المحاضرة الثانية:

Tractive Effort and Tractive Resistance

Tractive Effort

If the rear wheels of the vehicle in fig. (1) are driven with no slip taking place between the tyres and the level road surface, the propelling force or tractive effort (T_E) is equal to the torque at the driven wheels (T_r) divided by either leverage, which is termed the rolling radius or effective radius (r):

$$T_r = Tnfe \text{ and } \frac{Tnfe}{r} = TE\ N$$

where T_r is the torque at the roadwheels (N m); T the engine torque (N m); n the gear box ratio; f the final drive ratio; e the transmission efficiency; r the rolling radius of the roadwheels (m) and T_E the tractive effort or propelling force (N).

If the rear wheels have such a torque applied to them that they are no the point of slipping in the plane of the wheel, then the value of the frictional or adhesive force between tyre and road surface has been reached (μW_r N or μ, mg N). Under these conditions the engine torque has reached the aximum result in wheel slip and lower acceleration. Static friction is higher than kinetic friction.

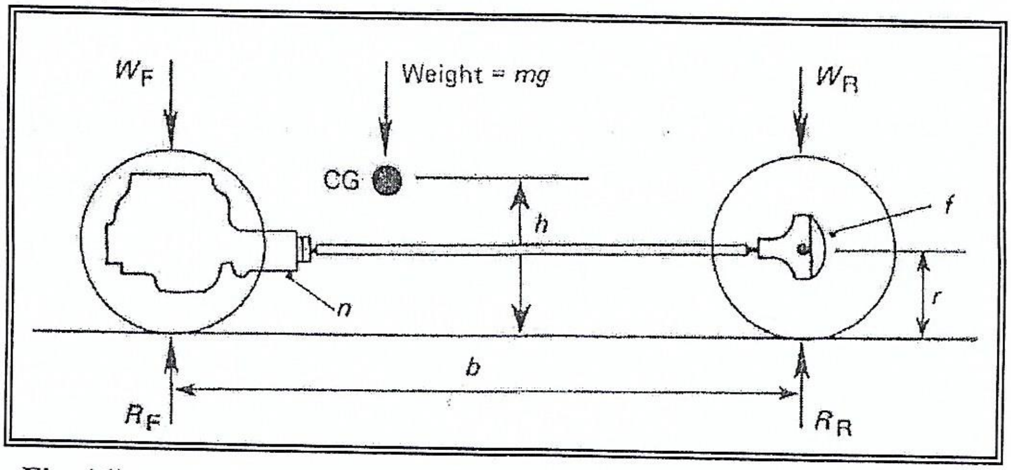

Fig. (1)

When a vehicle is under acceleration some vertical loading is lost from the front and passed to the rear, thus front wheel drive vehicles would be at a slight disadvantages.

When tractive effort TE is equal to the tractive resistance TR a vehicle would be either stationary or moving at a uniform velocity. If the tractive effort exceeds the resistance the vehicle will accelerate until the tractive effort once again equals the tractive resistance. It follows that if the tractive resistance becomes greater than the tractive effort, the vehicle will decelerate and come to rest unless the tractive effort is increased or the resistance reduced.

Torque at the roadwheels $T_r = Tnfe \ Nm$

Tractive effort at the roadwheels $TE = \frac{T_r}{r}$

Power at the roadwheels $(W) P_r = P_b e$

$$= \frac{T 2\pi N}{60} e$$

$$= \frac{TE \times km/h}{3.6} (1 km/h = 3.6 m/s)$$

$$= TE \times v (v = velocity\, m/s)$$

If the transfer of weight is not considered at this stage then the maximum possible tractive effort can be applied without wheel slip must equal the adhesive force, which is dependent on the vertical loading on the driven wheels and the acceleration between tyres and road surface.

Maximum TE = $\mu m g r$ N for rear wheel drive

Maximum TE = $\mu m g f$ N for front wheel drive

★ A useful formula connects engine speed, gearbox and final drive ratio with the size of the road wheels is as follows.

$$engine \ \ rev/\min = \frac{dis\tan ce \ \ moved \ \ (m/\min) \ \ nf}{circumfere\ nce \ \ of \ \ roadwheels \ \ (m)}$$

$$= \frac{1000 \times km/h \times nf}{60 \times 2\pi\ r} = \frac{2.652 \times km/h \times nf}{r}$$

$$rev/\min \ \ of \ \ the \ \ roadwheels \ \ N_r = \frac{engine \ \ rev/\min}{overall \ \ reduction \ \ ratio}$$

$$= \frac{N}{nf}$$

$$(\frac{1000}{2\ \pi\ 60} = 2.652\ ;\ 2\ \pi\ 60/1000 = 0.377)$$

Tractive Resistance

The three resistances that a vehicle has to overcome are rolling (R_r) gradient (R_g) and air resistance (R_a). The rolling resistance will always apply when a vehicle is moving increasingly effective. If at the same time the vehicle was traveling up a gradient this further resistance must be considered. A car traveling a 60 km/h up a gradient would be overcoming the three resistances.

$R_r + R_g + R_a = R_T$ total resistance (N)

1-Rolling resistance

A vehicle moving on a level road with no air resistance would be overcoming bearing and oil seal friction and the churning of the oil in the gearbox and final drive, but the greater part is due to the flattening of the tyres at the road surface. the flattening produces a resisting torque and so reduces the effective propelling force. A simple example will prove the point.

$R_r = \mu F$

Worked Examples

A wheel of 0.5 m radius carries a vertical loading of 5000 N. a torque of 1000 N m is applied to the wheel. Determine (*a*) the tractive effort available with no flattening of the tyre, and (*b*) when the tyre has flattened 0.24 m.

$$(a)\ TE = \frac{T_r}{r} = \frac{1000}{0.5} = 2000\ N$$

(*b*) resisting torque = $\frac{1}{2}$ flattening distance × vertical loading

$$= \tfrac{1}{2} \times 0.24 \times 5000 = 600 \text{ N m}$$

$$\text{Lost } T_E = \frac{resisting\ torque}{r} = 600/0.5 = 1200\,N$$

Effective TE = 2000 – 1200 = 800 N

which represents a loss of 60% effective propelling force.

The steel rail and tyre used for railway rolling stock create very little flatting of tyre and rail so the motion is almost entirely a rolling one. A 20 tonne truck on level rails could be moved by a force of only 900 N. to be accurate, the rolling resistance does increases as the vehicle speed increases, but the increases is so small that it is neglected in most applications.

2-Gradient Resistance

The incident plane or gradient is one of the oldest machines in existence. Neglecting surface conditions and rolling resistance, a gradient or incline of 1 in 100 (*movement ratio*) would require a force of only 100^{th} the weight of the vehicle to pull or push it up the slope. After moving 100 m on the road surface the vehicle would have been lifted vertically against gravity 1 m, and the work done along the road equal the work done against gravity.

Consider Fig. (2)

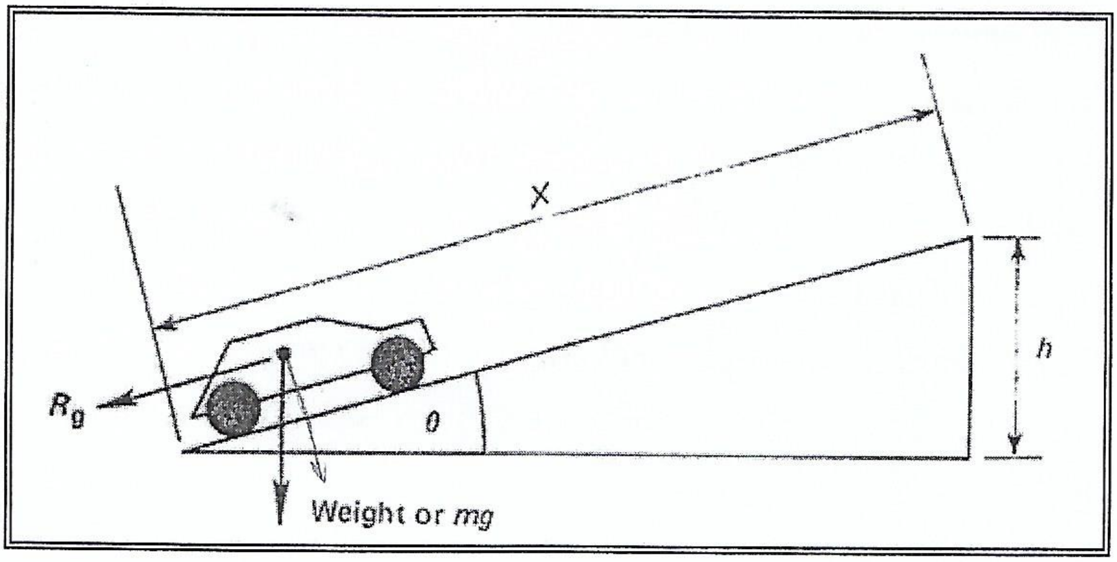

Fig. (2)

work done along surface = work done against gravity

$$R_g X = mgh$$

gradient resistance $$R_g = \frac{mgh}{X} = \frac{mg \times 1}{X} \quad as \; h = 1$$

$$\sin\,\theta = \frac{h}{X} = \frac{1}{X}$$

therefore

$$R_g = mg\ \sin\,\theta$$

A vehicle at rest at the top gradient when the breaks are released will accelerate down the gradient with an accelerating force equal to that of the gradient resistance minus rolling resistance and the increasing air resistance.

3-Air Resistance

At road speed in excess of approximately 50km/h conditions are changing. Engine torque is falling and air resistance is building up in proportion to the square of the air speed over the vehicle; twice the speed, four times the resistance. The air or wind resistance R_a depends upon the shape of the vehicle and its cross – sectional frontal area. The shape is given in terms of a streamline constant (K) and the cross-sectional frontal area (A) in square meters (m^2). The velocity of the air passing over the vehicle is v m/s. Thus

$$R_a = KAv^2 \quad \text{N force}$$

where K is the force in Newton for 1 m^2 of frontal area at an air speed of 1 km/h, A the total cross-sectional frontal area (m^2), and v the velocity of the air passing over the vehicle.

All three resistances are shown plotted on a velocity base in Fig. (3).