

UNIT-II

TURNING MOMENT DIAGRAM & FLYWHEELS

INTRODUCTION:-

The turning moment diagram is also known as crank effect diagram. It is graphical representation of turning moment or crank effect for various position of the crank.

PISTON EFFECT:-

The net force acting on the piston along the line of stroke is called as the piston effect. In case of horizontal engine (reciprocating engine) it will be the algebraic sum of inertia force & net load on the piston $F(P) = F(CL) + P(C)$

where $F(CL)$ = piston load

$P(C)$ = piston inertia force

when +ve sign is the case when piston is accelerated +ve sign when -ve sign is the case when piston is retarded.

is case when it is retarding.

CRANK PIN EFFECT OR CRANK EFFECT:

It is the net effect applied at the crank pin to the crank which shaft. The components of force acting along the connecting rod to the crank is known as the crank pin effect or crank effect.

ENGINE FORCE ANALYSIS:-

An engine is acted upon by various forces such as weight of reciprocating masses & connecting rod, gas, forces, forces due to friction & inertia forces due to acceleration & retardation of engine elements, the last being dynamic in nature. In this section the analysis is made of the forces neglecting the effect of the weight.

R-Plane

* the Inertia Effect of the connecting rod.

INERTIA FORCE IN RECIPROCATING ENGINES

GRAPHICAL METHOD:-

The inertia forces in reciprocating engines can be obtained graphically as follows:

→ Draw the acceleration diagram by Klein's construction. Remember that the acceleration diagram is turned through 180° from the actual diagram & therefore the directions of accelerations are towards "O".

→ Replace the mass of the connecting rod by a dynamically equivalent system of two masses. If one mass is placed at B, the other will be at D given by $d = k^2/b$, where

k is the radius of gyration & b is the distance of the centre of the mass from B & D respectively.

Point D can also be obtained graphically. Draw $AB \perp AB$ at point C. Make $\angle BCD = 90^\circ$ & obtain the point D on AC .

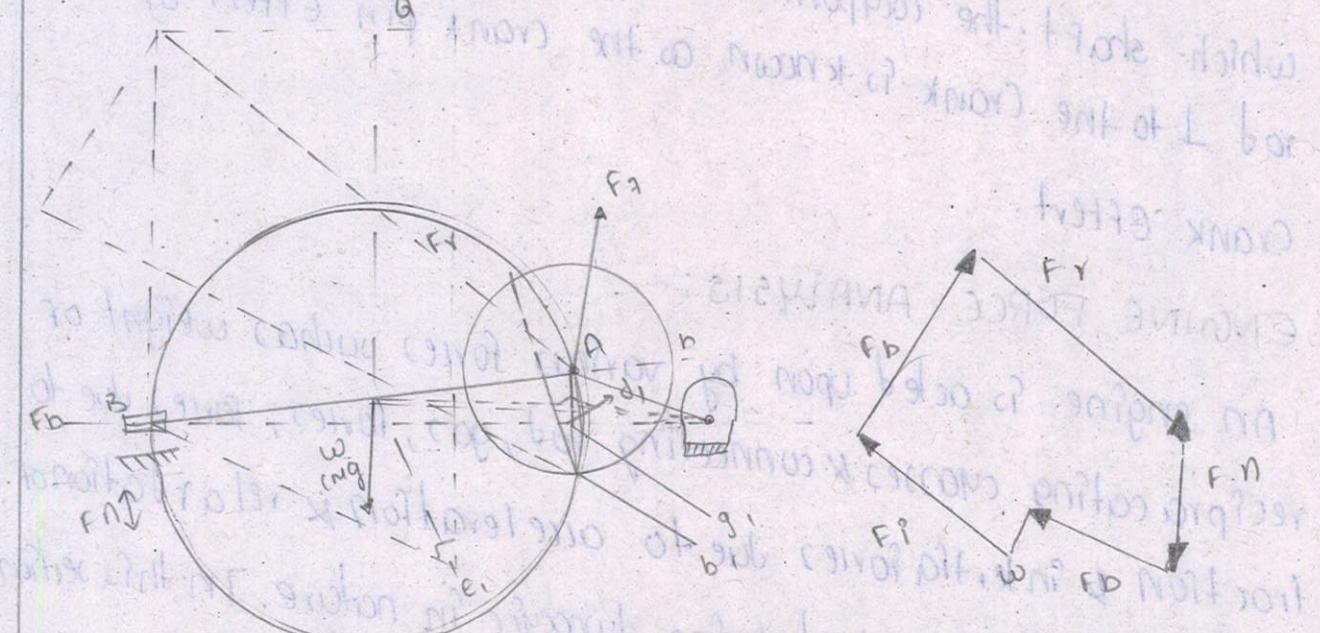


Figure (a)

Figure (b)

→ obtain the acceleration of points C & D from the acceleration diagram by locating the points g_1 & d_1 on AB, which represents the total acceleration of the connecting rod.

→ As A_1 , L_1 & A_2 , L_2 are equal to AB , $AB \parallel O_1O_2$ & O_1O_2 is drawn parallel to O_1B , thus J_1O_2 & g_1O_2 represent acceleration of points D & C respectively.

→ the acceleration of the crank of B is along B_1O_2 & in the direction $B \rightarrow O_2$. therefore, the inertia force due to this mass acts in the opposite direction.

→ the acceleration of the crank of D is H_1O_2 & in the direction $D_1 \rightarrow O_2$, therefore, the inertia force due to this mass acts in the opposite direction through D. Draw a line $ll \perp O_1O_2$ through D to represent the direction of the inertia force.

To represent the direction of the two inertia forces due to let the lines of action of the two inertia forces which masses at B & D meet at L. then the resultant of the force which is the total inertia force of the connecting rod $\& g_1ll \perp O_1O_2$, must also pass through the point L. therefore, draw a line $ll \perp O_1O_2$ through L to represent the direction of the inertia force of

the connecting rod.

Now, the connecting rod is under the action of the following forces:

- Inertia force of reciprocating part F_r along OB
- Inertia force of the guide F_n (magnitude & direction unknown)
- the reaction of the connecting rod if it is rigid (neglect)
- the weight of connecting rod $w = cu g$
- tangential force F_t at the crank pin (to be found).

• Radial force F_r at the crank pin along OA.
 produce the lines of action of F_r & F_n to meet at I, the instantaneous centre of the connecting rod.
 Draw IP & IZL to the lines of action of F_r & the weight (w) respectively.
 For the equilibrium of the connecting rod, taking moment about I,

$$F_t \times IA = F_D \times IB + F_r \times IP + Mg \times IZL$$

 obtain the value of F_t from it & draw the force polygon to find the magnitude & directions of forces F_r & F_n .
 If it indicates clockwise torque, then insert torque on the crank shaft $= F_t \times r_0$ counter clockwise.

TURNING MOMENT DIAGRAMS:
 During one revolution of the crank shaft of an IC engine or IC engine, the torque on it varies & is given by

$$T = F_t \times r$$

$$T = F_r [\sin \theta + \frac{2 \sin \theta}{\sqrt{n^2 - \sin^2 \theta}}]$$

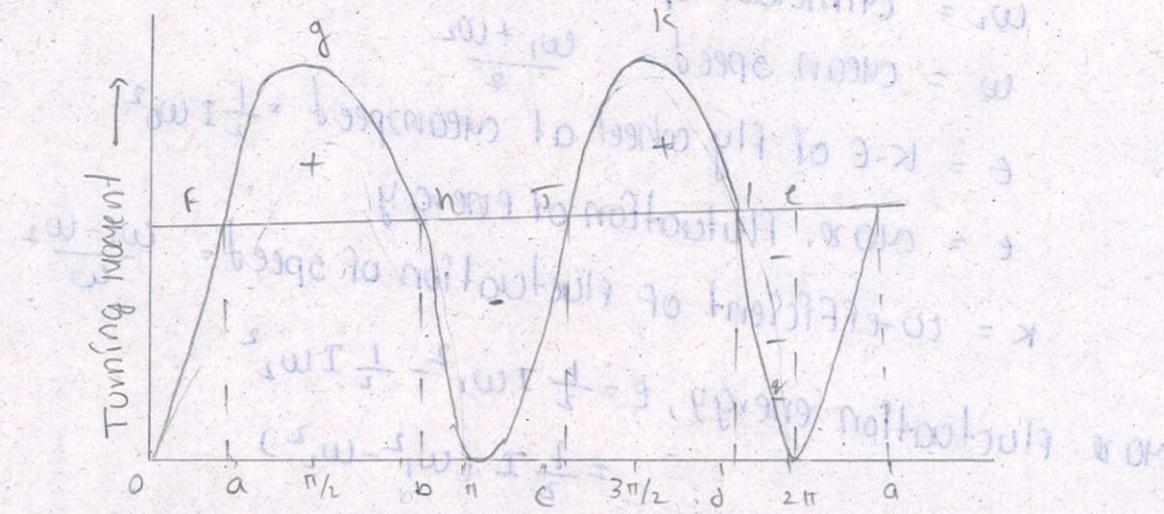
where, F_r is the net piston effort

A plot of T vs. θ is known as the turning moment diagram. The inertia effect of the connecting rod is usually ignored while drawing these diagrams, but can be taken into account if desired.

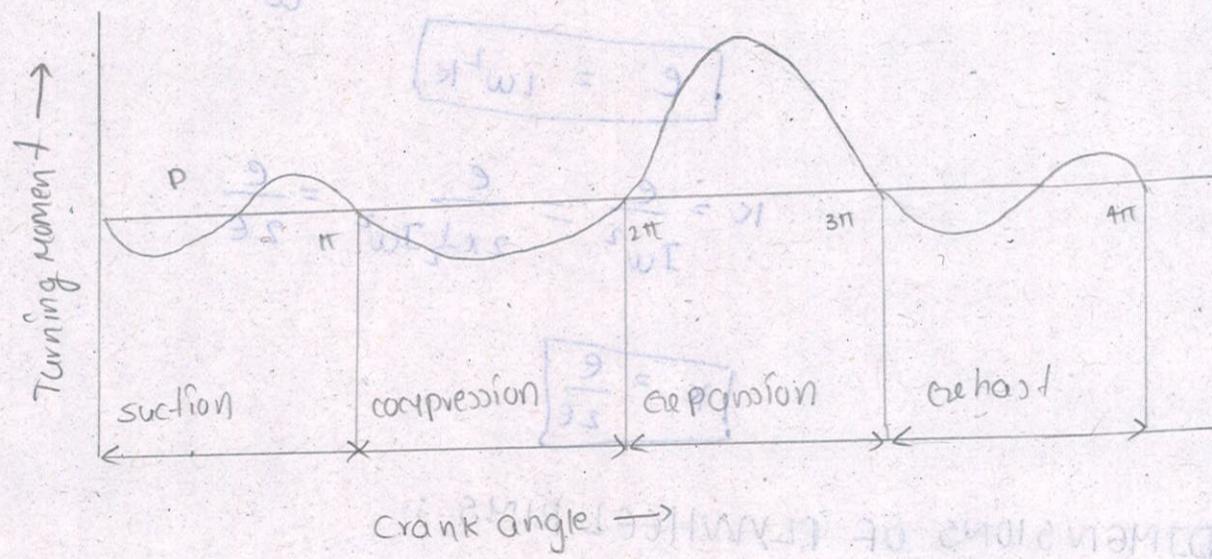
As $T = F_t \times r$, a plot of F_t vs. θ (known as crank effort diagram) is identical to a turning moment diagram.

The turning moment diagram for different types of engines are being given below.

1. SINGLE - CYLINDER DOUBLE-ACTION STEAM ENGINE



2. SINGLE CYLINDER FOUR-STROKE ENGINE



FLY WHEELS :

A fly wheel is used to control the variations in speed during each cycle of an engine. A fly wheel of suitable dimensions attached to the crank shaft make the moment of inertia of rotating parts quite large & thus, acts as a reservoir of energy. During the periods when the supply of energy is more than required, it stores energy & during the periods the requirements is more than the supply, it releases energy.

Let, I = moment of inertia of fly wheel

ω_1 = max. speed

ω_2 = minimum speed

ω = mean speed = $\frac{\omega_1 + \omega_2}{2}$

$e = K \cdot E$ of fly wheel at mean speed = $\frac{1}{2} I \omega^2$

$e = m o r. \text{ fluctuation of energy}$

$K = \text{coefficient of fluctuation of speed} = \frac{\omega_1 - \omega_2}{\omega}$

M.W. fluctuation energy, $e = \frac{1}{2} I \omega_1^2 - \frac{1}{2} I \omega_2^2$

$$= \frac{1}{2} I (\omega_1^2 - \omega_2^2)$$

$$= I \left(\frac{\omega_1 + \omega_2}{2} \right) (\omega_1 - \omega_2)$$

$$= I \omega (\omega_1 - \omega_2)$$

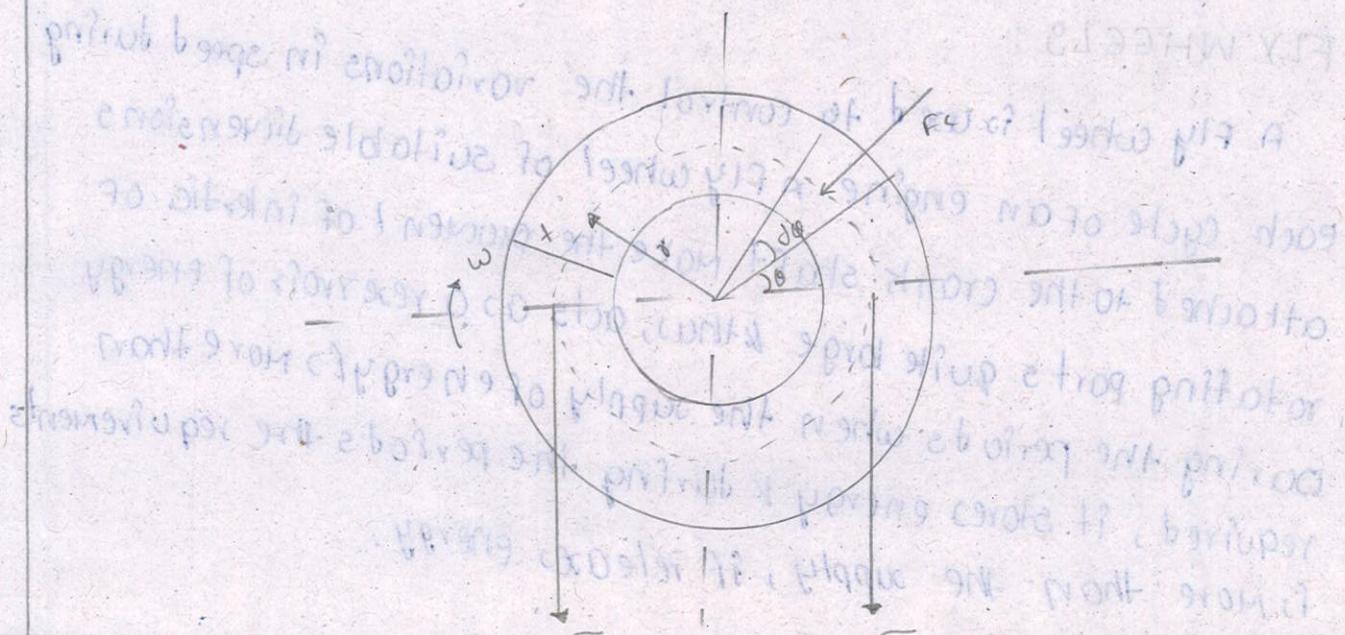
$$= I \omega^2 \left(\frac{\omega_1 - \omega_2}{\omega} \right)$$

$$\boxed{e = I \omega^2 K}$$

$$K = \frac{e}{I \omega^2} = \frac{e}{2 \times \frac{1}{2} I \omega^2} = \frac{e}{2 e}$$

$$\boxed{K = \frac{e}{2 e}}$$

DIMENSIONS OF FLYWHEEL RIMS :-



the inertia of a fly wheel is provided by the hub, spokes & the rim however, as the inertial due to the hub & the spokes is very small, usually it is ignored. In case it is known, it can be taken into account.

Consider a ray of the fly wheel

Let ω = angular velocity

r = mean radius

t = thickness of the rim

ρ = density of the material of rim

Consider a element of the rim

centrifugal force on the element / unit length

$$= [\rho (r \cdot \omega^2) t] r \cdot \omega^2$$

Total vertical force / unit length

$$= \int_0^\pi \rho r^2 d\theta \cdot \omega^2 + \omega^2 \sin \theta$$

$$= \rho \cdot r^2 + \omega^2 \int_0^\pi \sin \theta d\theta$$

$$= \rho r^2 + \omega^2 [(-\cos \theta)]_0^\pi$$

$$= 2\rho r^2 + r^2 \omega^2$$

Let σ = circumferential stress induced in the rim

[Circumferential stress is also known as hoop stress]

$$\text{Then for equilibrium } \sigma = 2 \int r^2 d\omega^2$$

$$\sigma = \rho \cdot r^2 \omega^2 = \rho r^2 \quad \text{--- (ii)}$$

$$\boxed{\sigma = \rho r^2}$$

The above relation provides the resulting tangential velocity at the mean radius of the rim of the fly wheel.

then the diameter can be calculated from relation

$$D = \pi d N / 160 \text{ mm rev/min forward } \rightarrow D = \frac{\pi d N}{160}$$

$$\text{also, } M = \text{density} \times \text{volume} \times \text{circumference} \times \text{area of cross-section}$$

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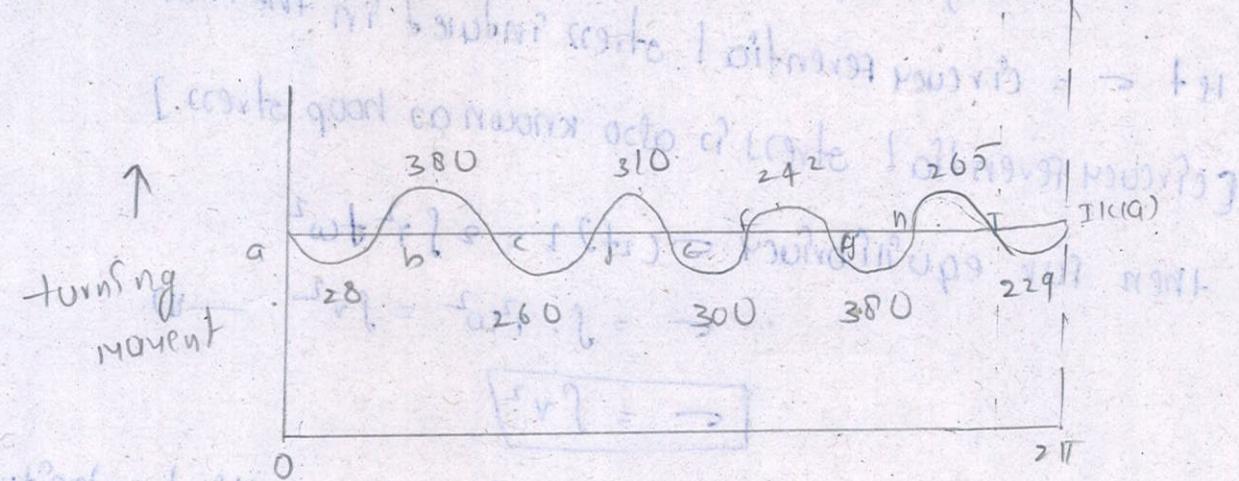
$$M = \pi d^2 b t \quad (2)$$

The relation can be used to find the width and the thickness of the ring.

The turning moment diagram for a multicylinder engine has been drawn to a vertical scale of $1 \text{ MM} = 650 \text{ NM}$ & horizontal scale of $1 \text{ MM} = 4.5^\circ$. The area above & below the mean torque line are $-28, +380, -260, +310, -300, +242, -380, -265 \text{ & } -229 \text{ MM}^2$

The fluctuation of speed is considered to $\pm 1.8\%$ of the mean speed which is 400 RPM . The density of the rim material is 7000 kg/m^3 & width of the ring is 4.5 mm & its thickness is 2 mm .

The centrifugal stress (hoop) in the rim material is required to 6 N/mm^2 . Neglecting the effect of the boss arms, determine the dia. & cross section of the fly wheel ring.



Angular velocity $\omega = \frac{2\pi f}{60} = \frac{\pi}{30} \text{ rad/s}$

$$\rho = 7000 \text{ kg/m}^3$$

$$N = 400 \text{ rpm}$$

$$c = 6 \times 10^6 \text{ N/m}^2$$

$$K = 0.018 + 0.018 = 0.036$$

$$D = 4.5 \text{ m}$$

$$c = \rho v^2 \Rightarrow v = \frac{6 \times 10^6}{7000} \text{ m/s}$$

$$v = 29.28 \text{ m/s (or)}$$

$$v = \frac{\pi D n}{60} = \frac{\pi \times 4 \times 400}{60} = 29.28 \text{ m/s}$$

$$d = 1.398 \text{ m}$$

let the flywheel k go at $a = e$

$$b = e - 28$$

$$c = e - 28 + 380 = e + 352$$

$$d = e + 352 - 260 = e + 92$$

$$e = e + 92 + 310 = e + 402$$

$$f = e + 402 - 300 = e + 102$$

$$g = e + 102 + 242 = e + 344$$

$$h = e + 344 - 380 = e - 36$$

$$i = e - 36 + 265 = e + 229$$

$$k = e + 229 - 229 = e$$

now energy = $e + 402$

min. energy = $e - 36$

$$P_{\text{ENR}} = (e + 402) - (e - 36) \times \text{horoscopes} \times \text{vert scale}$$

$$= 438 \times \left(4.5 \times \frac{\pi}{180}\right) \times 650$$

$$= 22360 \text{ N.m}$$

$$r = \frac{e}{\pi d^2} = \frac{e}{\pi \times 2.2^2}$$

density \times volume = 724.5

$$\rho \times \pi r^2 \times 4.5t = 724.5 \quad 0.0 = 810.0 + 810.0 = 1620.0$$

$$7000 \times \pi \times 1.398 \times r^2 \times 4.5t = 724.5$$

$$r = 0.0512 \text{ m} \text{ or } 51.2 \text{ mm}$$

$$b = 4.5 \times 51.2$$

$$= 230.3 \text{ mm} \quad 85.0 \times \frac{0.0512 \times \pi}{0.0} = \frac{162\pi}{0.0} = r$$

$$162\pi/1 = 6$$

$$\theta = 0 + 0.3 + 1.060 \text{ rad. sin } 109^\circ$$

$$85 - \theta = 6$$

$$85 + \theta = 98.8 + 85 - \theta = 9$$

$$85 + \theta = 0.05 - 57.8 + \theta = 6$$

$$-50 + \theta = 0.16 + 0.05 + \theta = 6$$

$$-50 + \theta = 0.08 - 50.8 + \theta = 6$$

$$+48 + \theta = -5 + 5 + 50 + \theta = 6$$

$$48 - \theta = 0.08 - 4.08 + \theta = 6$$

$$P_{\text{ext}} + \theta = 0.08 + 0.08 + \theta = 6$$

$$P_{\text{ext}} + \theta = 0.16 + 0.08 + \theta = 6$$

$$\therefore \theta = P_{\text{ext}} + P_{\text{int}} + \theta = 6$$

$$0.08 - \theta = 0.08 \times 0.08 \times 0.08$$

$$d\theta - \theta = 0.08 \times 0.08 \times 0.08$$

$$\text{close } 1.08 \times 0.08 \times 0.08 \times (d\theta - \theta) - (0.08 + \theta) = 0.0049$$

$$0.0049 \left(\frac{\pi}{0.08} \times 0.08 + \theta \right) + 0.08 + \theta = 0.0049$$

$$0.0049 \times 3.14159 \times 0.08 + 0.08 + \theta = 0.0049$$

$$0.0049 \times 3.14159 \times 0.08 = 0.0049$$

$$0.0049 \times 3.14159 \times 0.08 = 0.0049$$