main line service is best and most easily replaced by a trapezoid. Since the area of the speed-time curve represents the total distance travelled hence the areas of the two curves should be same. The values of acceleration and retardation are also kept the same as those of the original speed-time curve. In case of simplified trapezoidal speed-time curve, speed curve running and coasting periods are replaced by constant speed period, as illustrated in

Fig. 11.4 (*a*). While in case of quadrilateral speed-time curve, initial acceleration and coasting periods are extended, as illustrated in Fig. 11.4 (*b*).

The following examples illustrate the methods of calculations.

1. *Calculations By Trapezoidal Speed-Time Curve*

Let α = Acceleration in kmphps

β = Retardation in kmphps

V_m = Crest speed in kmph

T = Total time of run in seconds.

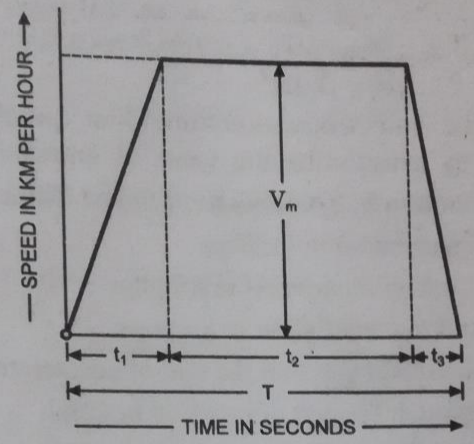


Fig. 11.5. ***Trapezoidal Speed-Time Curve***

Time for acceleration in seconds, $t_1 = \dfrac{V_m}{\alpha}$

Time for retardation in seconds, $t_3 = \dfrac{V_m}{\beta}$

Time for free running in seconds, $t_2 = T - (t_1 + t_3)$

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

Total distance of run in km,

S = Distance travelled during acceleration
+ distance travelled during free run
+ distance travelled during braking

$$= \frac{1}{2} V_m \frac{t_1}{3,600} + V_m \frac{t_2}{3,600} + \frac{1}{2} V_m \frac{t_3}{3,600}$$

Substituting $t_1 = \dfrac{V_m}{\alpha}$, $t_3 = \dfrac{V_m}{\beta}$ and $t_2 = T - \left(\dfrac{V_m}{\alpha} + \dfrac{V_m}{\beta}\right)$ we have

$$S = \frac{V_m^2}{7,200\alpha} + \frac{V_m}{3,600}\left[T - \left(\frac{V_m}{\alpha} + \frac{V_m}{\beta}\right)\right] + \frac{V_m^2}{7,200\beta}$$

or $$S = \frac{V_m^2}{7,200\alpha} + \frac{V_m}{3,600}T - \frac{V_m^2}{3,600\alpha} - \frac{V_m^2}{3,600\beta} + \frac{V_m^2}{7,200\beta}$$

$$= \frac{V_m T}{3,600} - \frac{V_m^2}{7,200\alpha} - \frac{V_m^2}{7,200\beta} \qquad ...(11.1)$$

or $$\frac{V_m^2}{3,600}\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right) - \frac{V_m T}{3,600} + S = 0$$

$$KV_m^2 - V_m T + 3{,}600\ S = 0$$

or $$V_m = \frac{T \pm \sqrt{T^2 - 4K \times 3{,}600S}}{2K}$$

$$= \frac{T}{2K} \pm \sqrt{\frac{T^2}{4K^2} - \frac{3{,}600\ S}{K}}$$

The +ve sign cannot be adopted, as value of V_m obtained by using +ve sign will be much higher than that is possible in practice. Hence –ve sign will be used and, therefore, we have

$$V_m = \frac{T}{2K} - \sqrt{\frac{T^2}{4K^2} - \frac{3{,}600\ S}{K}} \quad \text{...(11.2)}$$

From the above equation unknown quantity can be determined by substituting the value of known quantities.

4).

can be obtained.

Example 11.1. A train service consists of following :

Uniform acceleration of 5 km/hr/sec for 30 seconds followed by free running for 10 minutes, then uniform braking at 5 km/hr/sec to stop followed by a stop of 5 minutes.

Draw the speed Vs time curve and calculate

(*i*) Distance between the stations

(*ii*) Average speed and (*iii*) Scheduled speed.

[U.P. Technical Univ. Utilization of Electrical Energy & Electric Traction 2005-06]

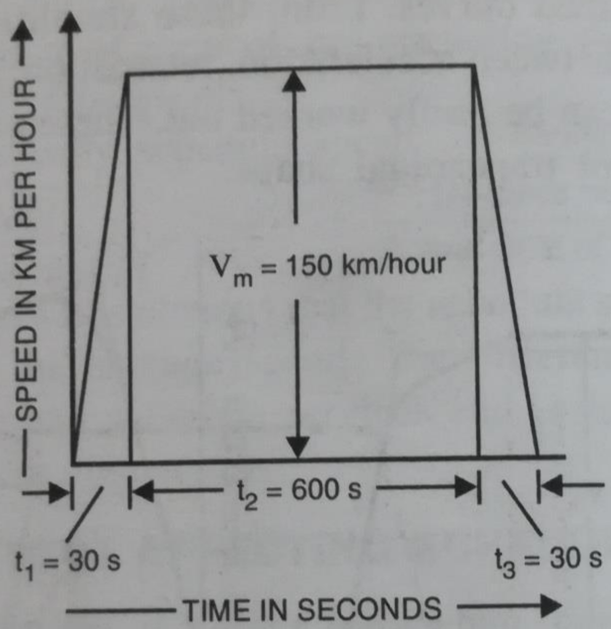


Fig. 11.7

Solution : Acceleration, $\alpha = 5$ kmphps

Accelerating period, $t_1 = 30$ seconds

Maximum speed, $V_m = \alpha t_1 = 5 \times 30 = 150$ kmph

Time for free running, $t_2 = 10 \times 60 = 600$ seconds

Retardation, $\beta = 5$ kmphps

$$\text{Time for retardation, } t_s = \frac{V_m}{\beta} = \frac{150}{5} = 30 \text{ seconds}$$

Distance travelled during acceleration period,

$$S_1 = \frac{1}{2}\frac{V_m t_1}{3,600}$$

$$= \frac{1}{2} \times \frac{150 \times 30}{3,600} = 0.625 \text{ km}$$

hor 7x

Distance travelled during free running,

$$S_2 = \frac{V_m \times t_2}{3,600} = \frac{150 \times 600}{3,600} = 25 \text{ km}$$

Distance travelled during braking period,

$$S_3 = \frac{1}{2} \times \frac{V_m \times t_3}{3,600} = \frac{1}{2} \times \frac{150 \times 30}{3,600} = 0.625 \text{ km}$$

(*i*) Total distance between stations, S

$$= S_1 + S_2 + S_3 = 0.625 + 25 + 0.625$$

$$= 26.25 \text{ km} \quad \textbf{Ans.}$$

$$\text{Average speed, } V_a = \frac{S \times 3,600}{T} = \frac{26.25 \times 3,600}{30 + 600 + 30}$$

$$= 143.18 \text{ kmph} \quad \textbf{Ans.}$$

$$\text{Scheduled speed, } V_s = \frac{S \times 3,600}{T + \text{stop time}} = \frac{26.25 \times 3,600}{660 + 5 \times 60}$$

$$= 98.44 \text{ kmph} \quad \textbf{Ans.}$$

... average speed of 42 kmph

5).

= 15.15 seconds **Ans.**

11.6. MECHANICS OF TRAIN MOVEMENT

Essential driving mechanism of an electric locomotive is shown in Fig. 11.9. The armature of the driving motor has a pinion of diameter d' attached to it. The tractive effort at the edge of the pinion is transferred to the driving wheel by means of a gearwheel.

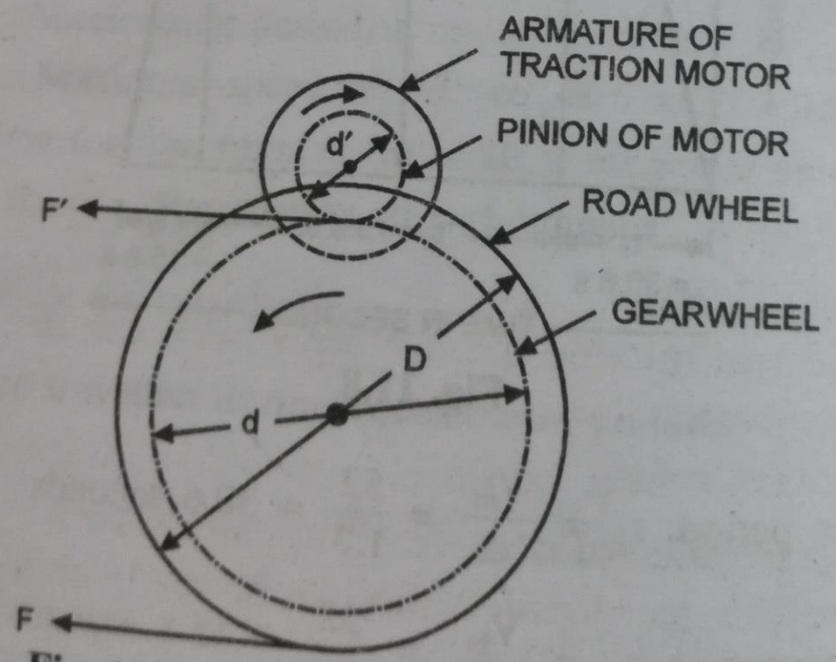


Fig. 11.9. ***Transmission of Tractive Effort***

Let the driving motor exert a torque T in Nm.

Tractive effort at the edge of pinion is given by the equation

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

Tractive effort transferred to the driving wheel

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

$$= \eta T\frac{2\gamma}{D} \quad \text{...(11.5)}$$

where d is diameter of gearwheel in metres, D is diameter of driving wheel in metres and η is the efficiency of transmission, γ is the gear ratio and is equal to $\frac{d}{d'}$.

The maximum frictional force between the driving wheel and the track = μW where μ is the *coefficient of adhesion* between the driving wheel and the track and W is the weight of the train on the driving axles (called *adhesive weight*). Slipping will not take place unless tractive effort $F > \mu W$. For motion of trains without slipping tractive effort F should be less than or at the most equal to μW but in no case greater than μW.

The magnitude of the tractive effort that can be employed for propulsion, therefore, depends upon the weight coming over the driving wheels and the coefficient of adhesion between the driving wheel and the track. The coefficient of adhesion is defined as

i.e., Coefficient of adhesion,

$$\mu = \frac{\text{Maximum tractive effort that can be applied without slipping of wheels}}{\text{Adhesive weight (Weight on the driving wheels)}} \quad \text{...(11.6)}$$

The coefficient of adhesion reduces with the increase in speed as shown below in Table 11.2.

Table 11.2. Variation of coefficient of adhesion with speed on dry rails.

Speed in kmph	0	15	30	45	60	75
Coefficient of Adhesion	0.25	0.18	0.14	0.12	0.10	0.09

The normal value of coefficient of adhesion with clean dry rails is 0.25 and with wet or greasy rails the value may be as low as 0.08.

Electric traction has a very important advantage over steam traction and that is on account of greater adhesive weight - in a motor coach 100 per cent of the weight is on the driving wheels, in an electric locomotive 70 per cent whereas in a steam locomotive less than 50 per cent. The coefficient of adhesion in electric traction is also greater than that in steam traction due to the following two reasons.

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

(*ii*) In electric traction the driving wheels are distributed over ... steam traction they

6).

suburban areas.

11.7. TRACTIVE EFFORT FOR PROPULSION OF TRAIN

The effective force, necessary to propel the train, at the wheels of locomotive is called the *tractive effort*. It is tangential to the driving wheels and measured in newtons.

Total tractive effort required to run a train on track

= Tractive effort required for linear and angular acceleration + tractive effort to overcome the effect of gravity + tractive effort to overcome the train resistance.

or $F_t = F_a \pm F_g + F_r$ ...(11.7)

1. ***Tractive Effort For Acceleration.*** According to laws of dynamics force is required to accelerate the motion of the body and is given by the expression

$$\text{Force} = \text{Mass} \times \text{acceleration}$$

Consider a train of weight W tonnes being accelerated at α kmphps

$$\text{The weight of train} = 1{,}000 \text{ W kgf}$$

$$\text{Mass of train, } m = 1{,}000 \text{ W kg}$$

$$\text{Acceleration} = \alpha \text{ kmphps}$$

$$= \alpha \times \frac{1{,}000}{3{,}600} \text{ m/s}^2$$

$$= 0.2778\ \alpha \text{ m/s}^2$$

Tractive effort required for linear acceleration,

$$F_a = m\alpha$$

$$= 1{,}000 \text{ W} \times 0.2778\ \alpha$$

$$= 277.8 \text{ W } \alpha \text{ newtons} \quad ...(11.8)$$

With the linear acceleration of the train, the rotating parts of the train such as wheels and motors also accelerate in an angular direction, and therefore, the tractive effort required is equal to the arithmetic sum of tractive effort required to have the angular acceleration of rotating parts and tractive effort required to have the linear acceleration. The tractive effort required to have the angular acceleration depends upon the individual weight, radius of gyration etc. of the rotating parts requiring angular acceleration. Hence the equivalent or accelerating weight of the train is taken as W_e which is higher than the dead weight W requiring linear acceleration to consider the tractive effort for the angular acceleration. In practice W_e is higher than W by 8 to 15%. The normal value lies between 10 and 12 per cent.

i.e., $G = \sin\theta \times 100$

or $\sin\theta = \dfrac{G}{100}$

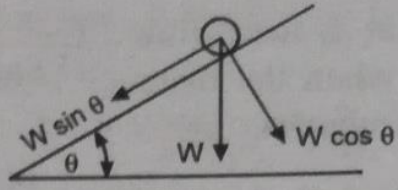


Fig. 11.10

Substituting $\sin\theta = \dfrac{G}{100}$ in Eq. (11.10) we have,

$$F_g = 1{,}000\ W \times \frac{G}{100}$$
$$= 10\ WG\ kg = 10\ WG \times 9.81$$
$$= 98.1\ WG\ \text{newtons} \quad ...(11.11)$$

When the train is going up a gradient, the tractive effort will be required to balance this force due to gradient but while going down the gradient, the force will add to the tractive effort.

3. ***Tractive Effort For Overcoming Train Resistance.*** Train resistance consists of all the forces resisting the motion of a train when it is running at uniform speed on a straight and level track. Under these circumstances the whole of the energy output from the driving axles is expended against train resistance. Train resistance is due to (*i*) the friction at the various parts of the rolling stock (*ii*) friction at the track and (*iii*) air resistance. The first two components constitute the *mechanical resistance* component of train resistance. The train resistance depends upon various factors, such as shape, size and condition of track etc., and is expressed in newtons per tonne of the dead weight. For a normal train the value of specific resistance has been 40 to 70 newtons/tonne.

The general equation for train resistance is given as

$$R = k_1 + k_2V + k_3V^2 \quad ...(11.12)$$

where k_1, k_2 and k_3 are constants depending upon the train and the track, R is the resistance in newtons and V is the speed in kmph. The first two terms represent the mechanical resistance and the last term represents air resistance.

Tractive effort required to overcome the train resistance,

$$F_r = W \times r\ \text{newtons} \quad ...(11.13)$$

where r is the specific resistance in newtons per tonne of the dead weight.

Total tractive effort required,

7).

11.11. FACTORS AFFECTING SPECIFIC ENERGY CONSUMPTION OF AN ELECTRIC TRAIN OPERATING ON A GIVEN SCHEDULE SPEED

The specific energy consumption of a train operating at a given schedule speed depends upon the following factors

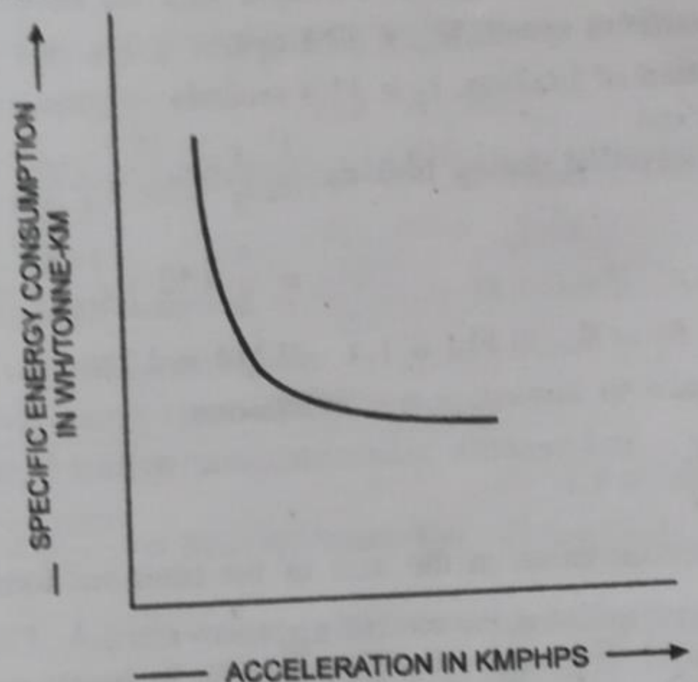
(*a*) distance between stops (*b*) acceleration (*c*) retardation (*d*) maximum speed (*e*) nature of route and (*f*) the type of train equipment.

Specific energy output is given by the expression

Specific energy output

$$= \frac{0.01072\, V_m^2 W_e}{SW} + \frac{0.2778\,(98.1\,G + r)S_1}{S} \text{ watt-hours/tonne-km} \quad ...(11.25)$$

Specific energy output is independent of locomotive overall efficiency but the specific energy consumption being equal to specific energy output divided by locomotive overall efficiency depends upon the overall efficiency of the locomotive. Greater the overall efficiency lesser will be the specific energy consumption for a given specific energy output at axles.



(*a*)

of acceleration and retardation, more will be the period of coasting and, therefore, lesser the period during which power is on *i.e.*, S_1 will be small and, therefore, specific energy consumption will accordingly be less. Steep gradient will involve more energy consumption even if regenerative braking is used. Similarly more the train resistance, greater will be the specific energy consumption.

How the specific energy consumption falls with the increase in value of acceleration (retardation) and distance of run is illustrated in Figs. 11.11 (*a*) and 11.11 (*b*) respectively.

Typical values of specific energy consumption are (*i*) 50 – 75 watt-hours per tonne-km for suburban services and (*ii*) 20 – 30 watt-hours per tonne-km for main line service.

8). Linear Induction Motor.

...ections of Italian State Railway.

12.7. LINEAR INDUCTION MOTOR

It is a special type of induction motor which gives linear motion instead of rotational motion as in the case of a conventional induction motor. It operates on the same principle on which a conventional induction motor operates *i.e.*, "whenever there occurs a relative motion between the field and the short-circuited conductors, currents are induced in them which results in electromagnetic forces and under the influence of these forces, according to Lenz's law, the conductors try to move in such a way as to eliminate the induced currents". In case of a conventional induction motor, movement of field is rotary about an axis so the movement of the conductors is also rotary. But is case of a linear induction motor, the movement of the field is rectilinear and so the movement of conductors.

In its simplest form, a linear induction motor consists of field system having a 3-phase distributed winding placed in slots as shown in Fig. 12.15. The field system may be a single primary system or double primary system (Fig. 12.15). The secondary of the linear induction motor is normally a conducting plate made of either copper or aluminium in which interaction currents are induced. Either member can be the *stator*, the other being the *runner* in accordance with the particular requirements imposed by the duty for which motor is intended.

In a single primary system a ferromagnetic plate is usually placed on the other side of the conducting plate to provide a path of low reluctance to the main flux. However, the ferromagnetic plate gets attracted towards the primary on energisation of the field and this causes unequal gap length on two sides of the conducting plate. This problem can be overcome by employing double primary system. [Fig. 12.15 (*b*)].

Which of the two primary and secondary will be shorter in length compared to the other depends upon the use of the motor. When the operating distance is large, the primary is made shorter than the secondary because it is uneconomical to wind a very long 3-phase primary. The short secondary form [Fig. 12.15 (*c*)] is useful with limited operating distance.

When the three phase primary winding of a linear induction motor is energized from a balanced three phase source, a magnetic field moving in a straight line from one end to the other at a linear synchronous speed v_s is developed. The linear synchronous speed is given as

$$v_s = 2\tau f \text{ metres/second} \quad ...(12.17)$$

where τ is the pole pitch in metres and f is the supply frequency in Hz. *It is to be noted here that the synchronous speed does not depend on the number of poles, but only on the pole pitch and the stator supply frequency.*

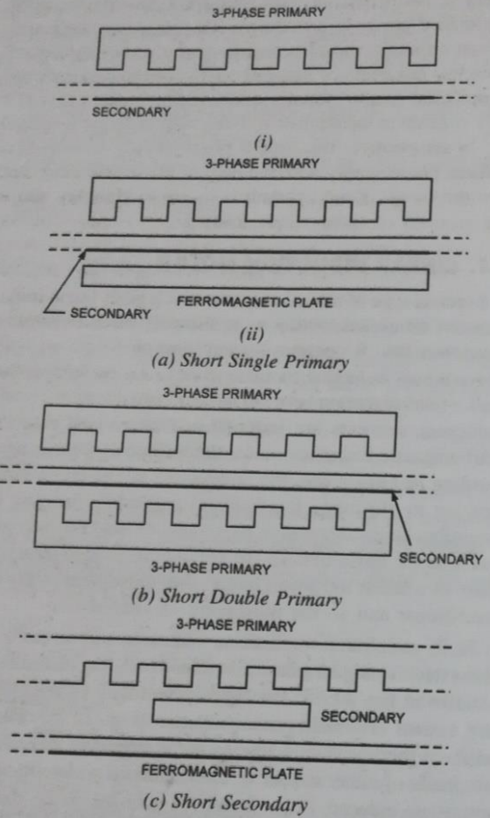


Fig. 12.15

As the flux moves linearly, it drags rotor plate alongwith it in the same direction. This reduces the relative speed of travel of the flux with respect to rotor plate. If the speed of the rotor plate is equal to that of the magnetic field, latter would be stationary when viewed from rotor plate. This is corresponding to the synchronous speed of induction motor. If the rotor plate is moved faster than this speed, the direction of the force would be reversed and a form of regenerative braking based on the principle of induction generator will come into being.

Slip of a linear induction motor is given as

$$s = \frac{v_s - v}{v_s} \quad ...(12.18)$$

where v is the actual speed of rotor plate.

Thrust or force or tractive effort is given as

$$F = \frac{P_2}{v_s} \quad ...(12.19)$$

where P_2 is the actual power supplied to the rotor.

Active power flow is similar to that in a conventional rotary induction motor *i.e.*,

$$\text{Copper losses in rotor} = sP_2 \quad ...(12.20)$$

and mechanical power developed, $P_{mech} = (1 - s) P_2$ ...(12.21)

Tractive effort will be a function of slip s *i.e.*, $(v_s - v)$. The thrust (or tractive effort)-speed characteristics of a linear induction motor, as shown in Fig. 12.16, are similar to the torque-speed characteristics of a conventional rotary induction motor.

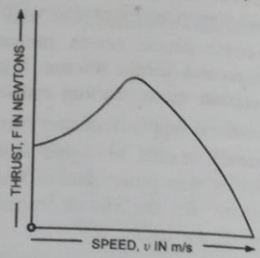


Fig. 12.16

Tractive effort, F can be controlled by varying both frequency and voltage simultaneously so that induction density remains constant.

There are two peculiar effects, which are encountered in a linear induction motor but not in a conventional rotary induction motor. These effects are *transverse edge effect* and *end effect*.

The paths of the induced currents in the secondary are not well defined because the secondary of a linear induction motor is a solid conducting plate. The portion of the current paths parallel to the direction of motion of secondary does not make any contribution towards the production of useful thrust but only contributes towards losses. This effect reduces the effective thrust and increases the losses and is known as the *transverse edge effect* because the current paths parallel to the direction of motion are more towards the edges of the conducting plate.

In the case of linear induction motors with short primary, the current paths towards the end of field structure on the conducting plate go beyond the field structure and such portions of current paths do not contribute to useful thrust but only towards motor losses. This is called the *end effect*. The end effect can be effectively reduced by increasing the number of poles on the motor.

The **advantages** of linear induction motors are (*i*) low initial cost (*ii*) low maintenance cost because of absence of rotating parts (*iii*) simplicity (*iv*) no limitation of tractive effort due to adhesion between the wheel and the rail (*v*) no limitation of maximum speed due to centrifugal forces (*vi*) no overheating of rotor because the motor moves continuously over cool rotor plate leaving behind heated rotor portion and (*vii*) better power to weight ratio.

The **disadvantages** of linear induction motors are (*i*) poor utilisation of motor due to transverse edge effect and end effect (*ii*) larger air gap and non-magnetic reaction rail (rotor plate)

9).

$\frac{}{8}$ = 2,667 N-m Ans.

Example 11.9. A 200 tonne motor coach having 4 motors each developing 6,000 N-m torque during acceleration, starts from rest. If the gradient is 30 in 1,000; gear ratio 4, gear transmission efficiency 90%, wheel radius 45 cm, train resistance 50 N/tonne; addition of rotational inertia 10%, calculate the time taken to attain a speed of 50 kmph. If the line voltage is 3,000 V dc and efficiency of motors 85%, find the current during notching period.

[Pb. Univ. Electric Drives and Utilization Dec. 1989; Rajasthan Univ. Utilization of Electrical Power 2006]

Solution : Weight of train, W = 200 tonnes

Diameter of driving wheels, D = 2 × 45 = 90 cm = 0.9 m

Percentage gradient, $G = \frac{30}{1,000} \times 100 = 3\%$

Tractive resistance, r = 50 N/tonne

Gear ratio, $\gamma = 4$

Gear transmission efficiency, η = 90% or 0.9

Equivalent accelerating weight of the train,

$W_e = 1.10 \times 200 = 220$ tonnes

Total torque developed, $T = 4 \times 6,000 = 24,000$ N-m

Tractive effort,

$$F_t = \frac{\eta T 2\gamma}{D} = \frac{0.9 \times 24,000 \times 2 \times 4}{0.9} = 192,000 \text{ N}$$

Let the acceleration of the train be α kmphps

Then $F_t = 277.8\, W_e \alpha + 98.1\, WG + Wr$

or $192,000 = 277.8 \times 220\alpha + 98.1 \times 200 \times 3 + 200 \times 50$

$$\alpha = \frac{123,140}{277.8 \times 220} = 2.015 \text{ kmphps}$$

Time taken for the train to attain a speed of 50 kmph

$$t = \frac{V_m}{\alpha} = \frac{50}{2.015} = 24.82 \text{ seconds}$$ **Ans.**

Power output from the driving axles

$$= \frac{F_t \times V}{3,600} = \frac{192,000 \times 50}{3,600} = 2,666.7 \text{ kW}$$

$$\text{Power input} = \frac{\text{Power output}}{\eta_m} = \frac{2,666.7}{0.85} = 3,137 \text{ kW}$$

$$\text{Total current drawn} = \frac{\text{Power input in kW} \times 1,000}{V}$$

$$= \frac{3,137 \times 1,000}{3,000} = 1,046 \text{ A}$$

$$\text{Current drawn per motor} = \frac{1,046}{4} = 261.5 \text{ A}$$ **Ans.**

10). Characteristics of Linear Induction Motor.

magnetic field moving in a straight line from one end to the other at a linear synchronous speed v_s is developed. The linear synchronous speed is given as

$$v_s = 2\tau f \text{ metres/second} \quad ...(12.17)$$

where τ is the pole pitch in metres and f is the supply frequency in Hz. *It is to be noted here that the synchronous speed does not depend on the number of poles, but only on the pole pitch and the stator supply frequency.*

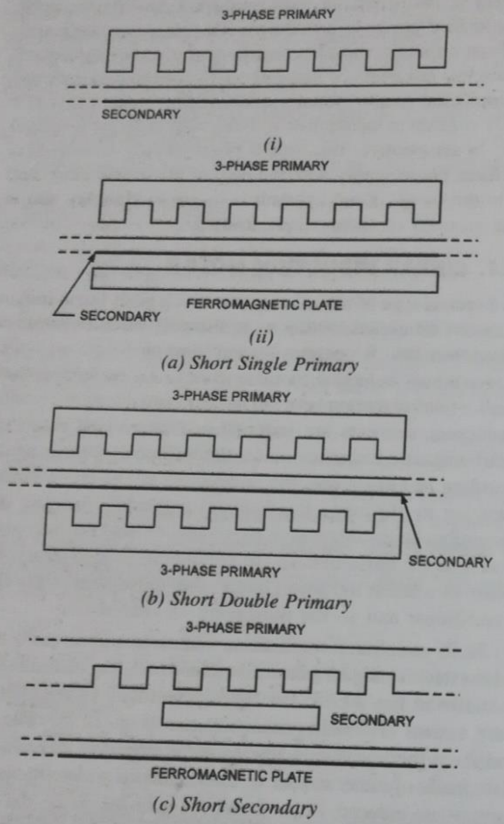


Fig. 12.15

As the flux moves linearly, it drags rotor plate alongwith it in the same direction. This reduces the relative speed of travel of the flux with respect to rotor plate. If the speed of the rotor plate is equal to that of the magnetic field, latter would be stationary when viewed from rotor plate. This is corresponding to the synchronous speed of induction motor. If the rotor plate is moved faster than this speed, the direction of the force would be reversed and a form of regenerative braking based on the principle of induction generator will come into being.

Slip of a linear induction motor is given as

$$s = \frac{v_s - v}{v_s} \quad ...(12.18)$$

where v is the actual speed of rotor plate.

Thrust or force or tractive effort is given as

$$F = \frac{P_2}{v_s} \quad ...(12.19)$$

where P_2 is the actual power supplied to the rotor

Active power flow is similar to that in a conventional rotary induction motor *i.e.*,

$$\text{Copper losses in rotor} = sP_2 \quad ...(12.20)$$

and mechanical power developed, $P_{mech} = (1 - s) P_2$ ...(12.21)

Tractive effort will be a function of slip s *i.e.*, $(v_s - v)$. The thrust (or tractive effort)-speed characteristics of a linear induction motor, as shown in Fig. 12.16, are similar to the torque-speed characteristics of a conventional rotary induction motor.

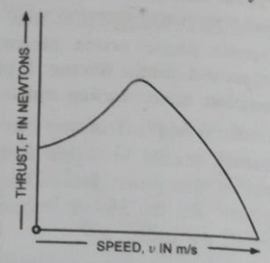


Fig. 12.16

Tractive effort, F can be controlled by varying both frequency and voltage simultaneously so that induction density remains constant.

There are two peculiar effects, which are encountered in a linear induction motor but not in a conventional rotary induction motor. These effects are *transverse edge effect* and *end effect*.

The paths of the induced currents in the secondary are not well defined because the secondary of a linear induction motor is a solid conducting plate. The portion of the current paths parallel to the direction of motion of secondary does not make any contribution towards the production of useful thrust but only contributes towards losses. This effect reduces the effective thrust and increases the losses and is known as the *transverse edge effect* because the current paths parallel to the direction of motion are more towards the edges of the conducting plate.

In the case of linear induction motors with short primary, the current paths towards the end of field structure on the conducting plate go beyond the field structure and such portions of current paths do not contribute to useful thrust but only towards motor losses. This is called the *end effect*. The end effect can be effectively reduced by increasing the number of poles on the motor.

The **advantages** of linear induction motors are (*i*) low initial cost (*ii*) low maintenance cost because of absence of rotating parts (*iii*) simplicity (*iv*) no limitation of tractive effort due to adhesion between the wheel and the rail (*v*) no limitation of maximum speed due to centrifugal forces (*vi*) no overheating of rotor because the motor moves continuously over cool rotor plate leaving behind heated rotor portion and (*vii*) better power to weight ratio.

The **disadvantages** of linear induction motors are (*i*) poor utilisation of motor due to transverse edge effect and end effect (*ii*) larger air gap and non-magnetic reaction rail (rotor plate)