4.3 MECHANICS OF TRAIN MOVEMENT

TRAIN MOVEMENT

Speed-Time Curve

The curve drawn between speed and time is called the speed-time-curve and is given in figure 4.3.1. The speed-time curve gives complete information of the motion of the train. The curve gives the speed at various instants after the start of run directly. Slop of the curve at any point gives the acceleration at the corresponding instant or speed. The area covered by the curve, the time axis and the ordinates through the instants between which the time is taken, represents the distance covered in the corresponding time interval.

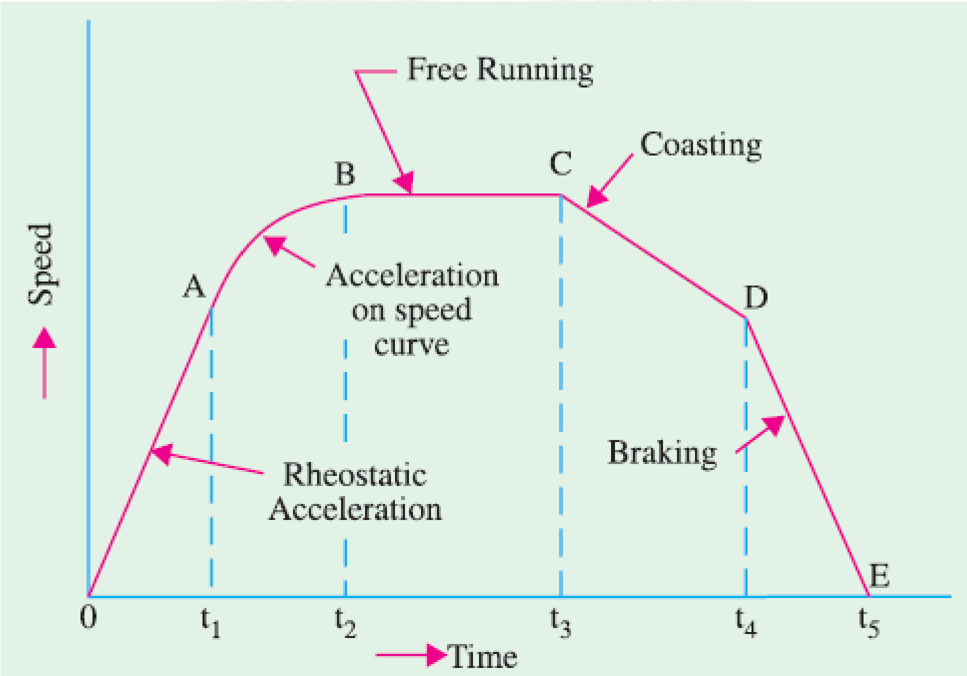

Figure 4.3.1 Driving mechanism of electric locomotives

[Source: "A Textbook of Electrical Energy" by B.L.Theraja, Page: 1711]

Speed-time curve mainly consists of

1) Initial acceleration

(a) Constant acceleration or acceleration while notching up and

(b)Speed curve running or acceleration on the speed curve

1. Acceleration period or Notching up period (0 to t_2):

From starting to the stage when locomotive attains maximum speed, the period is known as acceleration period, as the vehicle is constantly accelerated. This is represented by OA portion of the curve and time duration is t_1. During this period of run (0 to t_1), starting resistance is gradually cut so that the motor current is limited to a certain value and the voltage across the motor is gradually increased and the traction motor accelerates from rest. To cut the starting resistance, the starter handle has to be moved from one notch to another. Hence this period is called notching up period. The acceleration is almost uniform during this period. Now the torque decreases and speed increases according to the speed torque characteristics of the motor. Now the acceleration gradually decreases with the increase in speed and finally reaches the required torque for the movement of the train (at time t_2).

2. Free running period (t_2 to t_3):

During this period i.e. t_2 to t_3 the power supplied to the motor is at full voltage and speed of this period is constant, also during this period. Power drawn from the supply is constant. During this period the motor develops enough torque to overcome the friction and wind resistance and hence the locomotive runs at constant speed. This is shown by the portion AB of the curve.

3. Coasting (t_3 to t_4):

At the end of free running period supply to the motor is cut off and the train is allowed to run under its own kinetic energy. Due to train resistance speed of the train gradually decreases. The rate of decreasing of speed during this period is known as “coasting retardation”. When the locomotive is running at certain speed, if the motor is switch off, due to inertia the vehicle will continue to run, of course with little deceleration due to friction and windage.

4. Braking (t_4 to t_5):

At the end of coasting period the brakes are applied to bring the train to stop. During this period speed decreases rapidly and finally reduces to zero. The locomotive is retarded to stop it within short distance and at a particular spot. The shape of the curve will change depending upon the distance between consecutive stations. It is the curve drawn between speed of train in km/hour along y-axis and time in seconds along x-axis. The speed time curve gives complete information of the motion of the train. This curve gives the speed at various times after the start and run directly. The distance travelled by the train during a given interval of time can be obtained by determining the area between the curve and the time axis corresponding to this interval.

TYPES OF SERVICES

There are three types of electric traction services.

1. Main line service
2. Sub-urban service
3. Urban service

Speed – Time curve for suburban service

In this type of services, the distance between two successive stations is in the range of 1.5 km to 8 km. Figure represents speed-time curve for sub-urban service. Acceleration and braking retardation required are high. Free running period is not possible and coasting period will be comparatively longer than urban service.

Speed – Time curve for urban or city service

In city service the distance between the two stations is very short i.e., between 0.75 to 1 km. The time required for this run between the adjacent and retardation should be sufficient high. Fig shows the speed-time curve for urban or city service. It will be seen that there will be no free running period. The coasting period is also small.

MECHANICS OF TRAIN MOVEMENT

Essential driving mechanism of an electric locomotive is shown in figure 4.3.2.

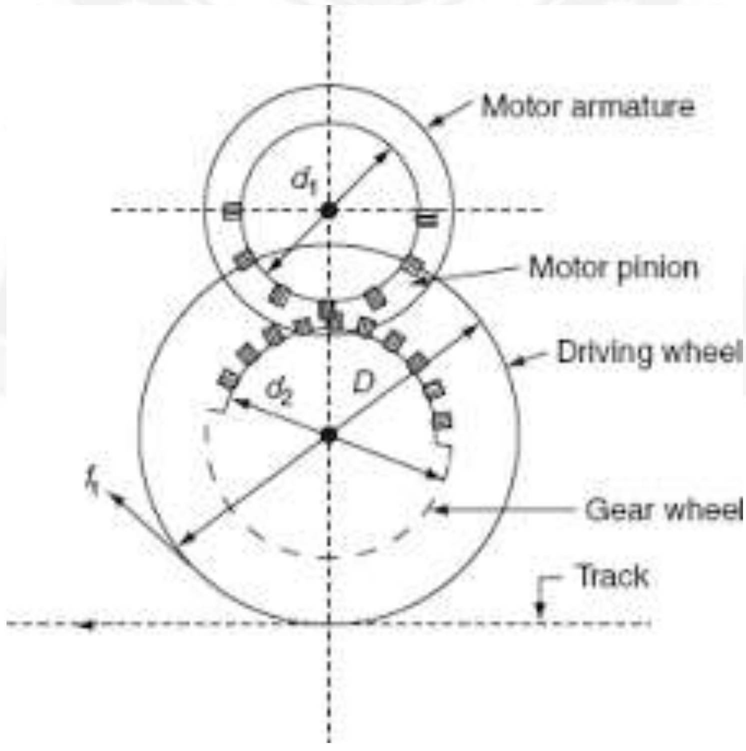

Figure 4.3.2 Driving mechanism of electric locomotives

[Source: "Generation and Utilization of Electrical Energy" by Sivanagaraju, Balasubba Reddy, Srilatha, Page: 499]

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. The armature of the driving motor has a pinion diameter ‘d’ attached to it. The tractive effort at the edge of the pinion is transferred to the driving wheel by means of a gear wheel.

Torque developed by the motor,

$$T = F_p \times \frac{d_1}{2}, (Nm)$$

Tractive effort at the edge of the pinion,

$$F_p = \frac{2T}{d_1}, (N)$$

Tractive effort at the edge of the pinion transferred to the wheel of locomotive,

$$F_t = \eta F_p \times \frac{d_2}{D}, (N)$$

$$F = \frac{2\eta T}{D}\left(\frac{d_2}{d_1}\right) = \frac{2\eta Tr}{D}, (N)$$

where, T is the torque exerted by the driving motor in Nm, d is the diameter of gear wheel in metres, D is the diameter of driving wheel in metres, η is the transmission efficiency and r is the gear ratio which is equal to d_2/d_1. For obtaining train motion without slipping tractive effort F should be less than or at the most equal to μW where μ the coefficient of adhesion between the wheel is and the track and W is the weight of the train on the driving axles (called the adhesive weight).

TRACTIVE EFFORT

The effective efforts required to run a train on track are:

- ➔ Tractive effort needed to provide acceleration, (F_a)
- ➔ Tractive effort needed to overcome the train resistance (F_r)
- ➔ Tractive effort needed to overcome gradients (F_g)

Tractive effort required for acceleration (F_a):

$$Force = mass \times acceleration$$

$$F = ma$$

$$Mass\ of\ train, m = 1000\ Wkg$$

$$Acceleration = \alpha, \left(\frac{\frac{km}{hr}}{sec} \right) = \alpha \times \frac{1000}{3600}, \left(\frac{m}{s^2} \right) = 0.2778\alpha, \left(\frac{m}{s^2} \right)$$

Tractive effort required for linear acceleration,

$$F_a = 1000W \times 0.2778\alpha = 277.8W\alpha, (N)$$

When a train is accelerated in a linear direction, its rotating parts like the wheels and armature 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. The accelerating weight (W_e) is much higher (about 8-15%) than the dead weight (W) of the train.

Tractive effort required for linear and angular acceleration,

$$F_a = 277.8W_e\alpha, (N)$$

Tractive effort required to overcome the train resistance (F_r):

While moving, the train has to overcome the opposing force due to the surface friction and wind resistance. The train resistance depends upon various factors such as shape, size, condition of track etc.

Tractive effort required to overcome the train resistance,

$$F_r = W \times r, (N)$$

where W – dead weight of the train in ton, r is the specific train resistance in N/ton of the dead weight.

Tractive effort required to overcome gradients (F_g):

Consider that an electric train is moving upwards on a slope. The dead mass of the train along the slope will tend to bring it downward. To overcome this effect of gravity, tractive effort is required in opposite direction.

Tractive effort to overcome the effect of gravity,

$$F_g = \pm Mg \sin\theta = \pm\ 1000Wg \sin\theta, (N)$$

where, g is the acceleration due to gravity = 9.81 m/sec^2, θ is the angle of slope.

$$F_g = \pm 1000W \times 9.81 \sin\theta, (N)$$

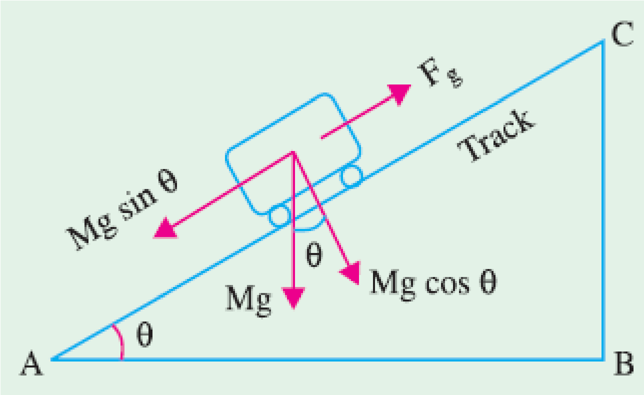

Figure 4.3.3 Train moving on up-gradient

[Source: "Generation and Utilization of Electrical Energy" by Sivanagaraju, Balasubba Reddy, Srilatha, Page: 501]

In railway practice, the gradient is expressed in terms of rise or fall in every 100 m of track and it is denoted by G %. From figure 4.3.3, we get,

$$Gradient, G = \sin\theta = \frac{BC}{AC} = \frac{Elevation}{distance\ along\ the\ track}$$

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

$$F_g = \pm 1000W \times 9.81 \times \frac{G}{100} = \pm 98.1WG, (N)$$

Positive sign is to be used for up-gradient and negative sign for down-gradient.

The total tractive effort required for the propulsion of train,

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

$$F_t = 277.8W_e\alpha + Wr \pm 98.1WG, (N)$$