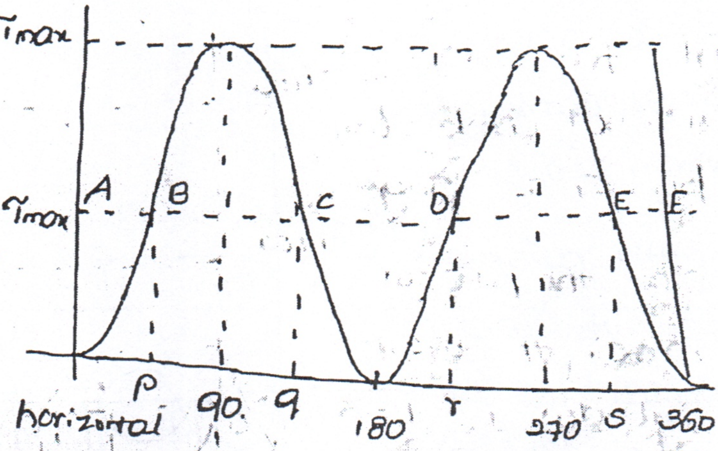
UNIT-III

TURNING MOMENT DIAGRAMS

The turning moment diagram is a graphical representation of crank for various position of crank it is plotted on Cartesian points. In which turning moment taken as ordinate and crank angle taken as absissa.

Turning moment diagram for single cylinder double acting steam engine:-

The turning diagram for single cylinder double acting steam engine shown in fig the vertical line rep turning moment and horizontal line represent crank angle(θ)



$$T = F_P \times r\left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2 - \sin^2\theta}}\right]$$

F_P = piston effort

r = radius of crank

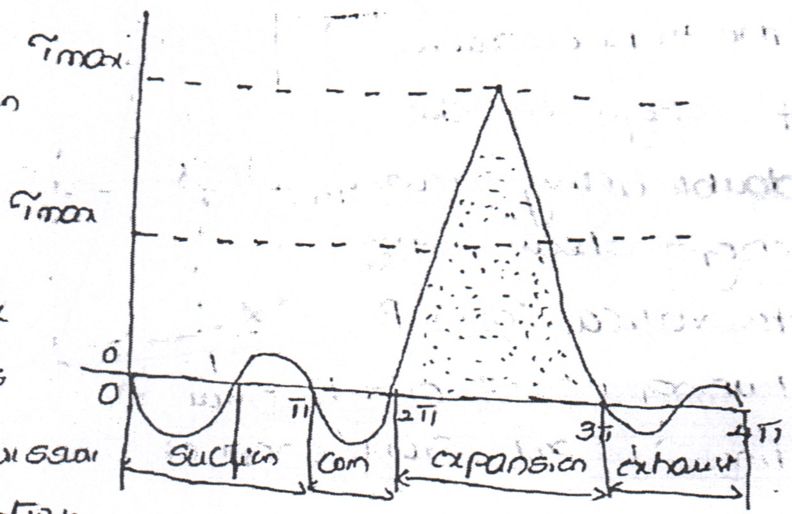
n = radius of connecting rod to radius of crank

θ = angle turn by crank from inner dead centre from above expression will see that turning moment is zero θ=0. it is maximum the crank angle at 90 and it is again zero at 180°. this is shown by a.b.c

since the work done is the product turning moment and crank angle. the area of turning moment diagram the work done per revolution.

turning moment diagram for 4-stroke internal combustion engine:

the four stroke internal combustion having 720° angle since the pressure inside the engine cylinder is less than the atm. pressure during suction stroke. therefore the negative loop is



formed shown in fig. during compression stroke work is done therefore high negative loop is formed during expansion (or) working stroke the fuel burn and gas expand there is a large +ve loop in this flow the work is done by the gass. during exhaust stroke the work is done on the gass. therefore -ve loop is formed

Fluctuation of energy:

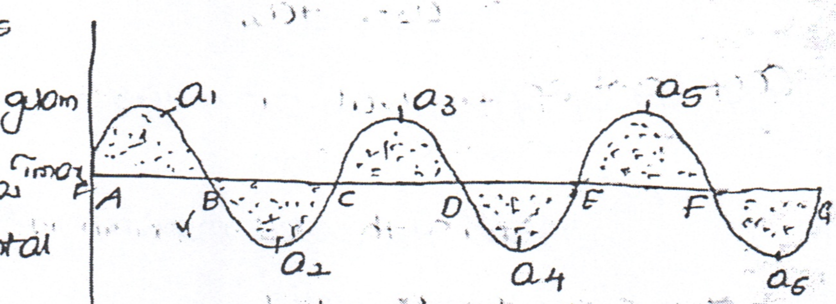
The variations of energy above and below the mean torque is called fluctuations of energy.

Maximum fluctuation of energy

The difference b/w maximum & minimum energies is known as maximum fluctuation of energy

Determination of maximum fluctuation of energy:

The diagram shows turning moment diagram from multi cylinder engine the horizontal line represent mean torque



let

a_1, a_3, a_5 are above mean torque line

a_2, a_4, a_6 are the area below mean torque line

let the energy in fly wheel at $A = E$ than $B = E + a_1$

energy at $C = E + a_1 - a_2$

$D = E + a_1 - a_2 + a_3$

$E = E + a_1 - a_2 + a_3 - a_4$

$F = E + a_1 - a_2 + a_3 - a_4 + a_5$

$G = E + a_1 - a_2 + a_3 - a_4 + a_5 - a_6 = E$

let us suppose the greatest energy at B

$B = E + a_1$

least energy at E

$E = E + a_1 - a_2 + a_3 - a_4$

maximum fluctuation energy ΔE =

maximum energy - minimum energy.

$\Delta E = (E + a_1) - (E + a_1 - a_2 + a_3 - a_4)$

$= a_2 - a_3 + a_4$

Coefficient of fluctuation of energy :-

It is the ratio maximum fluctuation of energy to work done per cycle

$$C_E = \frac{\text{maximum fluctuation of energy}}{\text{work done per cycle}}$$

The work done per cycle = $T_{mean} \times \theta$

θ = angle turned in one revolution

$\theta = 2\pi$ in case of 2-stroke

$\theta = 4\pi$ (4-stroke)

$$T_{mean} = \frac{P \times 60}{2\pi N}$$

work done per cycle also obtain $= P \times \frac{60}{n}$

n = no. of stroke per minute

$n = \frac{N}{2}$ (4-stroke) $n \cdot \frac{N}{2}$

$n = N$ (2-stroke)

Fly-wheel :-

A fly wheel is used in machines, serves as a reservoir it stores energy when supply of energy is more than requirement and releases when requirement is more than supply.

Coefficient of fluctuation speed :-

It is the ratio maximum fluctuation of speed to mean speed

let N_1, N_2 = maximum & minimum speed

$$N = \frac{N_1 + N_2}{2}$$

Coefficient of fluctuation energy speed

$$C_s = \frac{N_1 - N_2}{N}$$

$$= \frac{2(N_1 - N_2)}{N_1 + N_2}$$

Coefficient of steadyness :-

It is the reciprocal of coefficient fluctuation of speed

$$m = 1/C_s = \frac{N_1 + N_2}{2(N_1 - N_2)}$$

Energy stored in flywheel :-

We know that the fly wheel observe energy when it's speed increase than requirement and it gives energy and speed decreases

let m = mass of flywheel in (kg)

k = radius of gyration

I = mass moment of inertia about it's axis of rotation

$I = mk^2$

N_1, N_2 = maximum & minimum speed

ω_1 & ω_2 = angular speed maximum & minimum

N = mean speed

C_s = Coefficient of fluctuation speed

W.K.T

mean kinetic energy of flywheel

$E = \frac{1}{2} I\omega^2$

$= \frac{1}{2} mk^2\omega^2$

As the speed of flywheel changes ω_1, ω_2 than maximum fluctuation of energy

ΔE = maximum - minimum

$= \frac{1}{2} mk^2\omega_1^2 - \frac{1}{2} mk^2\omega_2^2$

$= \frac{1}{2} mk^2 [\omega_1^2 - \omega_2^2]$

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

$$\Delta E = \frac{(\omega_1+\omega_2)(\omega_1-\omega_2)}{2} \times I$$

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

$$\Delta E = I\omega^2 \frac{(\omega_1-\omega_2)}{\omega}$$

$$= I\omega^2 C_s \qquad \left[C_s = \frac{\omega_1-\omega_2}{\omega}\right]$$

$$\Delta E = 2 \times 1/2\, I\omega^2 C_s$$

$$= 2E \times C_s$$

The radius of gyration is taken equal to mean radius of rim 'R' because the thickness of rim is very small compare diameter of rim. substituting $K=R$

$$\Delta E = mR^2\omega^2 C_s$$

$$= mv^2 C_s \qquad [v = R\omega]$$

The mass of flywheel of engine is 6.5 tonnes and radius of gyration 1.8m is bdn from turning moment diagram the fluctuation of energy 68 KN-m the mean speed 150rpm find maximum & minimum speed

Given

$m = 6.5 \times 1000$

$= 6500\ N$

$K = 1.8m$

$\Delta E = 68 \times 10^3\ N\text{-}m$

$N = 150\,rpm$

$N = \frac{N_1+N_2}{2}$

$150 = \frac{N_1+N_2}{2}$

$N_1+N_2 = 300 \rightarrow (1)$

$$\Delta E = \frac{\pi^2}{900} m k^2 N (N_1 - N_2)$$

$$68 \times 10^3 = \frac{\pi^2}{900} (6500)(1.8)^2 (150)(N_1 - N_2)$$

$$N_1 - N_2 = 1.96 = 2 \longrightarrow (2)$$

from (1) & (2),

$$N_1 = 151 \text{ rpm}$$

$$N_2 = 149 \text{ rpm}$$

A horizontal cross compound steam engine develops 300 kW at 90 rpm the coefficient of fluctuation of energy as 1 found from the turning moment diagram. fluctuation speed is kept with in ±0.5% of mean speed find the weigh of flywheel required the radius of gyration is 2m?

Given

$P = 300$ kW

$N = 90$ rpm

$C_E = 0.1$

$C_S = \pm 0.5\% = \frac{N_1 - N_2}{}$

$k = 2$ m

$\omega_1 - \omega_2 = 0.5 + 0.5\, \omega$

$\omega_1 - \omega_2 = 0.01\, \omega$

$$\frac{\omega_1 - \omega_2}{\omega} = 0.01$$

$$\omega = \frac{2\pi N}{60}$$

$= 9.42$ rad/sec

Coefficient of speed $C_S = \frac{(\omega_1 - \omega_2)\omega}{\omega}$

$C_S = 0.01$

W.K.T work done per cycle

$= \frac{P \times 60}{n}$

$= \frac{300 (60)}{90}$

$= 2 \times 10^5$ N/m

maximum fluctuation of energy

$\Delta E =$ work done per cycle $\times C_E$

$= 2 \times 10^5 \times 0.1$

$= 2 \times 10^4$ N-m

$\therefore \Delta E = mk^2 \omega^2 C_S$

$2 \times 10^4 = m (2)^2 (9.42)^2 (0.01)$

$m = 5634.6$ kg

The turning moment diagram of a petrol engine is drawn to the following scales. turning moment 1mm = 5 N/m crank angle 1 = 1mm the turning moment diagram repeat every half revolution of engine and areas above & below mean turning moment line taking order 295, 685, 40, 340 960, 270 mm² the rotating part are equivalent to a mass of 50kg and radius of gyration 180mm. determine coefficient fluction of speed when engine runs at 1800 rpm?

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$m = 50\,kg$

$N = 1800\ rpm$

$k = 180mm = 0.18m$

$\omega = \frac{2\pi N}{60} = \frac{2\pi(1800)}{60} = 188.49\ rad/sec$

$A = E$

$B = E + 295$

$C = E + 295 - 685$

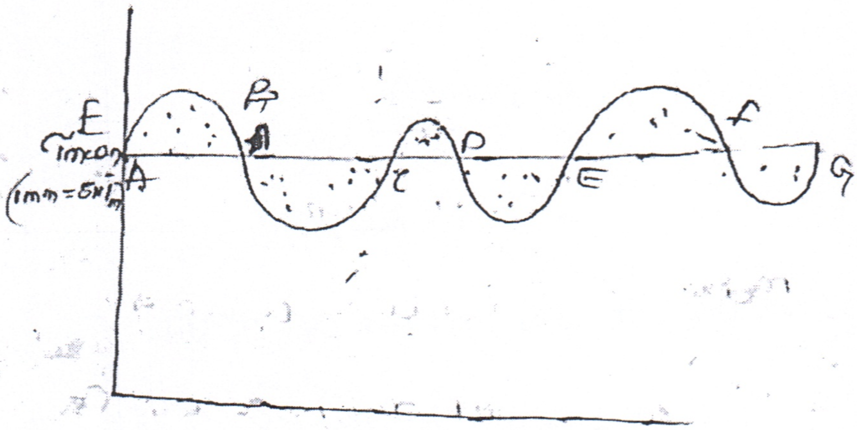
$= E - 390$

$D = E - 390 + 40$

$= E - 350$

$E = E - 350 - 340$

$= E - 690$



Crank angle (1°=1mm)

$F = E - 690 + 960$

$= E + 270$

$G = E + 270 - 270$

$G = E$

maximum $= E + 295$

minimum $= E - 690$

$\Delta E = max - min$

$= E + 295 - (E - 690)$

$= 985$

$\Delta E = 985 \times 5 \times \frac{\pi}{180}$

$\Delta E = 85.95\ N \cdot m$

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$\Delta E = m k^2 \omega^2 C_s$

$8595 = (50)(0.13)^2 (188.49)^2 \cdot C_s$

$C_s = 0.002$

Q) the turning moment diagram of multi cylinder engine as drawn as scale 1mm = 600N-m vertical, 1mm = 3° horizontally. the intercepted areas b/w the output torque curve & the mean resistance line taken in order from one end are as follows +52, -124, +92, -140, +85, -72, & +107 mm² when the engine is running at 600rpm. if the total fluctuation of speed is not exceed ± 1.5% of mean. find necessary mass of fly wheel of radius (0.5) m?

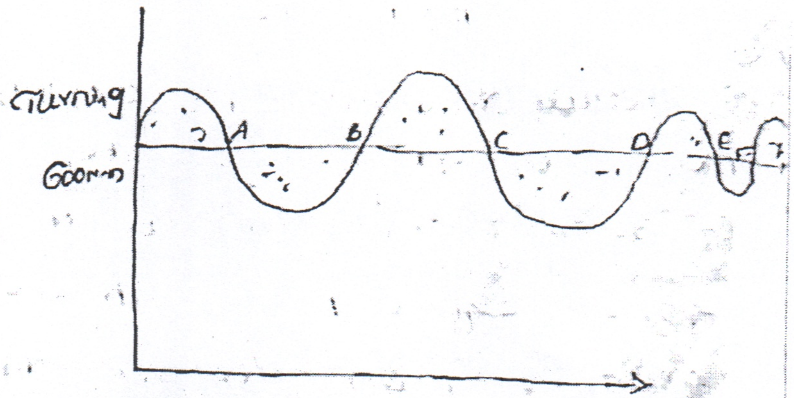
Given

$N = 600 \text{ rpm}$

$R = 0.5m$

$\omega_1 - \omega_2 = 0.03\omega$

$\frac{\omega_1 - \omega_2}{\omega} = 0.03$



crank angle $\theta = 1m = 3 \times \frac{\pi}{180}$

$\omega = 62.83$

$= 1mm^2 = 1mm \times 1mm$

$= 600 \times 3 \times \frac{\pi}{180}$ N-m

$A = E$

$B = E + 52$

$C = E + 52 - 124$

$= E - 72$

$D = E - 72 + 92$

$= E + 20$

$E = E + 20 - 140$

$= E - 120$

$F = E - 120 + 85$

$= E - 35$

$G = E - 35 - 72$

$G = E - 107$

$H = E - 107 + 107$

$H = E$

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maximum = $E + 52$

minimum = $E - 120$

$$\Delta E = E+52 - (E-120)$$

$$= 172 \text{ mm}^2$$

$$\Delta E = 172 \times 600 \times .3 \times \frac{\pi}{180}$$

$$= 5403.85 \text{ N-m}$$

$$\Delta E = m R^2 \omega^2 C_s$$

$$5403.85 = m (0.5)^2 (62.83)^2 (0.03)$$

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$$m = 182.5 \text{ kg}$$