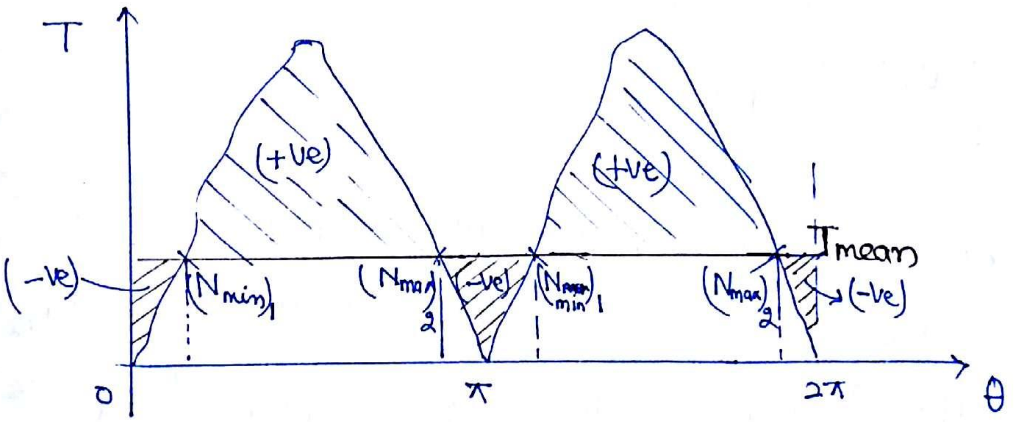
$$\boxed{T_{mean} = \frac{W.D./cycle}{T_{period}}}$$

Flywheel: it is a device which serve as a reservior to store energy when supply of the energy is more than the requirement and release energy when requirement is more then the supply.

Turning Moment Diagram of Double acting Steam engine:-



$$(WD)_{cycle} = \int_0^{T_{period}=2\pi} T\,d\theta = T_{mean} \times 2\pi$$

$$\boxed{T_{mean} = \frac{(WD)_{cycle}}{2\pi}}$$

After installing Flywheel.

N_{max} = max. of $[N_{max_1}, N_{max_2} \text{ - - - }]$

N_{min} = Min. of $[N_{min_1}, N_{min_2} \text{ - - - }]$

Variation of speed = $N_{max} - N_{min}$ = Fluctuation

C_s = Coefficient of fluctuation of speed

$$\boxed{C_s = \frac{N_{max} - N_{min}}{N}} \quad \because \boxed{N = \frac{N_{max} + N_{min}}{2}}$$

Coefficient of steadiness = m

$$m = \frac{1}{C_s}$$

Coefficient of fluctuation of energy

$$\boxed{C_E = \frac{E_{max} - E_{min}}{W_{cycle}}}$$

<u>Note:</u> ~~some of~~ sum of all positive areas (energy) about the mean line will be equal to sum of all Negative areas below the mean line.

06/12/16

Fundamental equation of Flywheel:-

$$E_{max} = \frac{1}{2} I \omega_{max}^2$$

$$E_{min} = \frac{1}{2} I \omega_{min}^2$$

$$\boxed{\Delta E = E_{max} - E_{min} = \frac{1}{2} I \left(\omega_{max}^2 - \omega_{min}^2 \right)}$$

Variation in E

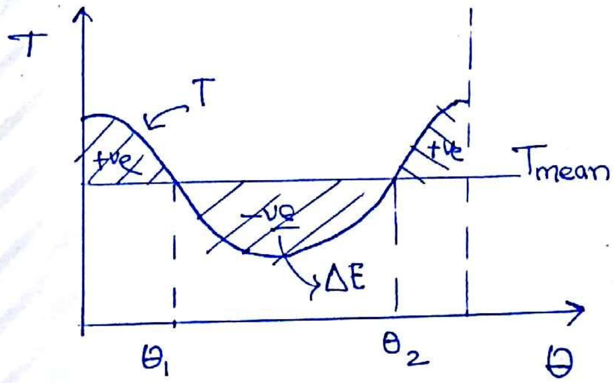
$$\Delta E = \frac{1}{2} I \left(\omega_{max}^2 - \omega_{min}^2 \right)$$

$$\Delta E = \frac{1}{2} I \left(\frac{\omega_{max} - \omega_{min}}{\omega} \right) \left(\omega_{max} + \omega_{min} \right) \times \omega$$

$$\omega = \frac{\omega_{max} + \omega_{min}}{2}$$

$$\boxed{\Delta E = I \omega^2 C_s}$$

eg

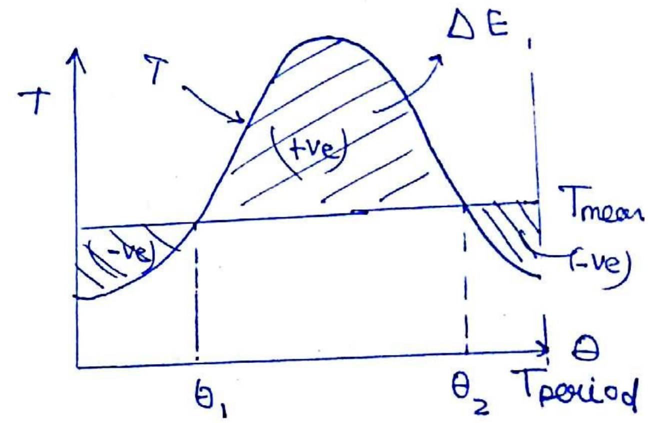


$$\boxed{\Delta E = \int_{\theta_1}^{\theta_2} \left(T_{mean} - T \right) d\theta}$$

How to Find θ_1 & θ_2

$T = T_{mean}$.

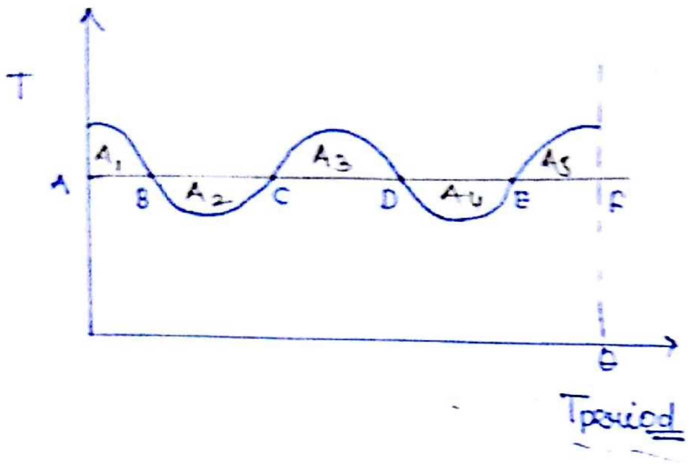
eg



$$\boxed{\Delta E = \int_{\theta_1}^{\theta_2} \left(T - T_{mean} \right) d\theta}$$

{ * Total Area's above & below the Tmean line are equal. }

c



$E_A = E$

$E_B = E + A_1$

$E_C = E + A_1 - A_2$

$E_D = E + A_1 - A_2 + A_3$

$E_E = E + A_1 - A_2 + A_3 - A_4$

$E_F = E + A_1 - A_2 + A_3 - A_4 + A_5$

$E_F = E$

$E_{max} = \text{max of} [E_A, E_B, E_C, E_D, E_E, E_F]$

$E_{min} = \text{min of} [E_A, E_B, E_C, E_D, E_E, E_F]$

$$\boxed{\Delta E = E_{max} - E_{min}}$$

★ eg

$E_{max} = E + 70 \qquad E_{min} = E - 30$

$\Delta E = 100$ unit → cm^2 / → mm^2

Scale $1\ mm^2 = 15$ Joule

$100\ mm^2 = 100 \times 15\ J$

★ scale

$1\ mm = 15\ Nm$

$1\ mm = \pi/3$ rad.

$100\ mm^2 = 100 \times 15 \times \pi/3\ (J)$

① A machine is coupled to a 2 stroke engine which produced a torque $T = (800 + 180 \sin 3\theta)$ Nm where θ is crank angle what is the max. fluctuation in energy.

Sol^n

$$T = 800 + 180 \sin 3\theta$$

$$T_{mean}\left(\frac{2\pi}{3}\right) = \int_0^{2\pi/3} (800 + 180 \sin 3\theta)\, d\theta$$

$$= 800\,\theta + 180\, \frac{\cos 3\theta}{3} \Bigg|_0^{2\pi/3}$$

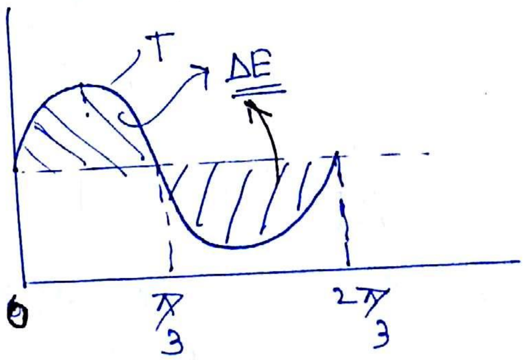
$$= 800\left(\frac{2\pi}{3}\right) - \frac{180}{3}\left\{ \cos 2\pi - \cos 0 \right\}$$

$$= \frac{1600\pi}{3} - \frac{180}{3}\,[+1 - 1] \qquad 3\theta \times \frac{2\pi}{3}$$

$$T_{mean}\left(\frac{2\pi}{3}\right) = \frac{1600\pi}{3} + \frac{0}{3}$$

$$\boxed{T_{mean} = 800 \text{ Nm}}$$

$$\Delta E = \int_0^{\pi/3} (T - T_{mean})\, d\theta$$



$$\Delta E = \int_0^{\pi/3} 180 \sin 3\theta \, d\theta$$

$$\Delta E = -\frac{180}{3} \left(\cos 3\theta \right)_0^{\pi/3}$$

$$= \frac{-180}{3} (-1 - 1) = 120 \text{ J}$$

Q.26

P.g.31
WB

$$T = 10000 + 2000\sin 2\theta - 1800\cos 2\theta$$

$$T_{mean}(\pi) = \int_0^{\pi} T.d\theta$$

$$\Theta = T_{mean}(\pi) = \int_0^{\pi} (10000 + 2000\sin 2\theta - 1800\cos 2\theta)d\theta$$

$$= 10000(\pi - 0) - 2000\left\{\cos 2\pi - \cos 0\right\} - 1800\left\{\sin 2\pi - \sin 0\right\}$$

$$T_{mean}(\pi) = 10000\pi - 2000(1-1) - 1800(0-0)$$

$$T_{mean} = 10000 \text{ Nm}$$

$$P = T_{mea} \times \omega = 10000 \times \frac{2\pi \times 250}{60}$$

$$P = 261.79 \text{ KW}$$

$T = T_{mean}$

$2000\sin 2\theta - 1800\cos 2\theta = 0$

$\tan 2\theta = 0.9$

$2\theta = 41.98^\circ$

$= 180 + 41.98$

$= 360 + 41.98^\circ$

$\theta = 20.99, 110.99^\circ$

$$\Delta E = \int_{(20.99)\pi/180}^{(110.99)\pi/180} (T - T_{mean})\, d\theta$$

$$= \int \cancel{(2000\sin 2\theta - 1800\cos 2\theta)}\, d\theta$$

$$\Delta E = \int_{(20.99)\frac{\pi}{180}}^{(110.99)\pi/180} (2000\sin 2\theta - 1800\cos 2\theta)\, d\theta$$

$$\Delta E = 2690.72 \text{ J}$$

* $T = 10000 + 2000 \sin 2\theta - 1800 \cos 2\theta$

$\frac{2\pi}{2} \qquad \frac{2\pi}{2}$

$$\boxed{\text{Time period} = \frac{\text{LCM of } N^r}{\text{HCF of } D^r}} = \frac{2\pi}{2} = \pi$$

↳ Highes common

⇒ eg $T = 800 + 1000 \sin 3\theta - \tan 5\theta$

$\frac{2\pi}{3} \qquad \frac{\pi}{5}$

$$T_{period} = \frac{2\pi}{1} = 2\pi$$

$P = 261.79 \text{ kW}$

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

$2690.72 = I \left(\frac{2\pi \times 250}{60}\right)^2 \times \frac{0.5}{100}$

(ii) $I = 785.16 \text{ kg-m}^2$

$C_s = \pm 0.25\%$

$C_s = 0.5\%$

$C_s = \frac{0.5}{100}$

(iii) $(T - T_{mean})_{\theta = 45°} = I\alpha$

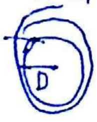
$(2000 \sin 2\theta - 1800 \cos 2\theta)\Big|_{\theta = 45°} = 785.16\, \alpha$

$(2000 \sin 90 - 1800 \cos 90) = 785.16\, \alpha$

$\alpha = 2.54 \text{ rad/sec.}$

if radius of Gyration Given

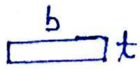
$I = mk^2$



$m = ?$

$m = \rho \times \text{Vol}$

$m = \rho \times (\pi D b t)$



Ring type flywheel

Q.25

P.g.31

$$T = 10000 + 1000\sin\theta - 1200\cos 2\theta$$

$$2\pi \qquad \pi$$

$$T_{period} = \frac{2\pi}{1} = 2\pi$$

$$T_{mean}(2\pi) = \int_0^{2\pi} (10000 + 1000\sin\theta - 1200\cos 2\theta)\, d\theta$$

$$= 10000(2\pi) + 1000\left[-\cos\theta\right]_0^{2\pi} - 1200\left[\frac{\sin 2\theta}{2}\right]_0^{2\pi}$$

$$T_{mean} \times (2\pi) = 10000(2\pi) - 1000\left(\underset{1}{\cos 2\pi} - \underset{1}{\cos 0}\right) - \frac{1200}{2}\left[\underset{0}{\sin 4\pi} - \underset{0}{\sin 0}\right]$$

$$T_{mean} = 10000 \text{ Nm}$$

$$P = T_{mean} \times \omega = 10000 \times \left(\frac{2\pi \times 100}{60}\right)$$

$$P = 104.719 \text{ kW}$$

Use of Flywheel in Power Presses :-

Motor

I/p ↙ ↘ I/p

Crank Cam

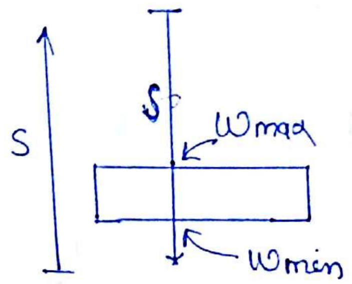
O/p ↓ ↓ O/p

Piston (Punch) Follower (Punch)

$\underline{T_c}$ - cycle time (2-strokes of punch)

$\underline{T_a}$ - Actual punching time

$\underline{T_a << T_c}$



$$\boxed{P_{motor} = \frac{\text{Energy req./hole}}{T_c}}$$

energy will be supplied only in cycle time

$\Delta E = E_{req/hole} - E_{\text{available during punching}}$

$$\boxed{\Delta E = E_{req/hole} - (P_{motor} \times T_a) = I\omega^2 C_s}$$

$$\Delta E = \frac{1}{2} I (\omega_{max}^2 - \omega_{min}^2)$$

ω_{max} ↓ before punching

ω_{min} ↓ After punching

Q.28

Pg.32

WB

hole = 720 holes/hr. = 720/3600 = $\frac{1 \text{ hole}}{5 \text{ sec.}}$

d = 2 mm, t = 3 mm   So Cycle time = 5 Sec.

$E_{req.} = 20 \ J/mm^2$

$T_a = 1/4$ sec. , $T_c = 5$ Se.

$N_{max} = 100$ rpm $N_{min} = 80$ rpm.

$E_{req} = 20 \times \pi \times D \times t = 20 \times \pi \times \frac{2}{\cancel{1000}} \times \frac{3}{1\cancel{000}}$

$E_{req.} = 376.99$ Joule per hole. $= 120\pi$

$P_{Motor} = \frac{376.99}{5} = 75.39 \ (W) = 24\pi$

$\Delta E = E_{req \text{ per hole}} - E_{avail}$

$= 376.99 - 75.39 \times \frac{1}{4}$

$\Delta E = 120\pi - 24\pi \times \frac{1}{4} = 114\pi$

$\Delta E = I\omega^2 C_s.$

$\Delta E = \frac{1}{2} I \left(\omega_{max}^2 - \omega_{min}^2\right) = 114\pi$

$= \frac{1}{2} I \left\{100^2 - 80^2\right\}\left(\frac{2\pi}{60}\right)^2 = 114\pi$

$$\frac{I}{g}\left(\frac{3600}{3600}\right)4\pi^{2} = 114\pi$$

$$I = 18.14 \text{ kg-m}^2$$

$$I = mk^2$$

$$18.14 = m(0.30)^2$$

$$m = 201.59 \text{ kg}$$

Q.27

$P_{motor} = 1.5$ kW 30 hole/min = 1 hole/2 sec

$P = 1500$ W

$T_c = 2$ sec.

$E = 1500 \times 2$

$E_{per\ hole} = 3000$ J

$$\frac{\theta_a}{\theta_c} = \frac{T_a}{T_c}$$

$$\frac{30}{360} = \frac{T_a}{2}$$

$T_a = 1/6$ sec.

★ $$\boxed{\omega_{mean} = \left(\frac{2\pi}{2}\right)}$$

$C_s = 90\%$

$= 90/100$

ΔE = $E_{per\ hole}$ − $E_{during\ punch}$

$\Delta E = 3000 - 1500 \times 1/6 = 2750$ J

$$I\omega^2 C_s = 2750$$

$$I\left(\frac{2\pi}{2}\right)^2 \times \frac{90}{100} = 2750$$

$$I = 1393.16 \text{ kg-m}^2$$

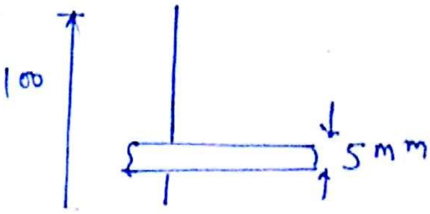
Pb-Case-1

$T_c = 5$ sec.

$S = 100mm$

$t = 5$ mm

↳ Metal sheet thick



200 mm → 5 sec.

1 mm → $\frac{5}{200}$

5 mm → $\frac{5}{200} \times 5 = \frac{1}{8}$ sec.

$T_a = \frac{1}{8}$ sec.

Que In the requirement of flywheel in punching press the cycle time is 6 sec. the stroke is 125 mm the thickness of sheet metal to be punch is to be 3 mm. the time req. for sheet metal is

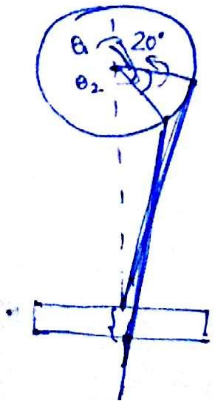
Soln.

$\frac{6}{250} \times 3 = 0.036 \times 2$ sec.

$= 0.072$ sec.

Pb - Case-2

T = 5 sec.



actual punching is done in 20° of crank rotation.

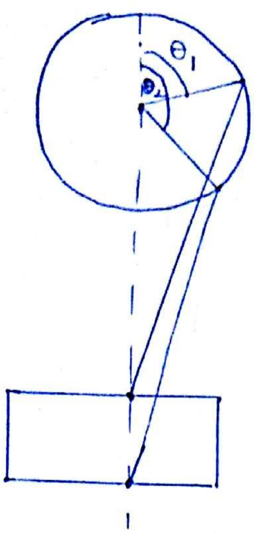
$\theta_1 - \theta_2 = 20°$

360° → 5 sec.

20° → $\frac{5 \times 20}{360}$

$T_a = 0.277$ sec

$\star$



$\theta_2 - \theta_1 = 20^\circ$

$\omega_{mean} = \left(\frac{2\pi}{5}\right)$ rad/se.

$\star$

$\star$

$$\boxed{\omega_{mean} = \frac{2\pi}{T_c} \text{ rad/sec}}$$

Design of Flywheel:-

For Rotating body

ρ – density

$V \rightarrow$ speed (circumferential speed)

$\sigma_h = \rho V^2$ kg/m³ × m²/s

↓

hoop stress develope in flywheel or Centrifugal stress.

$(\sigma_{ind}) < \sigma_{per}$

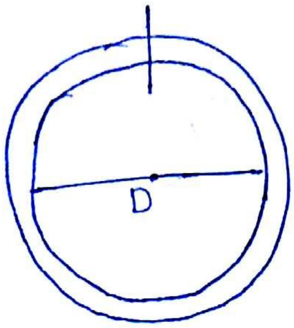
$\rho V^2 \leq \sigma_{per}$

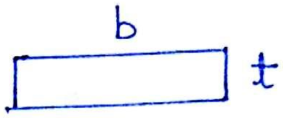
limiting $\sigma_{ind} = \sigma_{per}$

$\rho V^2 = \sigma_{per}$.

$\star$ $\boxed{V_{max} = \sqrt{\frac{\sigma_{per}}{\rho}}}$ $V_{max} = \frac{\pi D N_{max}}{60}$

rim type flywheel :-





$A_{x\text{-}s/c} = bt$

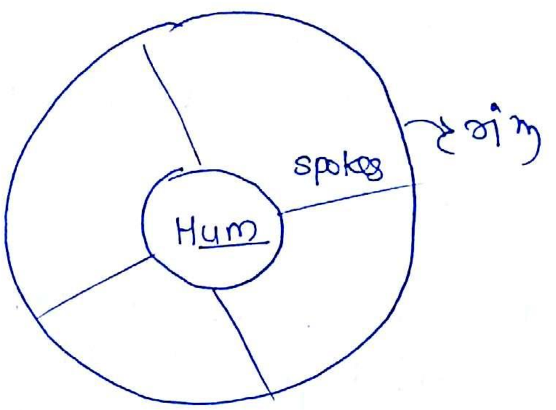
$m = \rho \times Vol.$

$I = mR^2 = \frac{mD^2}{4}$

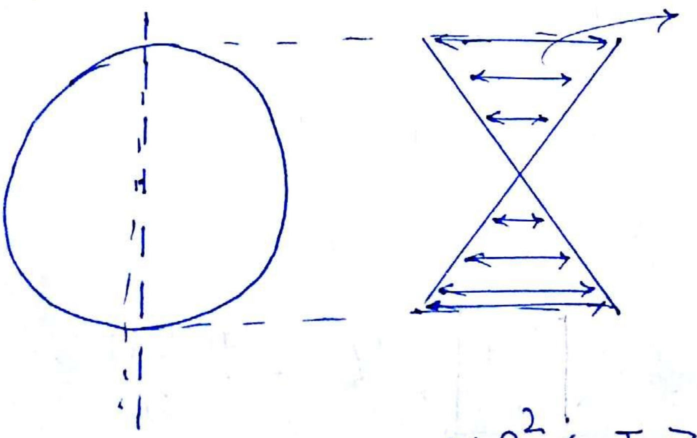
$m = \rho \pi D (A_{x\text{-}s/c})$

$m = \rho \pi D b t$

Medium speed flywheel



High speed Flywheel :-



thickness variation

$I < MR^2$

$I > \frac{MR^2}{2}$

Highest energy storing Capacity.

$MR^2 < I > \frac{MR^2}{2}$

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

Note:

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

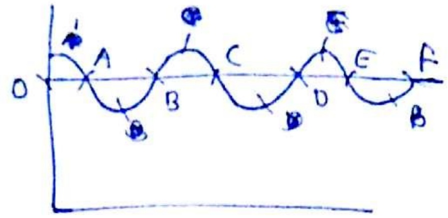
→ ω - high low-I { Small Flywheel } bullet bikes

→ ω - low low-I { High Flywheel } Scooty.

* Size of a Flywheel is less for the high speed movers and vice-versa.

Que An engine runs at a constant load at a speed of 480 rpm the crank effort diagram is drawn to a scale 1 cm = 2000 N-m torque and 1 cm = 36° crank angle the area of the diagram above & below the mean torque are measure in sq. cm units and are in the following order +1.1, -1.32, +1.53, -1.66, +1.97, -1.62. Design the flywheel if the total fluctuation of speed is not to exceeds 10 rpm and the centrifugal stress in rim is not to exceeds 5 MPa. You may assume that rim breadth is 2.5 time the rim thickness & 90% of MOI is due to rim. $\rho = 7250\ kg/m$ (material of flywheel)

Sol^n



$N = 480$ rpm $\quad 1\text{cm} = 2000$ Nm

$1\text{cm} = 36^\circ$

$N_{max} - N_{min} = 10$ rpm $\quad = 36\pi/180 = \pi/5$ rad.

$I_{rim} = 0.9\, I_{flywheel} \quad \rho = 7250\ kg/m^2$

$E_0 = E$

$E_A = E + 1.1$

$E_B = E - 0.22$

$E_C = E + 1.31$

$E_D = E - 0.35$

$E_E = E + 1.62$

$E_F = E$

$E_{max} = E + 1.62$

$E_{min} = E - 0.35$

$b = 1.25t$

$\Delta E = E + 1.62 - E + 0.35$

$\Delta E = 1.97\ cm^2$

$\Delta E = 1.97 \times 2000 \times \pi/5 = 2475.5\ J$

$C_s = \frac{10}{480}$

$\Delta E_{fly} = I_{fly}\, \omega^2 C_s$

$2475.5 = I_{fly} \times (16\pi)^2 \times \frac{10}{480}$

$I_{fly} = 47.03\ kg\text{-}m^3$

$I_{rim} = 0.9\, I_{fly} = 47.02 \times 0.9$

$I_{rim} = 42.327\ kg\,m^2 = \underline{\underline{mR^2}}$

$\Rightarrow \rho v^2 \leq 5 \times 10^6$

$7250 \times v^2 = 5 \times 10^6$

$V_{max} = 26.2611\ m/s.$

$$\frac{\pi D N_{max}}{60} = 26.2611$$

$$\frac{mD^2}{4} = 42.3487$$

$$\rho \pi D (bt) \frac{D^2}{4} = 42.3487$$

$$N_{max} = 485 \text{ rpm}$$
$$= 480 + 5$$

$$\frac{\pi \times 485 \times D}{60} = 26.2611$$

$$D = \underline{1.034 \text{ m}}$$

$$R = 0.517 \text{ m}$$

$$\Rightarrow \quad 7250 \times \pi \times 1.034 \times 2.5 t \times t \times \frac{(1.034)^2}{4} = 42.3487$$

$$t = \underline{\underline{0.052}} \text{ m}$$

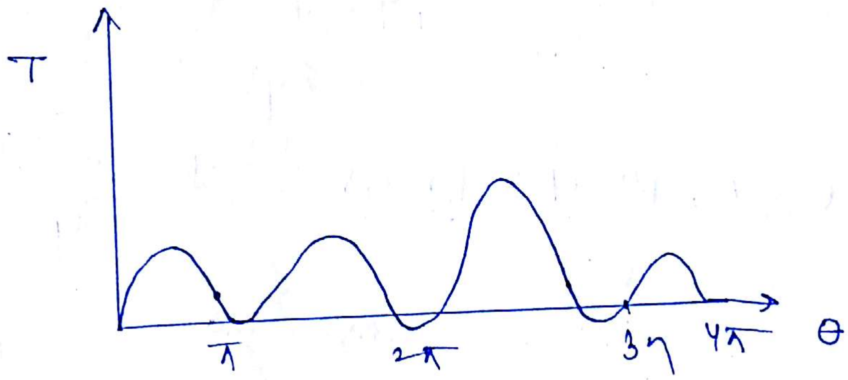
$$b = 0.13 \underline{\underline{\text{m}}}$$

Multi cylinder Engine:-

Multicylinder ~~cyli~~ engines are used to increase power as well as to increase the uniformity of power so that the fluctuation in engine can be decreased upto certain extent and requirement of flywheel can be supressed

<u>Note</u>:- Firing order of an engine is decided so has to minimize unbalance forces which intern reduces the requirenment of flywheel but not minimize the req. of flywheel.

4-5 <u>Cylinder</u>



<u>Multicylinder</u>