ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY

24AG401 THEORY OF MACHINES

UNIT V NOTES

Balancing of Reciprocating Masses

the various forces acting on the reciprocating parts of an engine. The resultant of all the forces acting on the body of the engine due to inertia forces only is known as unbalanced force or shaking force. Thus if the resultant of all the forces due to inertia effects is zero, then there will be no unbalanced force, but even then an unbalanced couple or shaking couple will be present. Consider a horizontal reciprocating engine mechanism as shown in Figure.

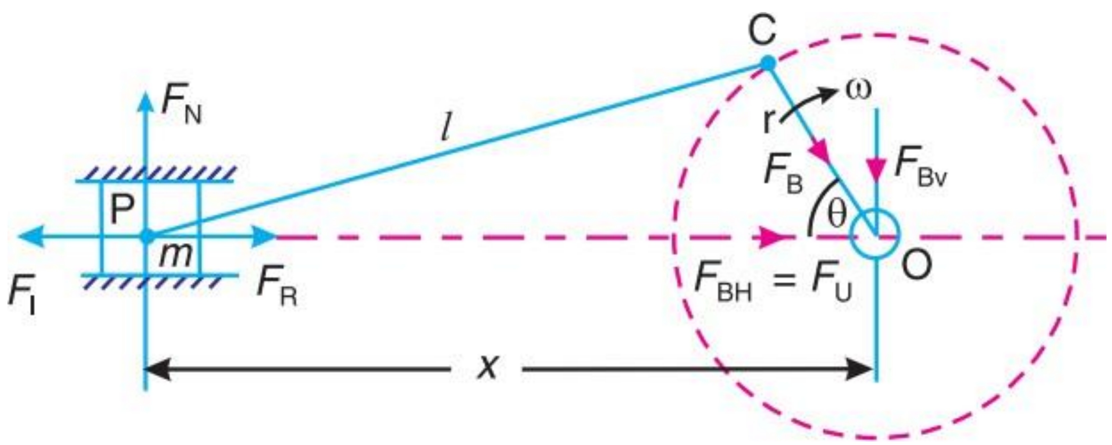


Figure: Balancing of Reciprocating mass

FI = Inertia force due to reciprocating parts, FN = Force on the sides of the cylinder walls or normal force acting on the cross-head guides, and FB = Force acting on the crankshaft bearing or main bearing. Since FR and FI are equal in magnitude but opposite in direction, therefore they balance each other. The horizontal component of FB (i.e. FBH) acting along the line of reciprocation is also equal and opposite to FI . This force FBH = FU is an unbalanced force or shaking force and required to be properly balanced.

The force on the sides of the cylinder walls (FN) and the vertical component of

FB (i.e. FBV) are equal and opposite and thus form a shaking couple of magnitude FN × x or FBV × x. From above we see that the effect of the reciprocating parts is to produce a shaking force and a shaking couple. Since the shaking force and a shaking couple vary in magnitude and direction during the engine cycle, therefore they cause very objectionable vibrations. Thus the purpose of balancing the reciprocating masses is to eliminate the shaking force and a shaking couple. In most of the mechanisms, we can reduce the shaking force and a shaking couple by adding appropriate balancing mass, but it is usually not practical to eliminate them completely. In other words, the reciprocating masses are only partially balanced. Note : The masses rotating with the crankshaft are normally balanced and they do not transmit any unbalanced or shaking force on the body of the engine.

Primary and Secondary Unbalanced Forces of Reciprocating Masses

Consider a reciprocating engine mechanism as shown in Figure

Let m = Mass of the reciprocating parts, l = Length of the connecting rod PC,

r = Radius of the crank OC,

θ = Angle of inclination of the crank with the line of stroke PO,

ω = Angular speed of the crank,

n = Ratio of length of the connecting rod to the crank radius = l / r.

∴ Inertia force due to reciprocating parts or force required to accelerate the reciprocating parts,

$$F_I = F_R = \text{Mass} \times \text{acceleration} = m \cdot \omega^2 \cdot r\left(\cos\theta + \frac{\cos 2\theta}{n}\right)$$

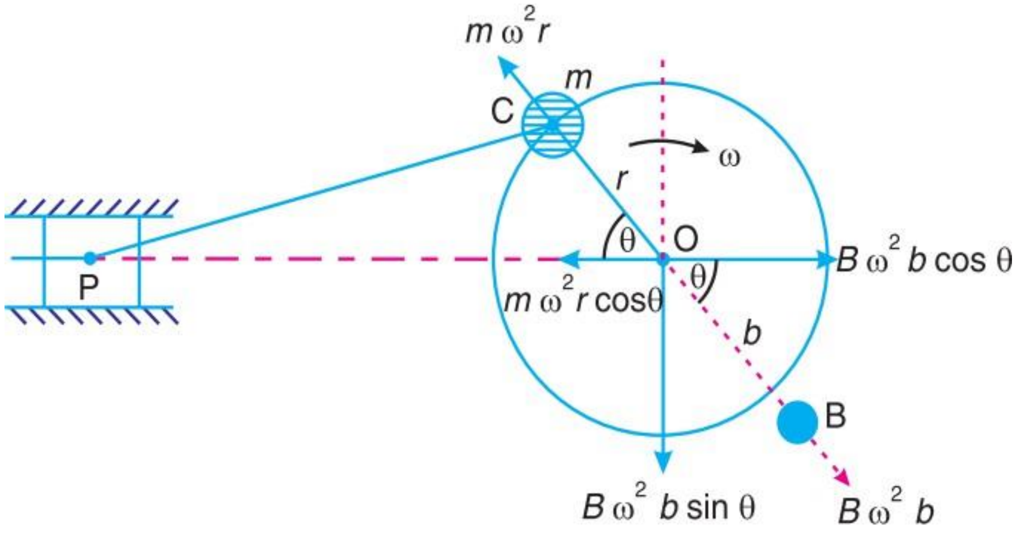
We have discussed in the previous article that the horizontal component of the force exerted on the crank shaft bearing (*i.e.* F_{BH}) is equal and opposite to inertia force (F_I). This force is an unbalanced one and is denoted by F_U.

∴ Unbalanced force,

$$F_U = m \cdot \omega^2 \cdot r\left(\cos\theta + \frac{\cos 2\theta}{n}\right) = m.\omega^2 \cdot r\cos\theta + m \cdot \omega^2 \cdot r \times \frac{\cos 2\theta}{n} = F_P + F_S$$

Partial Balancing of Unbalanced Primary Force in a Reciprocating Engine

The primary unbalanced force 2 (cos) m r ·ω · θ may be considered as the component of the centrifugal force produced by a rotating mass m placed at the crank radius r, as shown in Figure.



The primary force acts from O to P along the line of stroke. Hence, balancing of primary force is considered as equivalent to the balancing of mass m rotating at the crank radius r. This is balanced by having a mass B at a radius b, placed diametrically opposite to the crank pin C. We know that centrifugal force due to mass B.

$$= B \cdot \omega^2 \cdot b$$

nd horizontal component of this force acting in opposite direction of primary force

$$= B \cdot \omega^2 \cdot b \cos\theta$$

The primary force is balanced, if

$$B \cdot \omega^2 \cdot b \cos\theta = m \cdot \omega^2 \cdot r \cos\theta \quad \text{or} \quad B.b = m.r$$

A little consideration will show, that the primary force is completely balanced if B.b = m.r, but the centrifugal force produced due to the revolving mass B, has also a vertical component (perpendicular to the line of stroke) of magnitude B ω b ^{2}·sin θ . This force remains unbalanced. The maximum value of this force is equal to 2 B b ·ω · when θ is 90° and 270°, which is same as the maximum value of the primary force m^2 r ·ω · .

From the above discussion, we see that in the first case, the primary unbalanced force acts along the line of stroke whereas in the second case, the unbalanced force acts along the perpendicular to the line of stroke. The maximum value of the force remains same in both the cases. It is thus obvious, that the effect of the above method of balancing is to change the direction of the maximum unbalanced force from the line of stroke to the perpendicular of line of stroke.

As a compromise let a fraction ‘c’ of the reciprocating masses is balanced, such that c.m.r = B.b

Problem

A single cylinder reciprocating engine has speed 240 r.p.m., stroke 300 mm, mass of reciprocating parts 50 kg, mass of revolving parts at 150 mm radius 37 kg. If twothird of the reciprocating parts and all the revolving parts are to be balanced, find : 1. The balance mass required at a radius of 400 mm, and 2. The residual unbalanced force when the crank has rotated 60° from top dead centre.

Solution.

Given : N = 240 r.p.m. or ω= π× 2 240 / 60 = 25.14 rad/s ; Stroke = 300 mm = 0.3 m; m = 50 kg ; m1 = 37 kg ; r = 150 mm = 0.15 m ; c = 2/3.

1. Balance mass required.

Let B = Balance mass required, and

b = Radius of rotation of the balance mass = 400 mm = 0.4 m . . . (Given)

We know that

$$B.b = (m_1 + c.m)\, r$$

$$B \times 0.4 = \left(37 + \frac{2}{3} \times 50\right) 0.15 = 10.55 \quad \text{or} \quad B = 26.38 \text{ kg}.$$

2. Residual unbalanced force

Let θ = Crank angle from top dead centre = 60°

We know that residual unbalanced force

$$= m \cdot \omega^2 \cdot r \sqrt{(1-c)^2 \cos^2\theta + c^2 \sin^2\theta}$$

$$= 50(25.14)^2\, 0.15 \sqrt{\left(1-\frac{2}{3}\right)^2 \cos^2 60° + \left(\frac{2}{3}\right)^2 \sin^2 60°} \text{ N}$$

$$= 4740 \times 0.601 = 2849 \text{ N}$$