TOM – Fly Wheel

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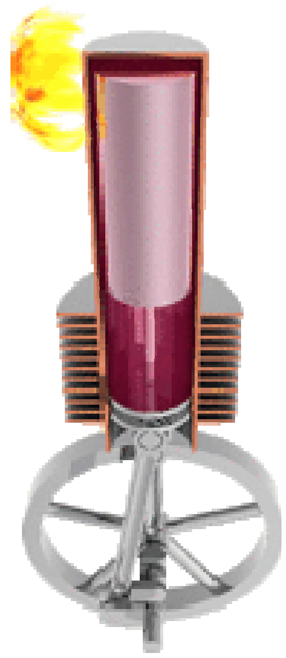
The principle of the flywheel is found before the many centuries ago… in spindle and the potter's wheel.

Potters Wheel

A heavy-rimmed rotating wheel used to minimize variations in angular velocity and revolutions per minute, as in a machine subject to fluctuation in drive and load.



A flywheel is a mechanical device with a significant moment of inertia used as a storage device for rotational energy.

A flywheel stores energy when the supply is in excess and releases energy when energy is in deficit.

A flywheel is a spinning wheel or disc with a fixed axle so that rotation is only about one axis. Energy is stored in the rotor as kinetic energy, or more specifically, rotational energy:

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

Where:

ω is the angular velocity, and

I is the moment of inertia of the mass about the center of rotation.

- The moment of inertia is the measure of resistance to torque applied on a spinning object (i.e. the higher the Moment of Inertia, the slower it will spin after being applied a given force).

Main Function

The main function of a fly wheel is to smoothen out variations in the speed of a shaft caused by torque fluctuations.

If the source of the driving torque or load torque is fluctuating in nature, then a flywheel is usually called for.

It absorbs mechanical energy and serves as a reservoir, storing energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than the supply.

Applications

Many machines have load patterns that cause the torque time function to vary over the cycle.

Internal combustion engines with one or two cylinders are a typical example. Piston compressors, punch presses, rock crushers etc. are the other systems that have fly wheel.

In a modern application, a momentum wheel is a type of flywheel useful in satellite pointing operations, in which the flywheels are used to point the satellite's instruments in the correct directions without the use of thruster rockets.

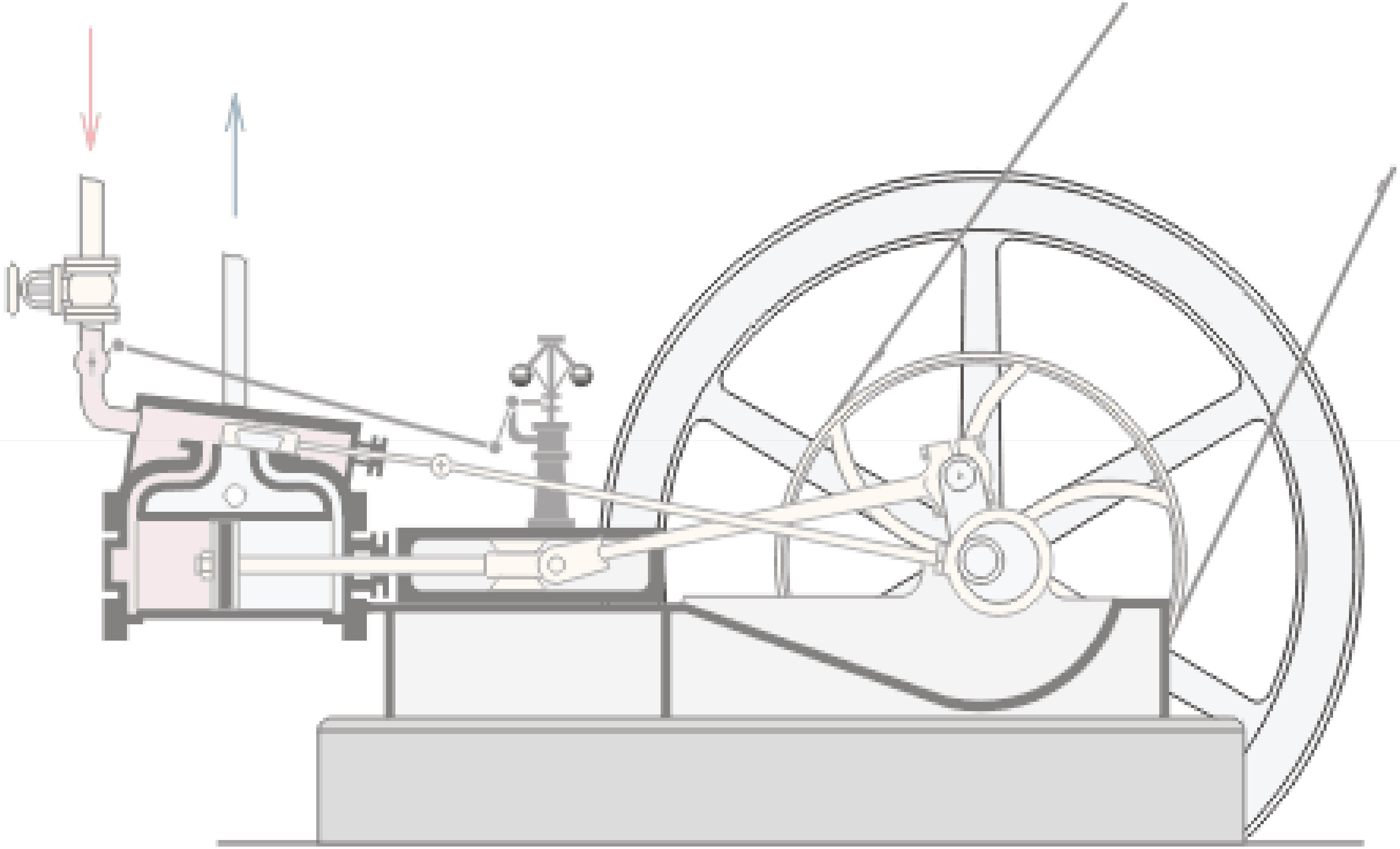
Flywheels are used in riveting machines, where they store energy from the motor and release it during the operation cycle (punching and riveting).

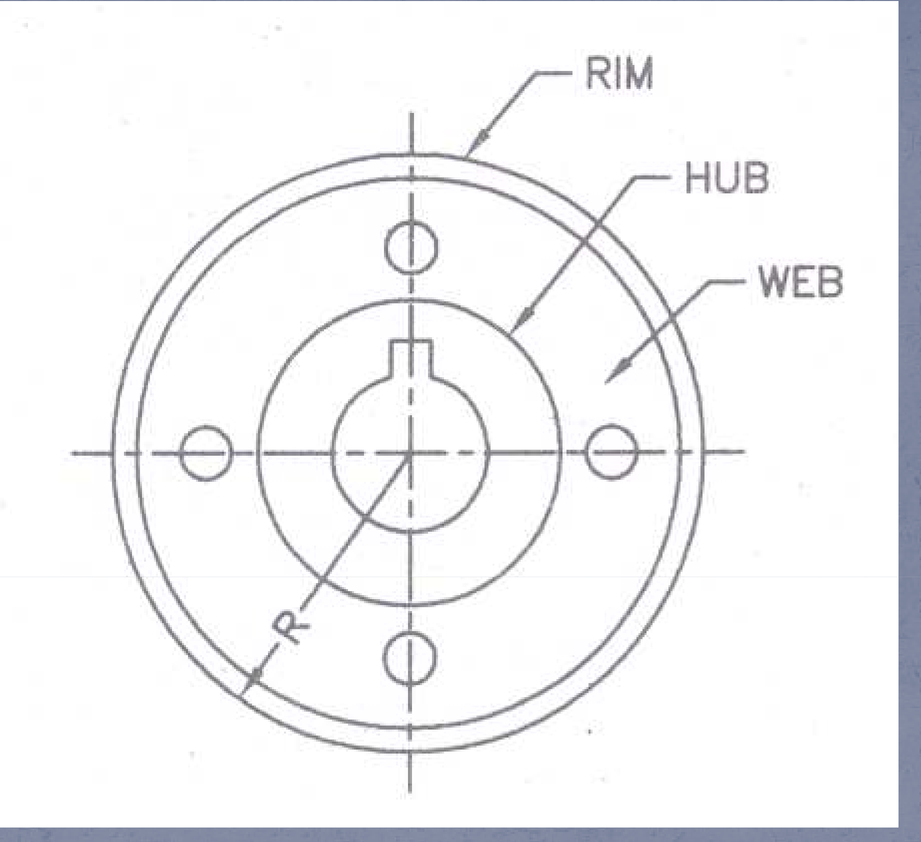
Fly Wheels

The function of a flywheel in an engine is entirely different from that of a governor. It controls the speed variation caused by the fluctuations of the engine turning moment during each cycle of operation.

Types of Fly Wheels

1. Disc type
2.Rim & arm type
3. Split

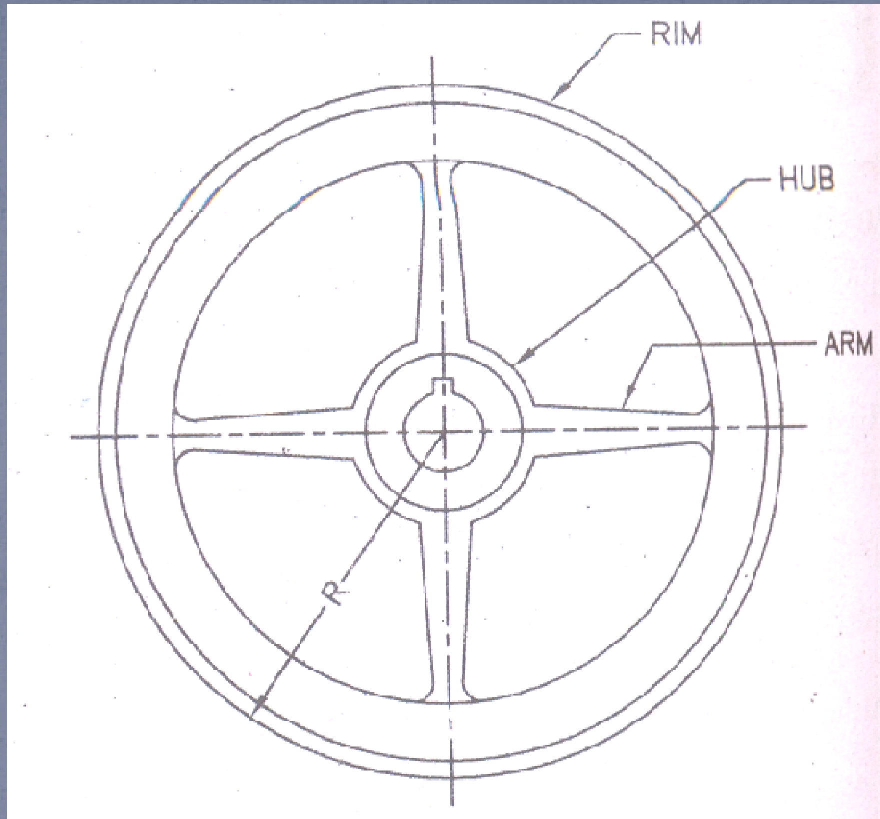




1. Disc type

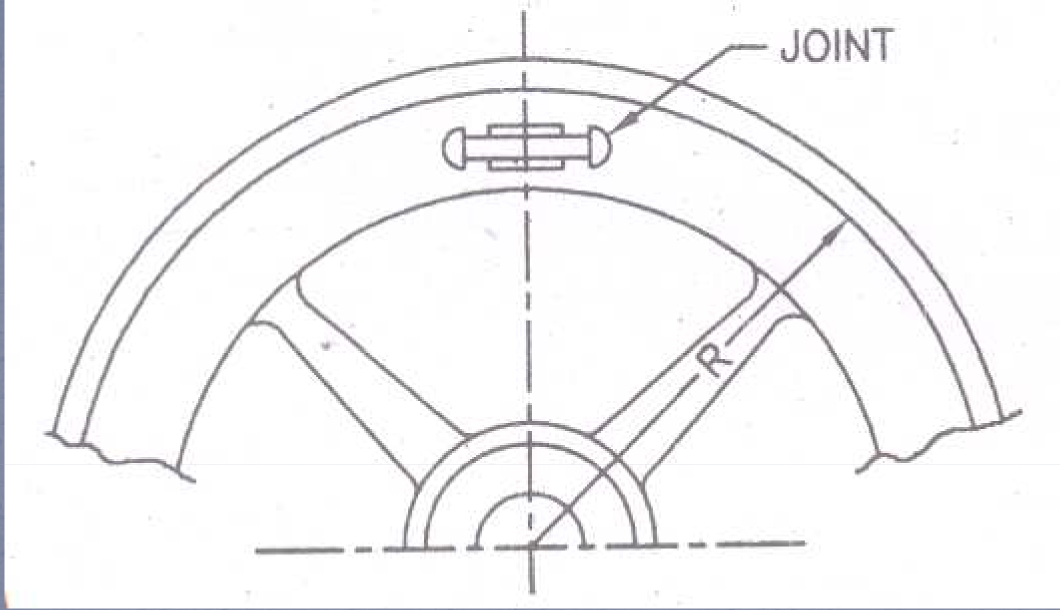
Up to 600 mm diameter

One piece



2. *Rim & Arm type*

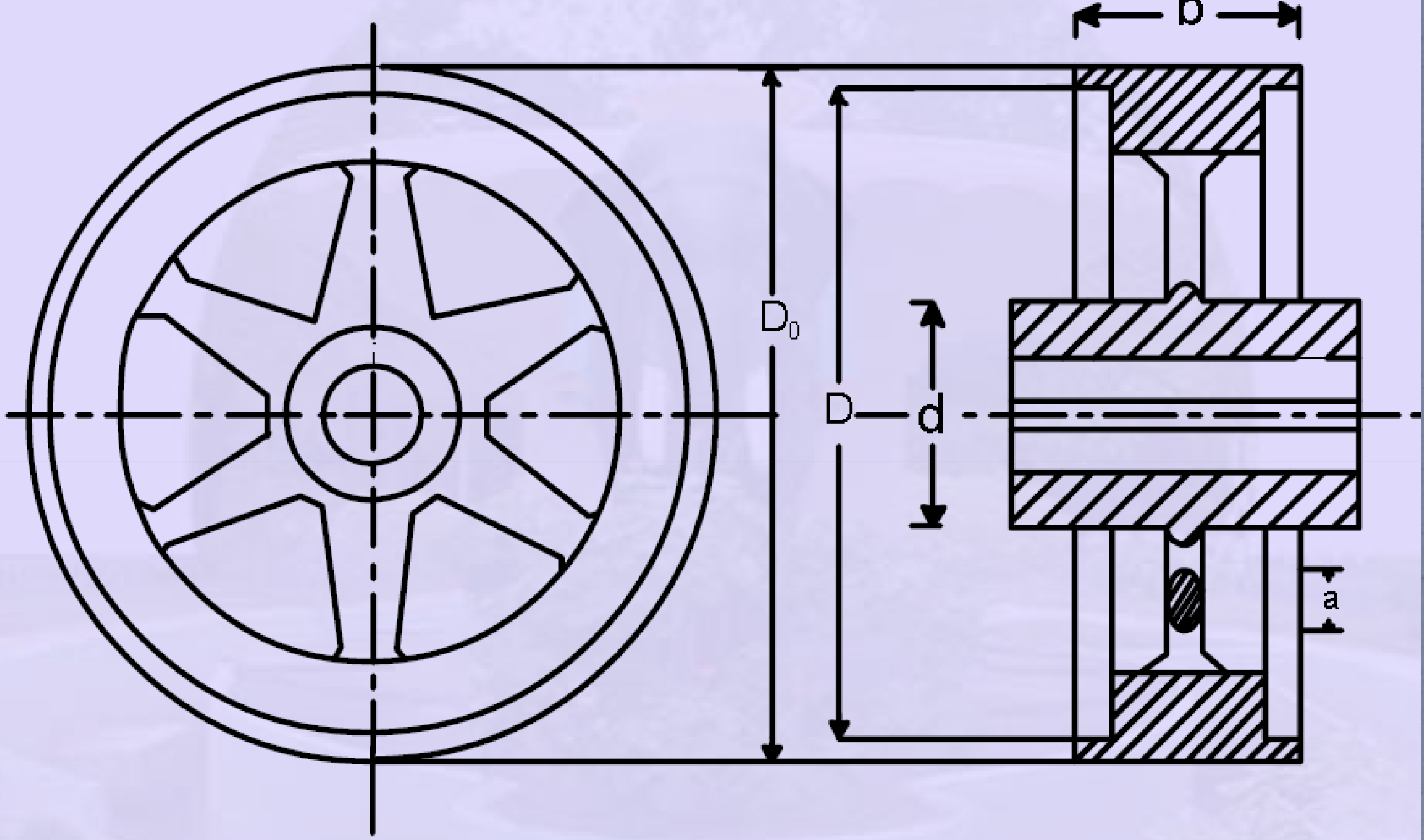
Generally of bigger diameters (600 to 2500 mm)
Hub is connected with 4,6 or 8 arms



3. Split Fly wheel

Larger size diameter above 2500mm

Fly wheel is spitted in 2 ,3 or more no. of components.



Arm Type Flywheel

Governor

- The function of governor is to regulate the mean speed of engine when there is variation in Load
- This regulation is accomplished by controlling fuel supply.
- Generally there is not cyclic variation of load on engine.
- Mathematically, It controls ΔN.
- There is effect of quality of fuel on Governor.
- Governor are mainly classify on the working principle e.g. Centrifugal type and inertia type governor

Flywheel

- The function of flywheel is to regulate speed of engine because of the fluctuation in turning moment.
- This is accomplished by storing and releasing energy in flywheel.
- As per the number of stroke there is cyclic variation in turning moment.
- Mathematically, It controls ΔN / Δt
- There No effect of quality of fuel on function of Fly wheel.
- Flywheels are mainly classified as per their size and shape e.g. Rim type, Disc type and split flywheel

The turning moment diagram (also known as *crank-effort diagram) is the graphical representation of the turning moment or crank-effort for various positions of the crank. It is plotted on Cartesian co-ordinates, in which the turning moment is taken as the ordinate and crank angle as abscissa.*

Turning moment diagram for single cylinder double acting steam

With the piston in the given position and the crank turning clockwise, let the pressure of the steam on the cover side of is p; similarly, the pressure on the crank side of the piston is p_1

The net steam thrust which tends to move the piston towards the right is therefore given by $F = p.A—p_1A_1$.

where A, A_1 are respectively the areas of the cover and crank sides of the piston.

If, for the present, the effect of the inertia of the moving parts is ignored, The variation of the turning moment due to the steam pressure, calculated, for a complete revolution of the crankshaft is shown in Fig 1. The mean height of the curve represents the mean steam torque on the crankshaft and is shown in the figure.

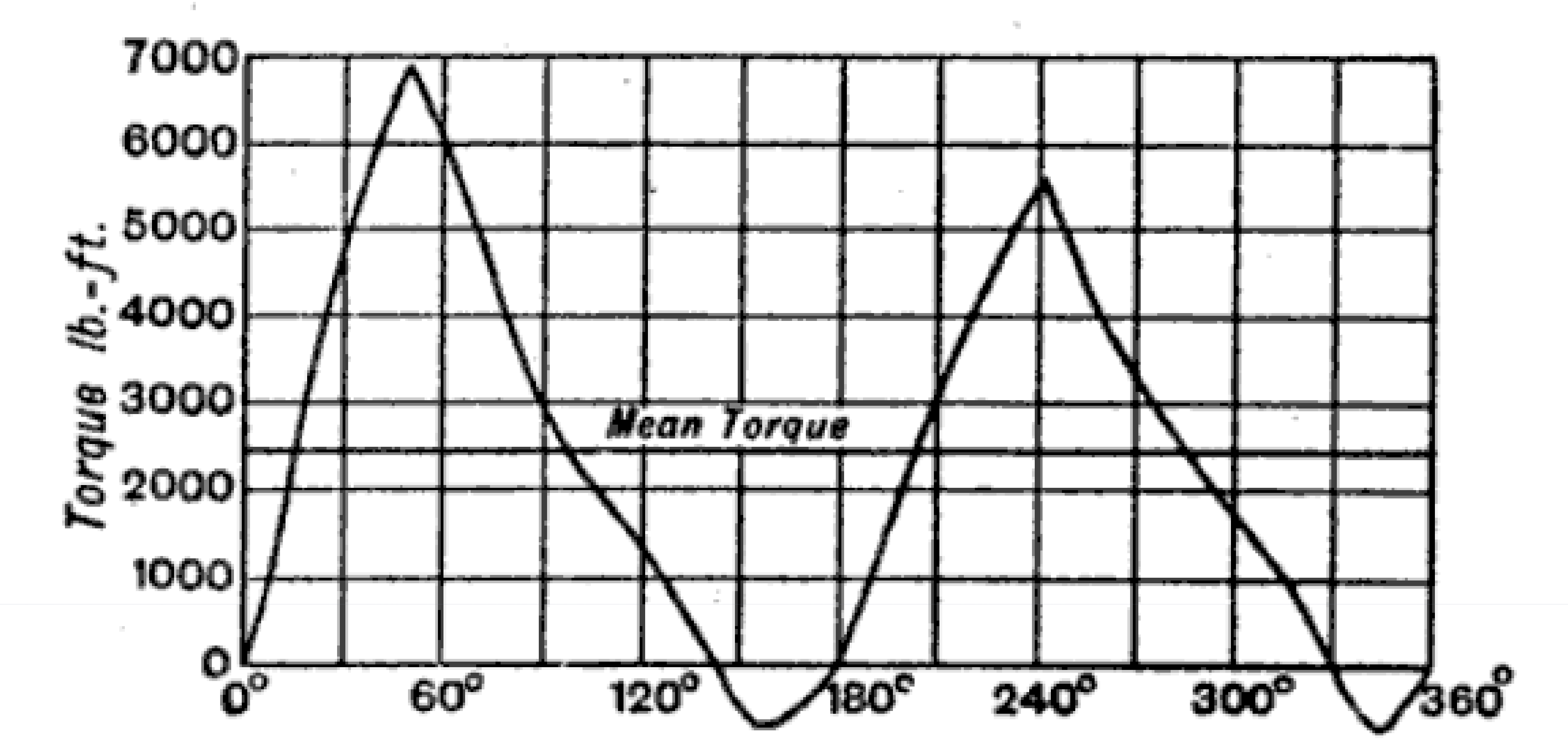
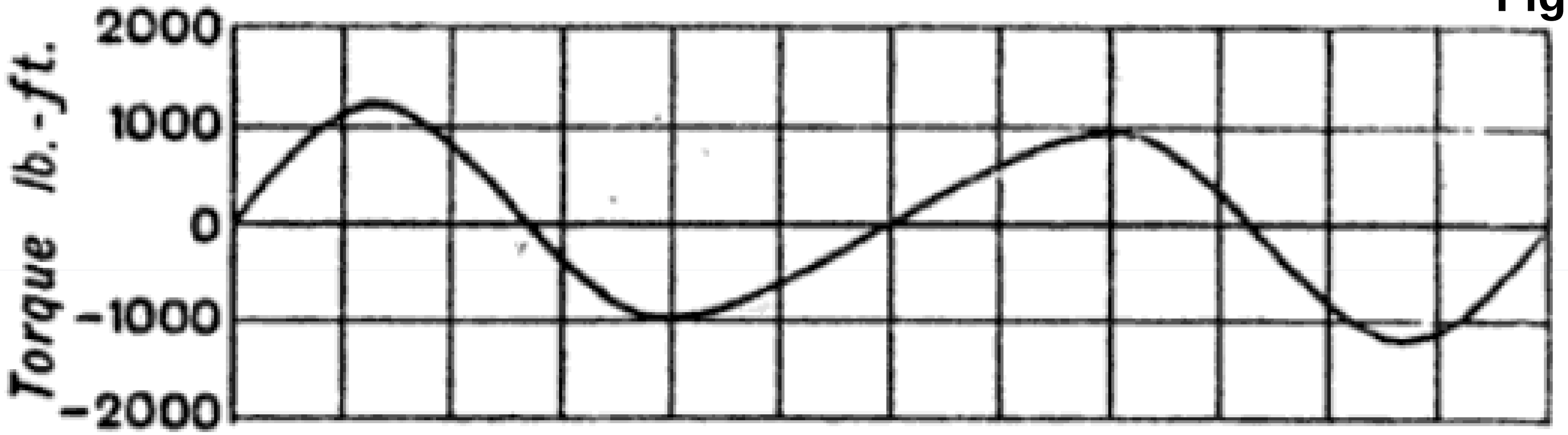


Fig 1.Turning Moment due to Steam Pressure

Note: *For a vertical engine the effect of the deadweight of the reciprocating parts must be taken into account. Obviously, when the piston is moving downwards the weight of the parts must be* ***added*** *to the effective steam thrust, and when the piston is moving upwards the weight of the parts must be* ***subtracted*** *from the effective steam thrust.*

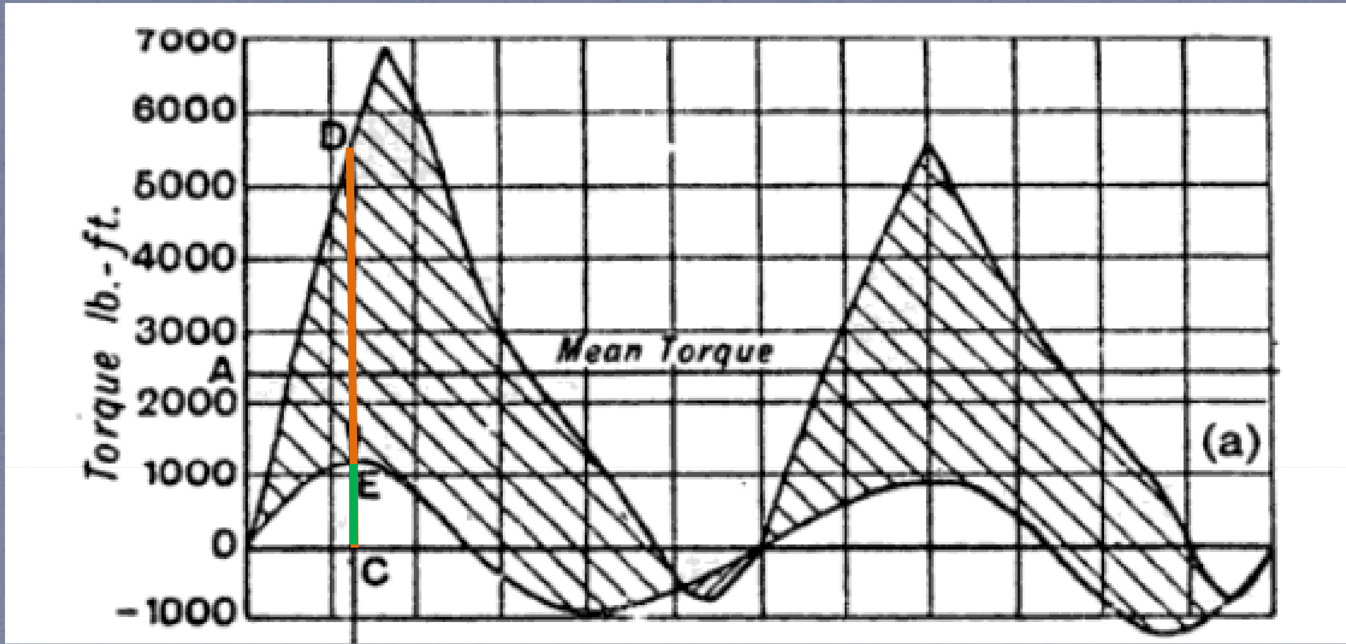
The variation in torque required, on the crankshaft in order to overcome the inertia of the reciprocating parts, for a complete revolution of the crankshaft is shown in Fig 2.

Fig 2.



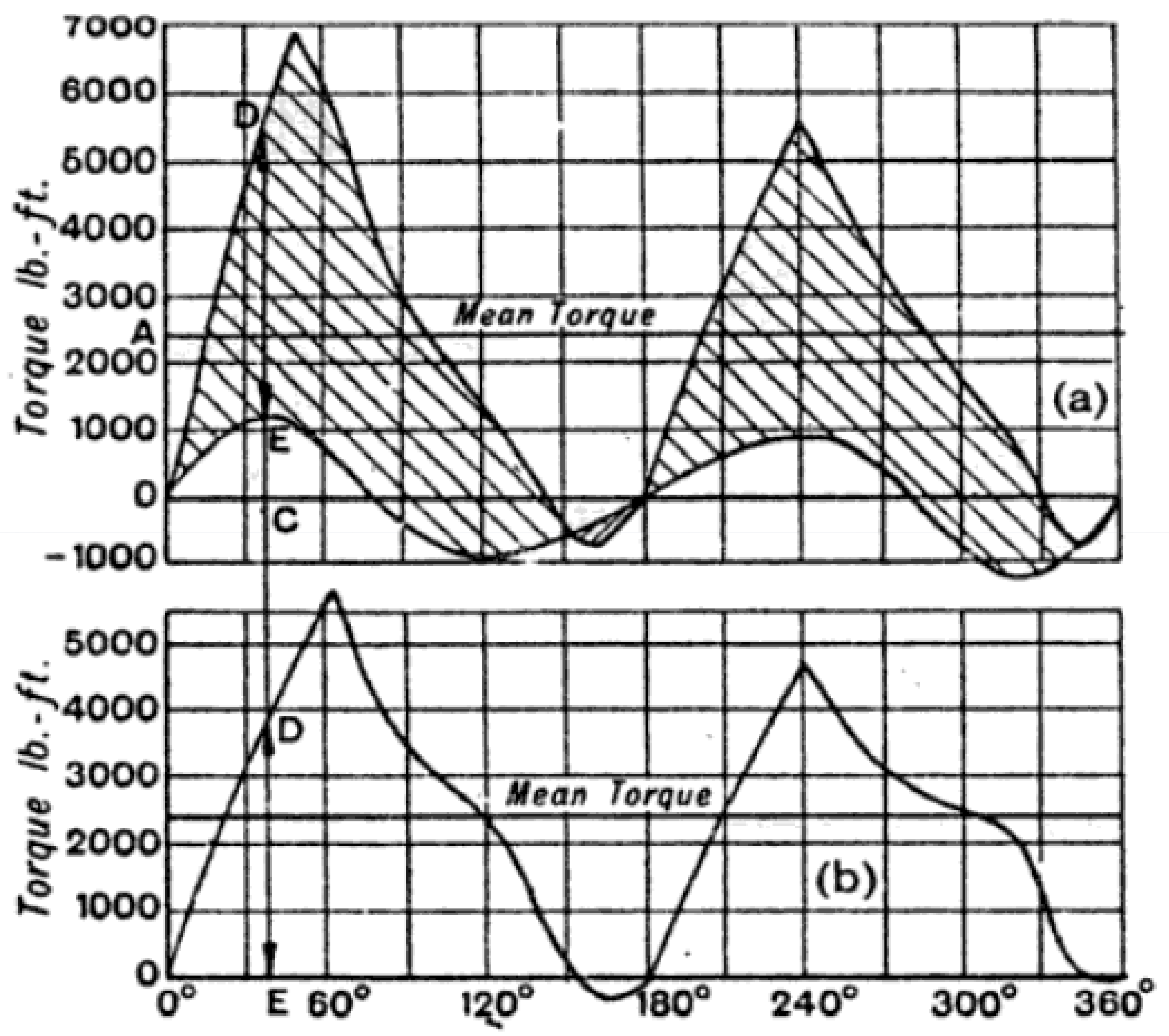
Note: For each half-revolution of the crank the diagram has a positive and a negative loop. The two loops are different in shape because of the effect of the **obliquity** of the connecting rod, but they are of equal area.

The diagrams of Figs. [1] and [2] have been combined in Fig. (a) to give the net torque or turning moment diagram.



The net torque for a given crank position is represented by the ordinate of the shaded portion of the diagram.

Thus for the crank position represented by C the steam torque is given by CD, the torque required to accelerate the parts by CE and the net torque by ED. The variation of net torque is shown in Fig. (b).



7000
6000
5000
4000
3000
2000
1000
0
-1000
Torque lb.-ft.
D
A
E
C
Mean Torque
(a)
5000
4000
3000
2000
1000
0
Torque lb.-ft.
D
Mean Torque
(b)
0°
E 60°
120°
180°
240°
300°
360°

Let,

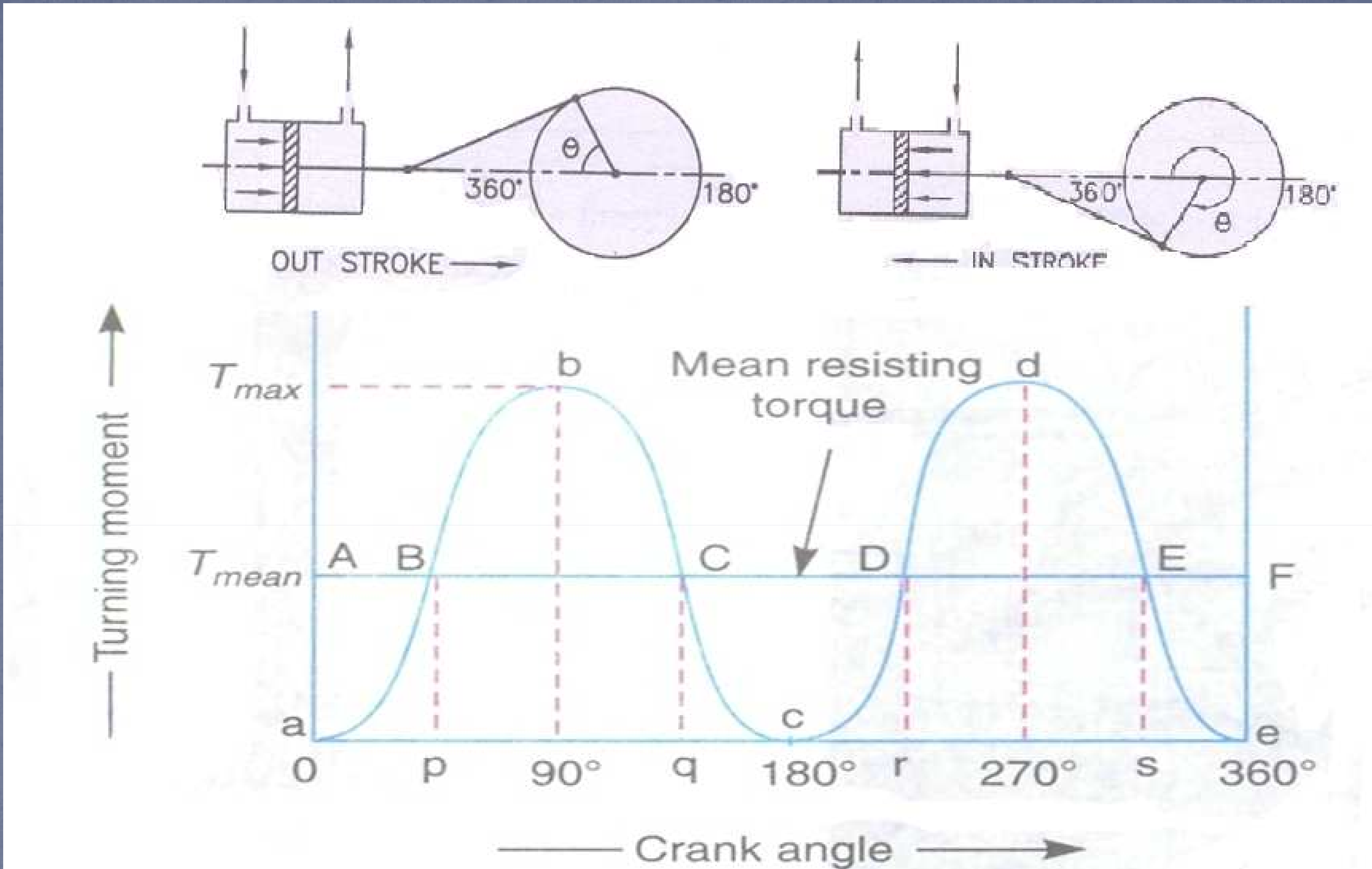
F_p = Piston effort,

r = Radius of crank,

n = Ratio of the connecting rod length and radius of crank, and

ϴ = Angle turned by the crank from inner dead centre.

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



Turning Moment Diagram for a Single Cylinder Double Acting Steam Engine

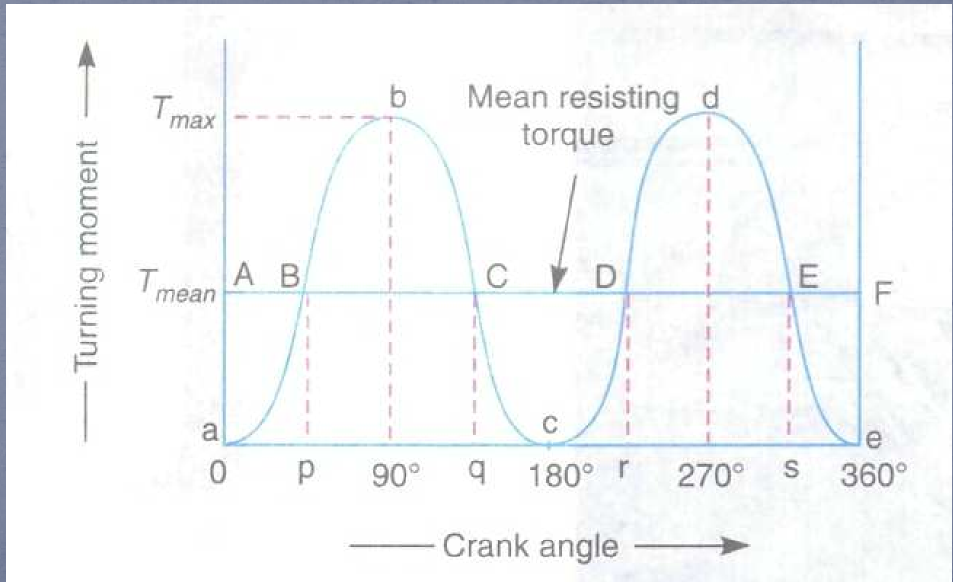
The turning moment T is zero, when the crank angle Θ is zero. It is maximum when the crank angle is 90 and again zero whent angle is 180.

This is shown by the curve *abc represents the turning moment diagram for outstroke. The curve cde is the turning moment diagram for instroke and is somewhat similar to the curve abc.*

Since the work done is the product of the turning moment and the angle turned, therefore the area of the turning moment diagram represents the work done per revolution.

In actual practice, the engine is assumed to work against the mean resisting torque, as shown by a horizontal line *AF. The height of the ordinate A represents the mean height of the turning moment diagram.*

Turning Moment Diagram for a Single Cylinder Double Acting Steam Engine



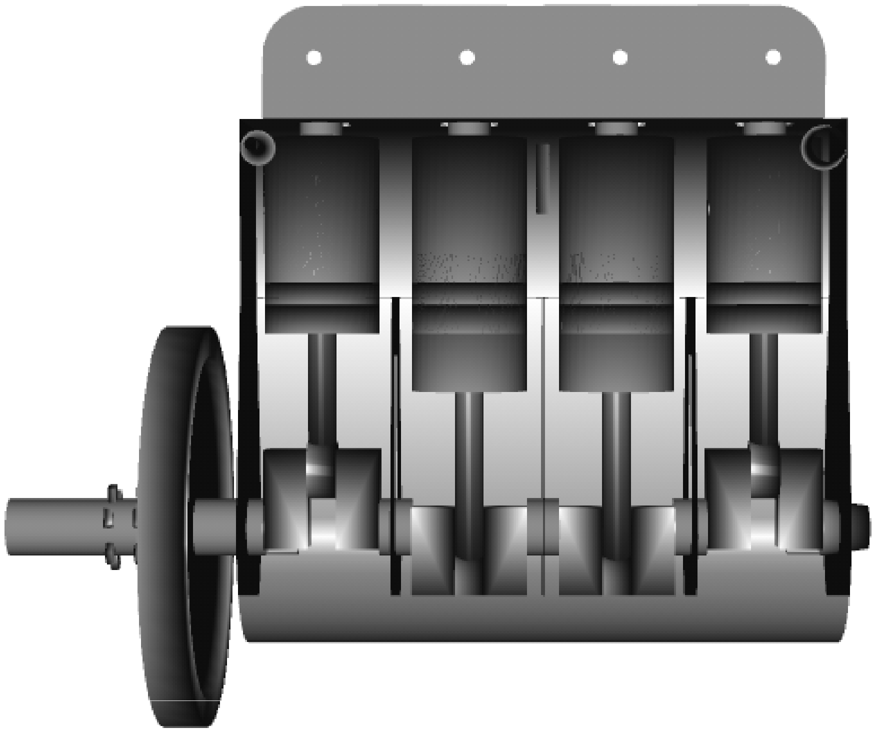
1. When the turning moment is positive *(i.e. when the engine torque is more than the mean resisting torque) as shown between points B and C (or D and E) in Fig. the crankshaft accelerates and the work is done by the steam.*

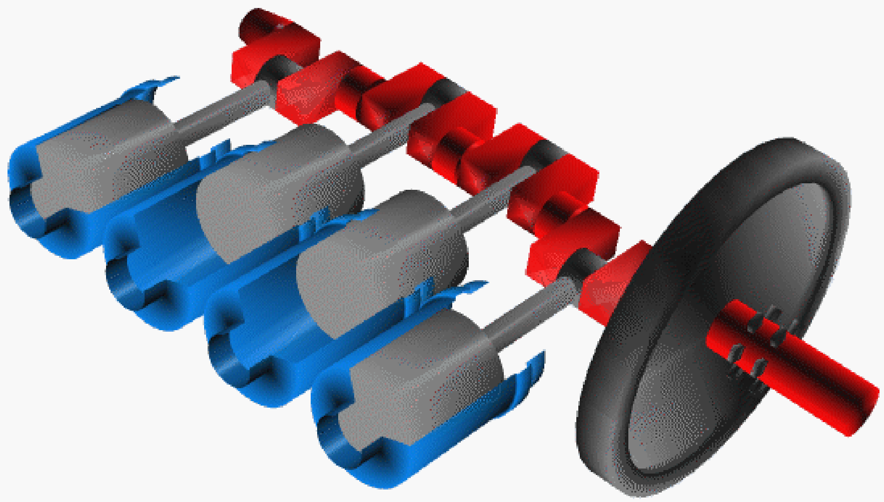
2. When the turning moment is negative *(i.e. when the engine torque is less than the mean resisting Torque) as shown between points C and D in Fig., the crankshaft retards and the work is done on the steam.*

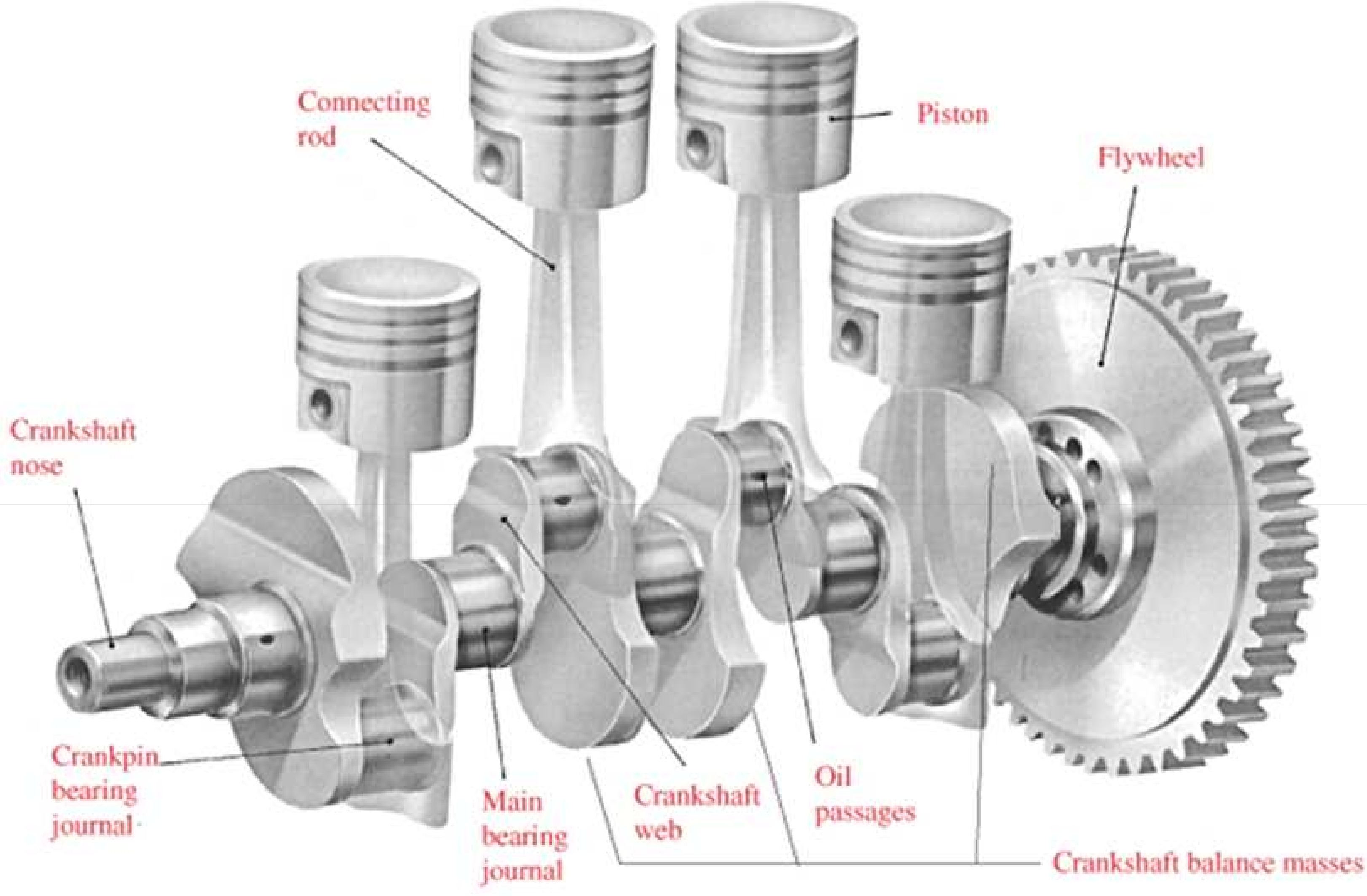
3. *if* T = *Torque on the crankshaft at any instant, and*
T_{mean} = *Mean resisting torque.*

Then accelerating torque on the rotating parts of the engine = $T - T_{mean}$

4, If ($T - T_{mean}$) is positive flywheel accelerates and if ($T - T_{iwan}$) is negative, then the flywheel retards.

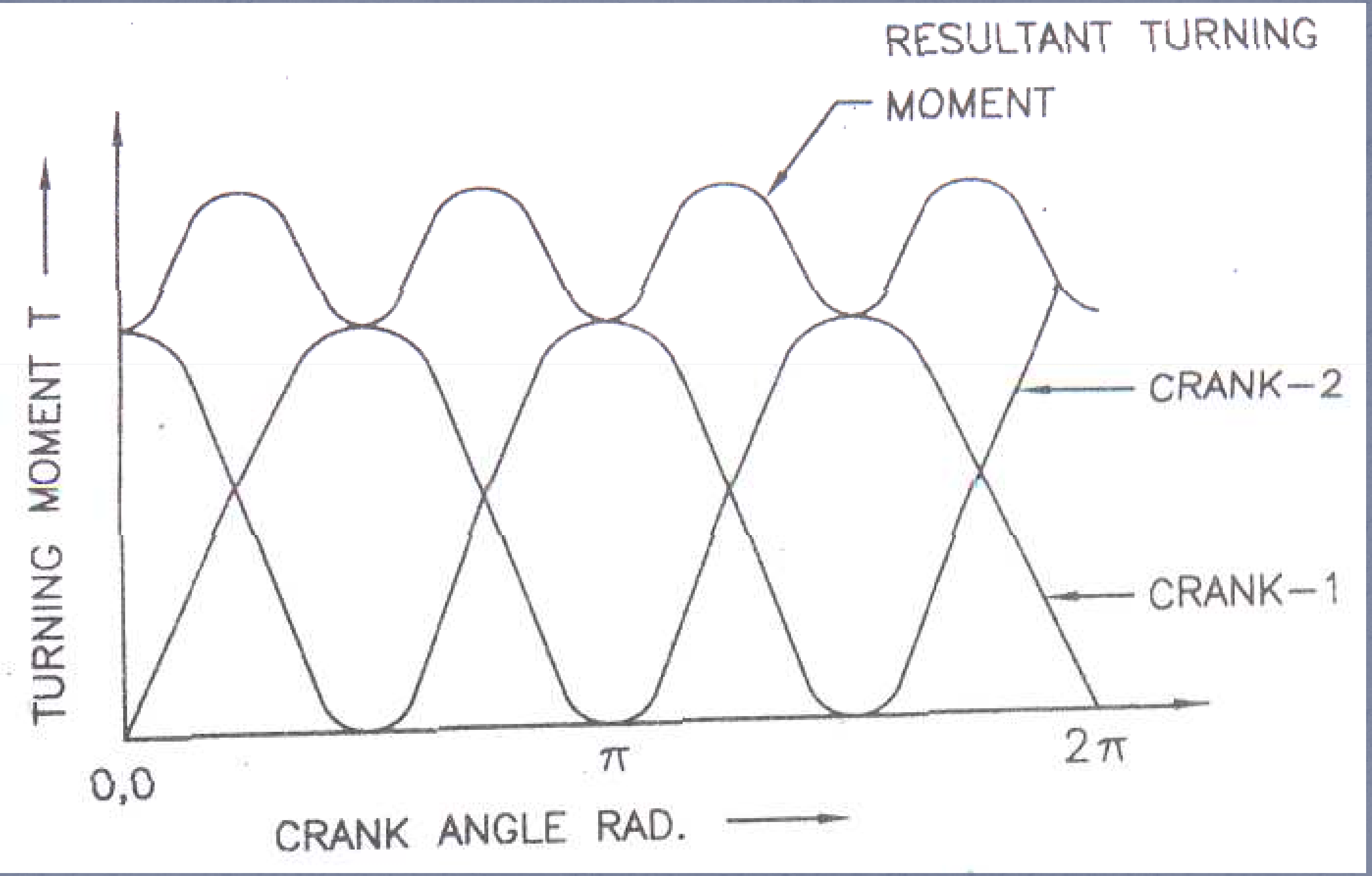






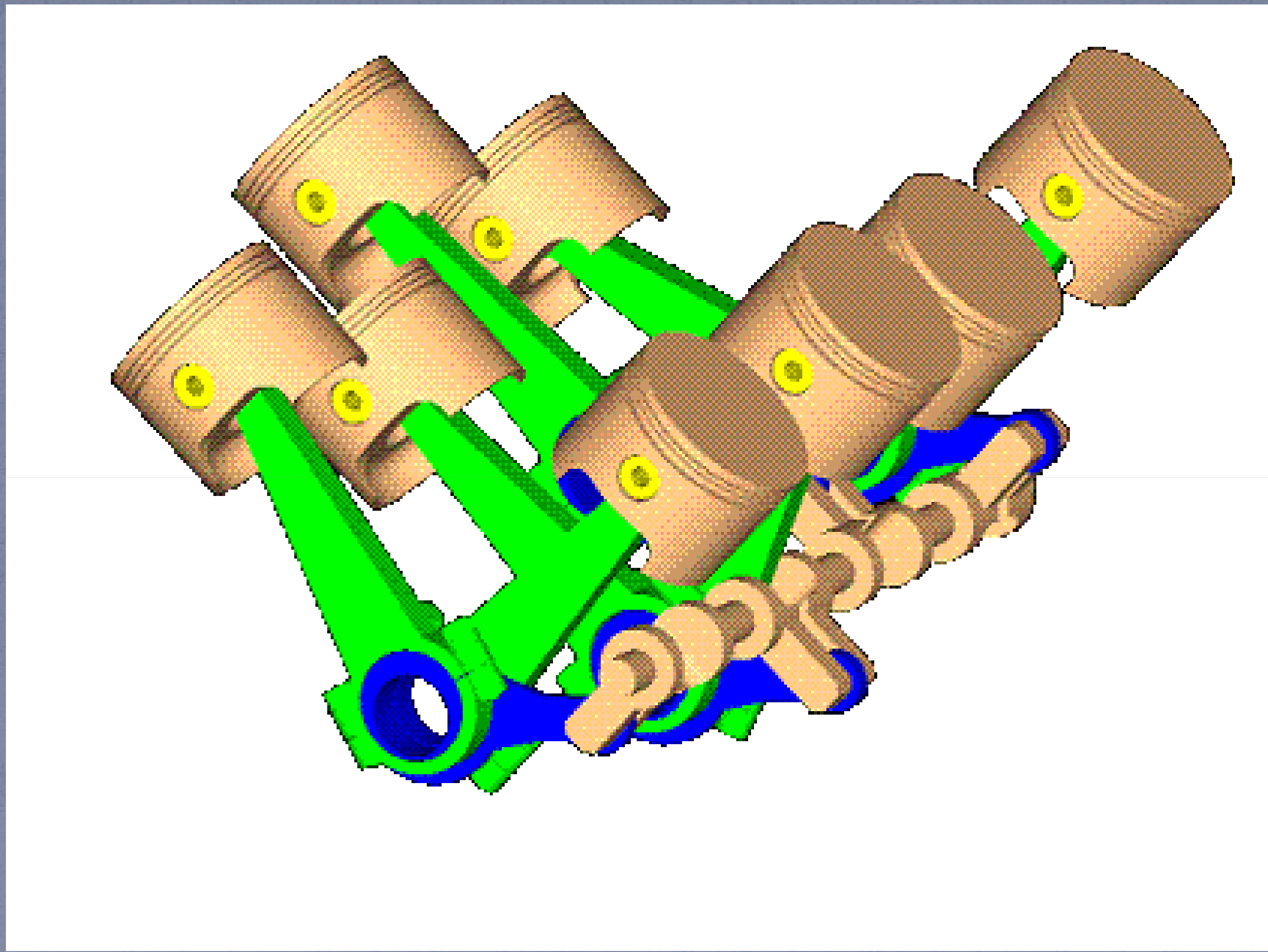
Crankshaft from an inline four-cylinder engine with pistons, connecting rods, and flywheel

Turning Moment Diagram for double cylinder double acting Steam Engine

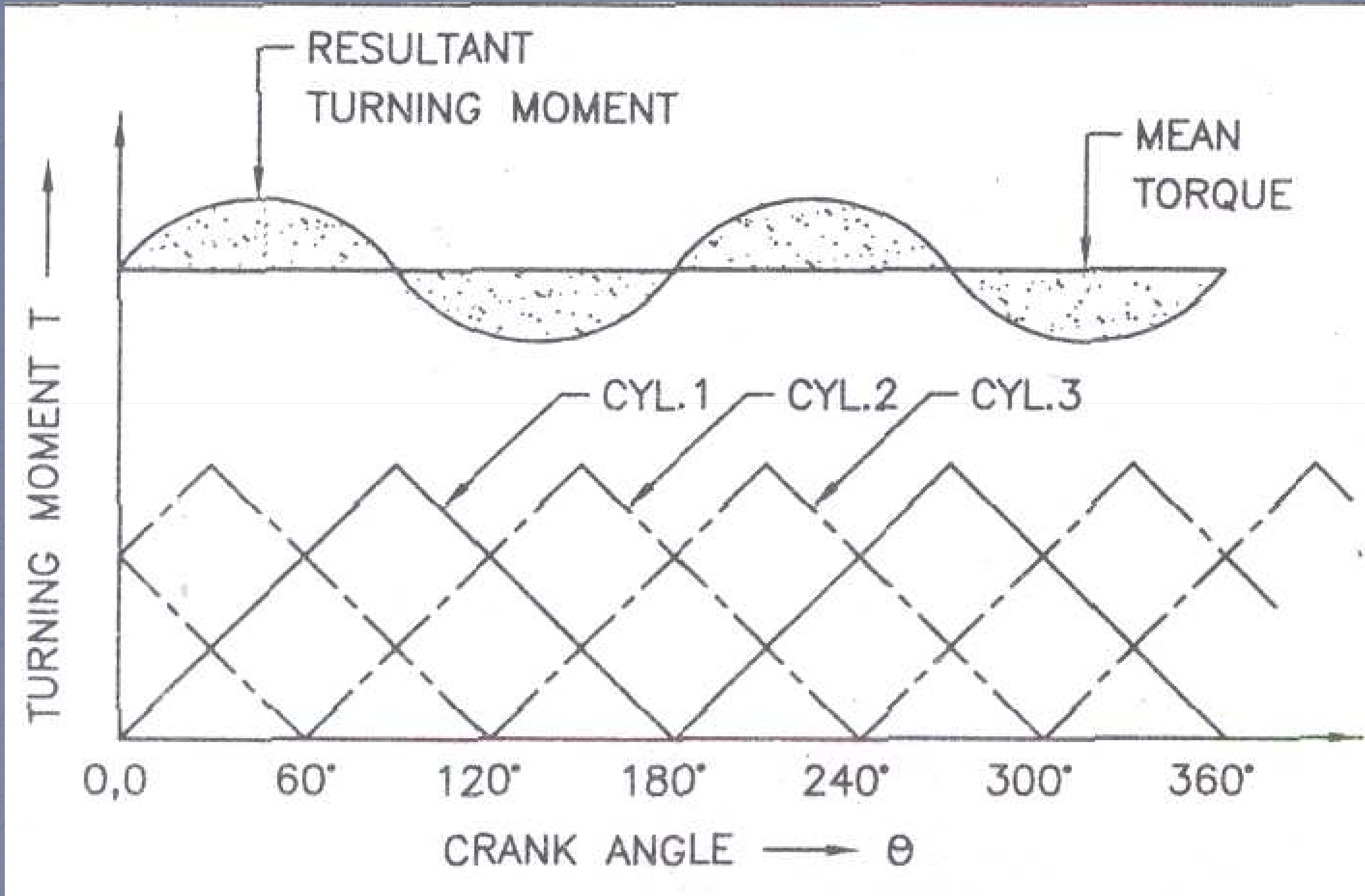


The diagram for each engine is drawn separately and After summation of all three, the resultant diagram is drawn .

The arrangement of cylinders are done in such a way that there is minimum possible variation in turning moment. That’s why cranks arranger on the angle of 90 degree.



TURNING MOMENT DIAGRAM TOR TRIPLE CYLINDER COMPOUND STEAM ENGINE

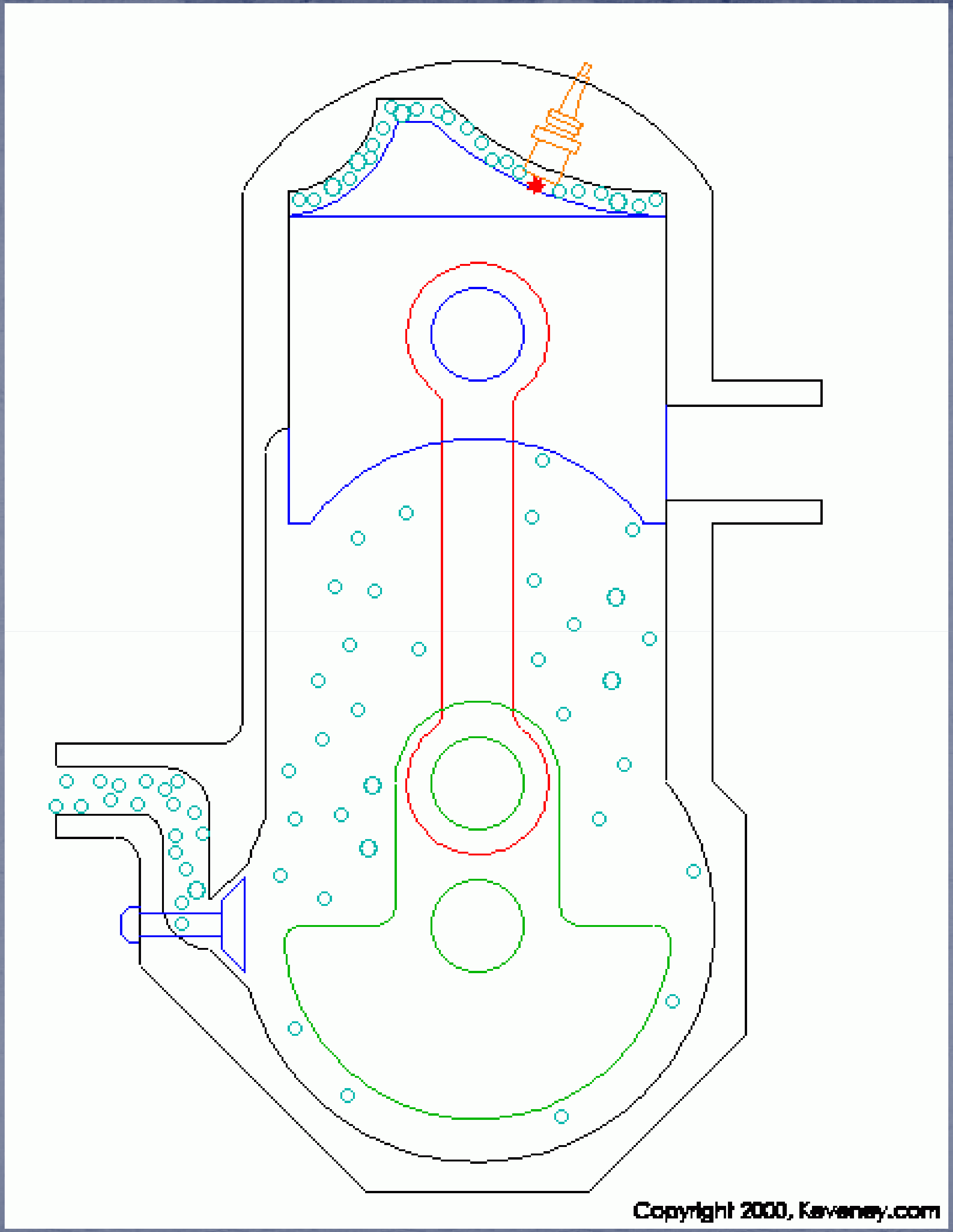


Three cylinders double acting compound steam engine.

the diagram for each engine is drawn separately and After summation of all three, the resultant diagram is drawn.

Here generally first cylinder is of high pressure second is of Medium and third is low pressure.

The arrangement of cylinders are done in such a way that there is minimum possible variation in turning moment. That's why cranks arranger on the angle of 120 degree.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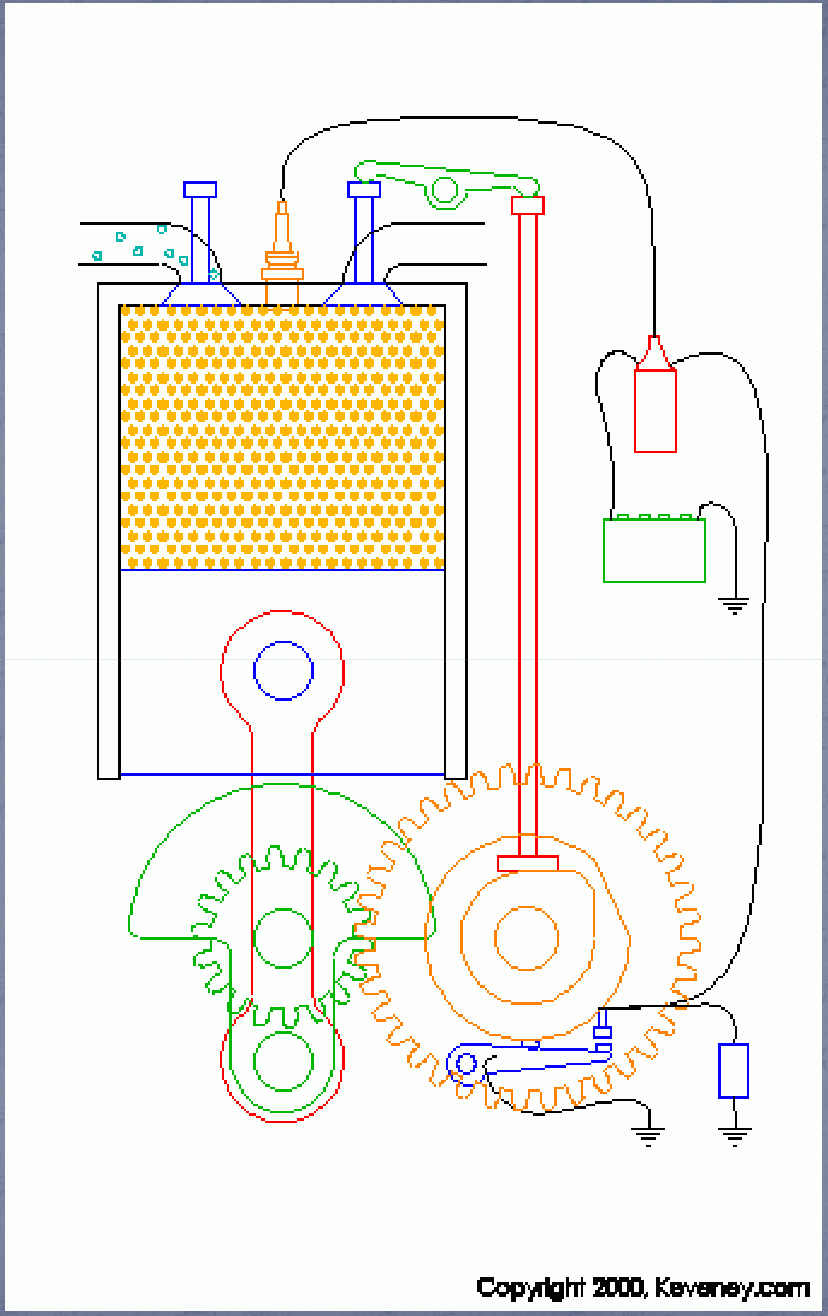
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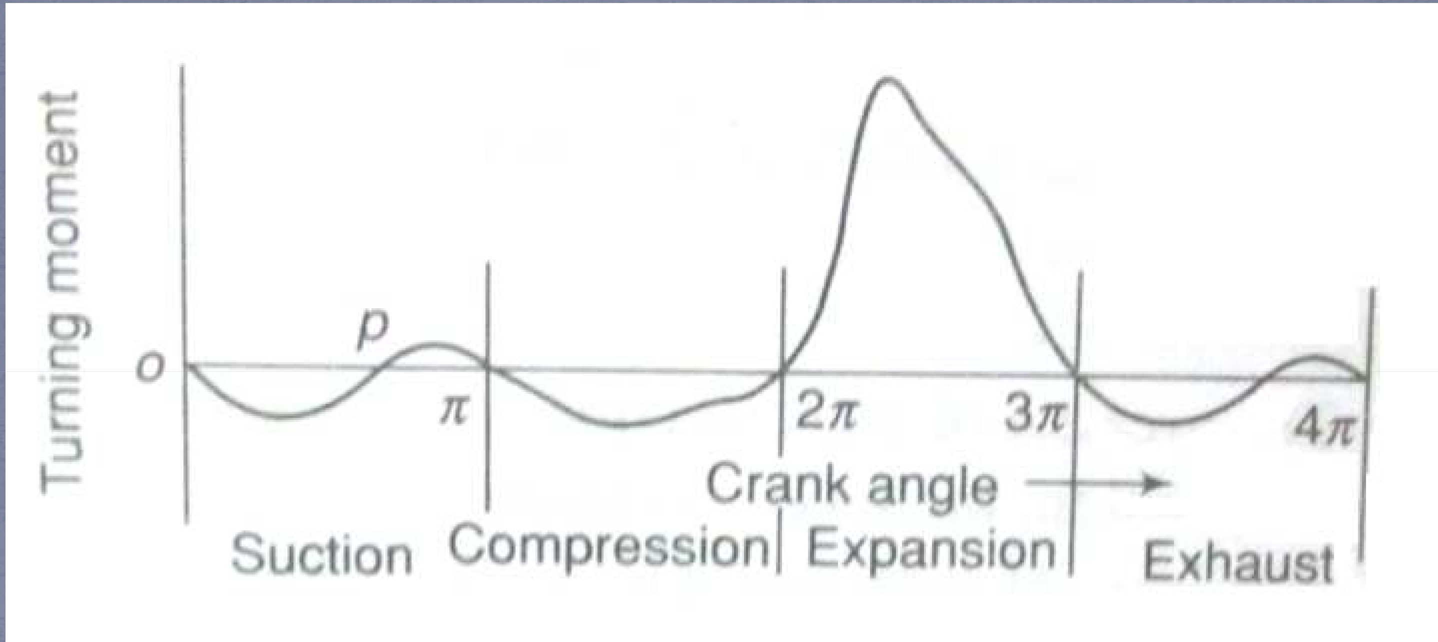
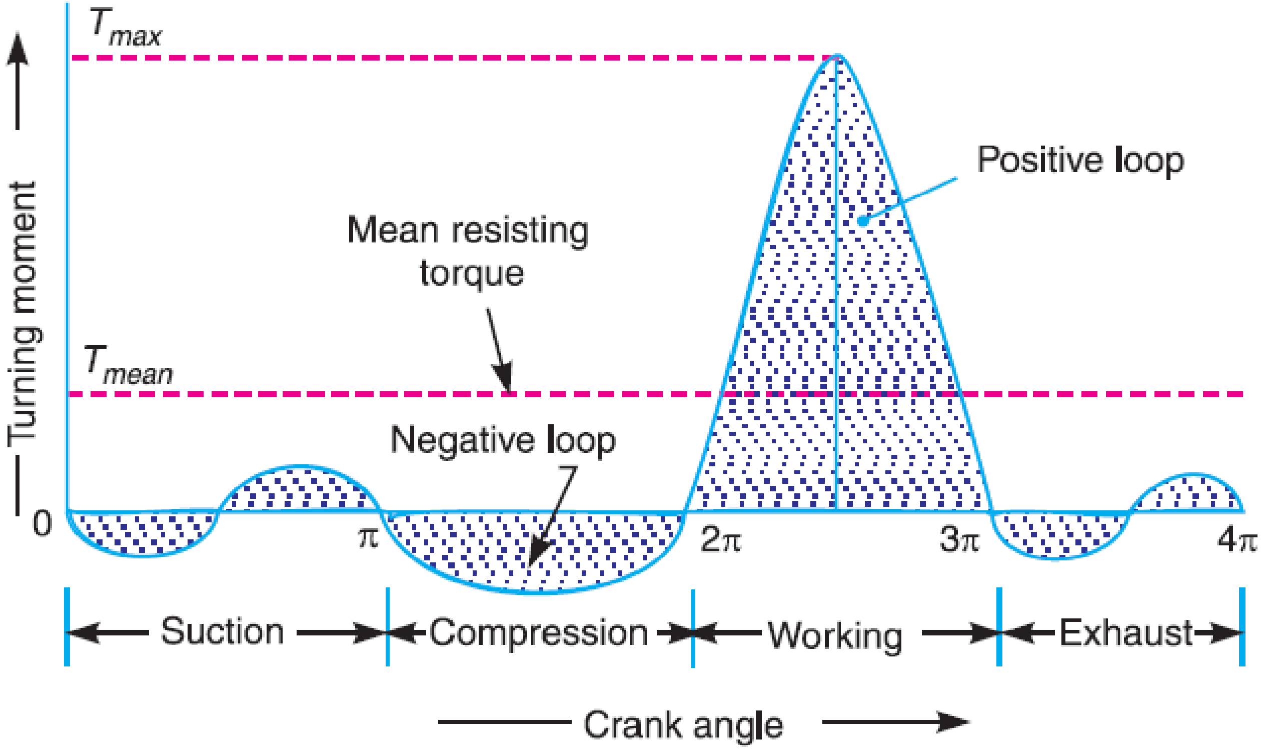
TURNING MOMENT DIAGRAM FOR FOUR STROKE CYCLE I.C. ENGINE



A turning moment diagram for a four stroke cycle internal combustion engine is shown in Fig. In a four stroke cycle IC engine, there is one working stroke after the crank has turned through two revolutions, *i.e. 720°(or 4 π radians).*



➢Since the pressure inside the engine cylinder is less than the atmospheric pressure during the suction stroke, therefore a negative loop is formed as shown in Fig.

➢During the compression stroke, the work is done on the gases, therefore a higher negative loop is obtained.

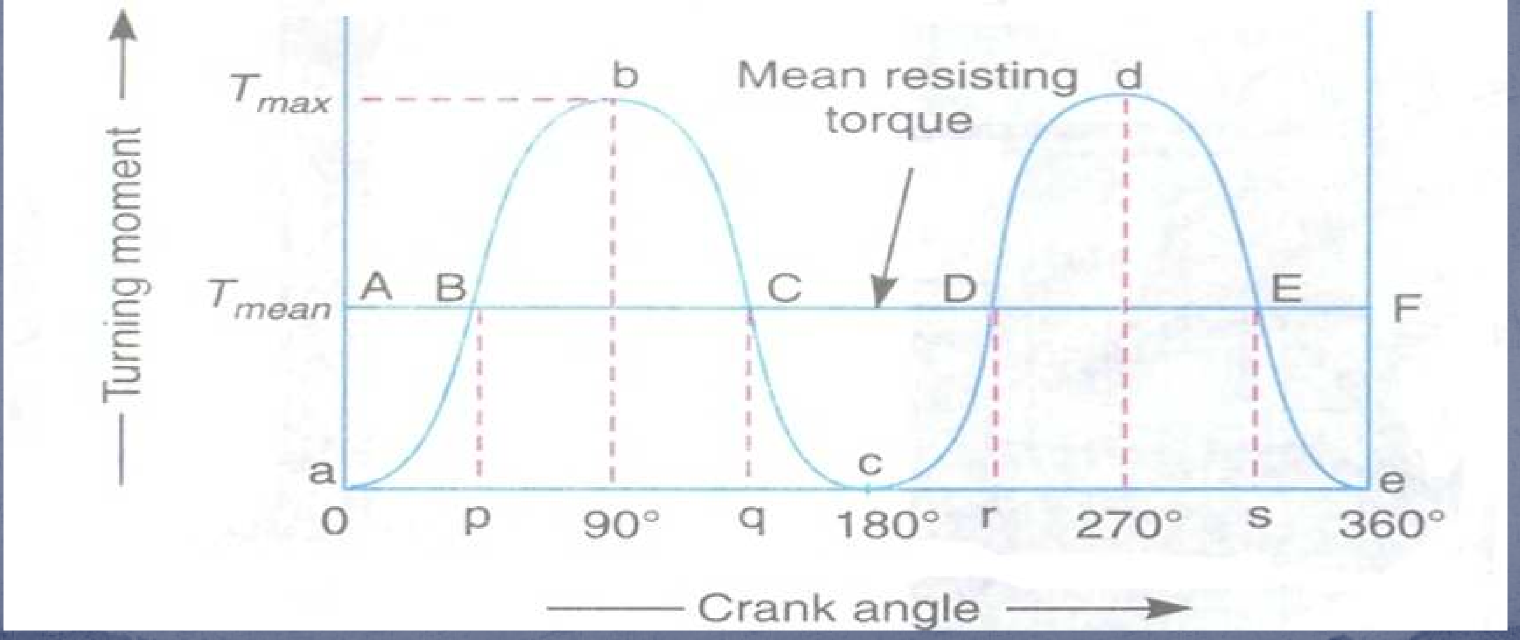
➢During the expansion or working stroke, the fuel burns and the gases expand, therefore a large positive loop is obtained. In this stroke, the work is done by the gases.

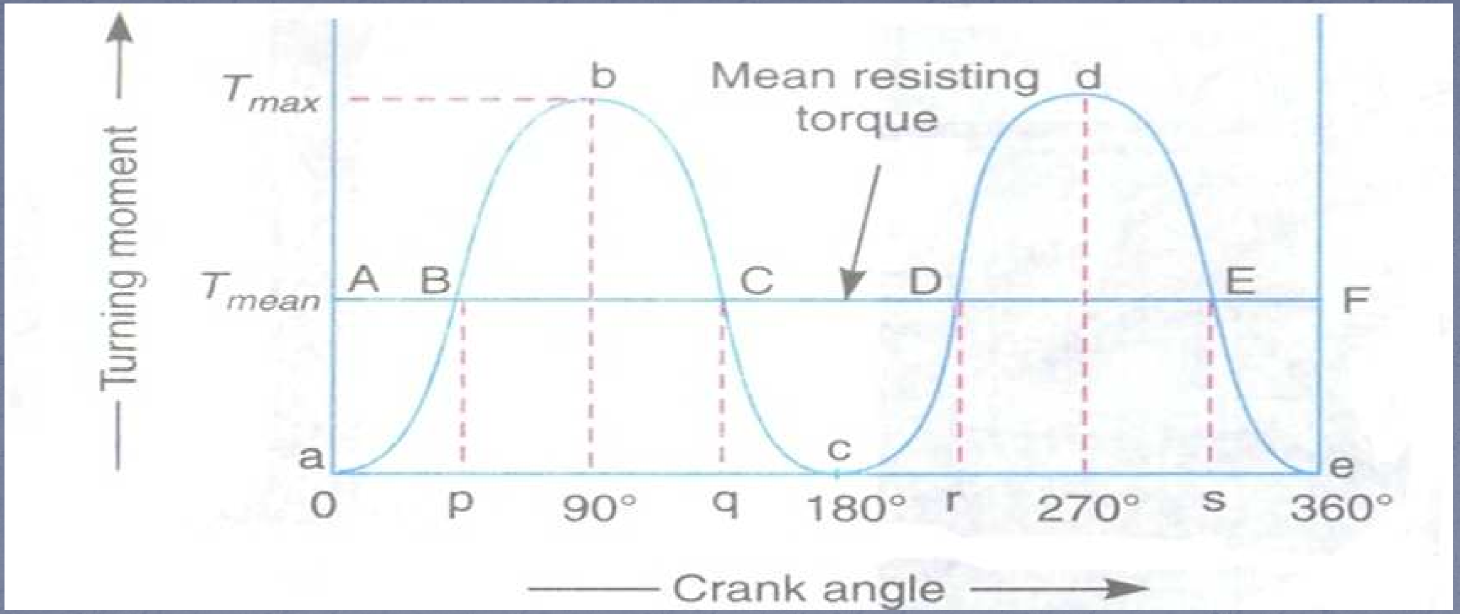
➢During exhaust stroke, the work is done on the gases, therefore a negative loop is formed. It may be noted that the effect of the inertia forces on the piston is taken into account in Fig.

Fluctuation of Energy

The fluctuation of energy may be determined by the turning moment diagram for one complete cycle of operation.

When the crank moves from a top, the work done by the engine is equal to the area aBp, whereas the energy required is represented by the area aABp.
The engine has done less work (equal to the area aAB) than the requirement. This amount of energy is taken from the flywheel and hence the speed of the flywheel decreases.





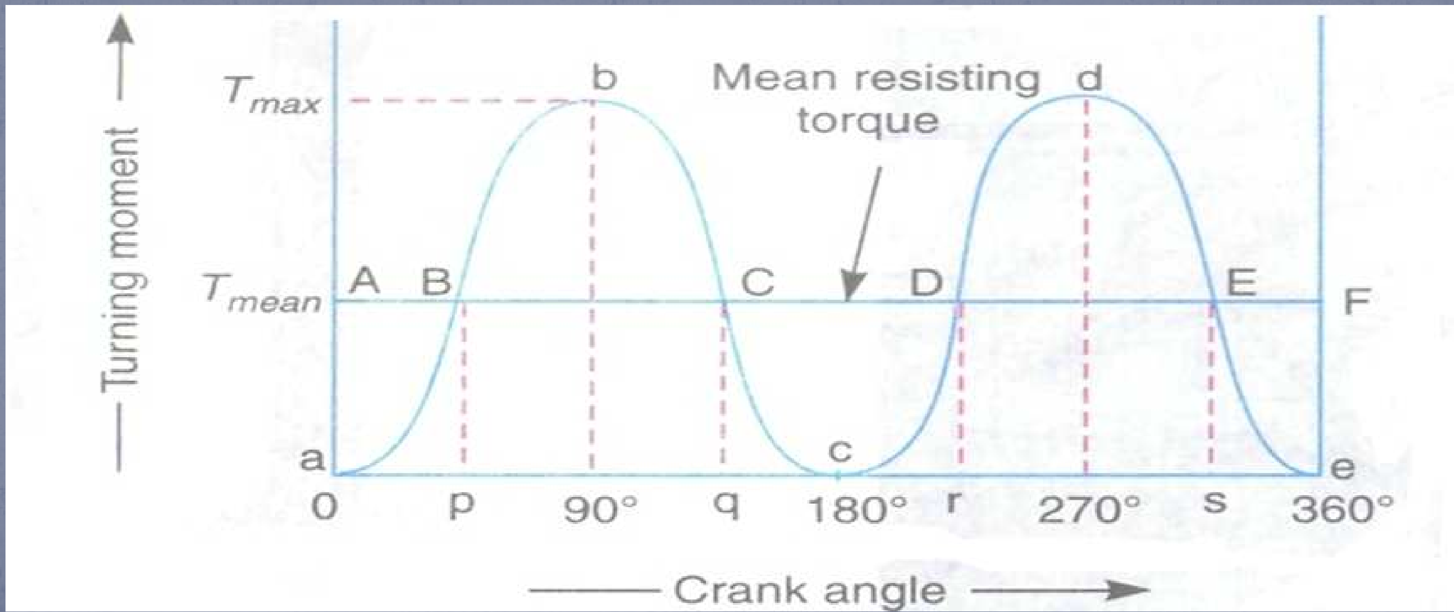
Now the crank moves from p to q, the work done by the engine is equal to the area pBbCq, whereas the requirement of energy is represented by the area pBCq. Therefore, the engine has done more work than the requirement. This excess work (equal to the area BbC) is stored in the flywheel and hence the speed of the flywheel increases while the crank moves from p to q.

A little consideration will show that the engine has a maximum speed either at *q or at s.*

this is due to the fact that the flywheel absorbs energy while the crank moves from p to q and from r to s.

On the other hand, the engine has a minimum speed either at p or at r. The reason is that the fly gives out some of its energy when the crank moves from a top and q to r.

The difference between maximum and the minimum energies is known as maximum fluctuation of energy.

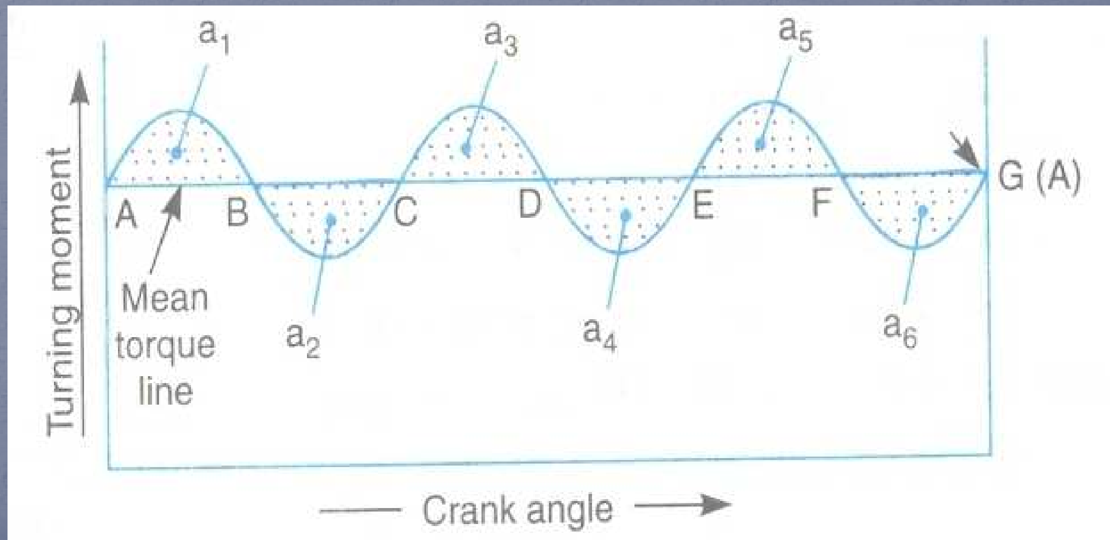


Determination of Maximum Fluctuation of Energy

A turning moment diagram for a multi-cylinder engine is shown by a wavy curve. The horizontal line *AG represents the mean torque line.*

Let a_1 a_3 a_5 be the areas above the mean torque line and a_2, a_4 and a_6 be the areas below the mean torque line.

These areas represent some quantity of energy which is either added or Subtracted from the energy of the Moving Parts of the engine.



Let the energy in the flywheel at $A = E$,

Energy at $B = E + a_1$

Energy at $C = E + a_1 - a_2$,

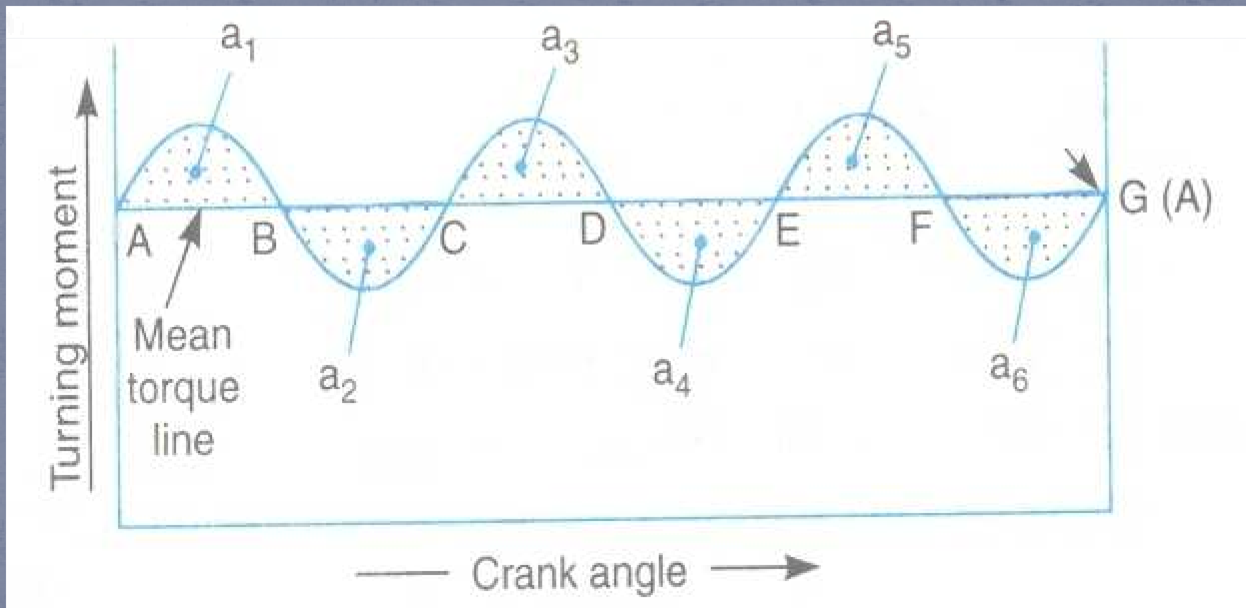
Energy at $D = E + a_1 - a_2 + a_3$

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

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

Energy at $G = E + a_l - a_2 + a_3 - a_4 + a_5 - a_6$

$\quad\quad =$ *Energy at A (i.e. cycle repeats after G)*



Let us now suppose that the greatest or highest energy in energies is at B and least at E. Therefore,

Maximum energy in flywheel $= E + a_1$

Minimum energy in the flywheel $= E + a_1 - a_2 + a_3 - a_4$

Maximum fluctuation of energy,

ΔE = *Maximum energy - Minimum energy*

$= a_2 - a_3 + a_4$

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

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

Where, moment of inertia, I $= mk^2$

$$\Delta E = 2EC_s = m K^2 \omega^2 Cs$$

N_1 = Max speed during cycle
N_2 = Min Speed during cycle
N = Avg. speed (N1 + N2) / 2

Coefficient of Fluctuation of Speed, Cs

$$= (N_1 - N_2) / N$$

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

Coefficient of steadiness, $m = \frac{1}{Cs}$

Coefficient of Fluctuation of Energy

It may be defined as the ratio of the maximum fluctuation of energy to the work done per cycle. Mathematically, coefficient of fluctuation of energy

$$C_E = \frac{\text{Maximum fluctuation of energy}}{\text{Work done per cycle}}$$

The work done per cycle (in N-m or joules) may be obtained by using the following two relations :

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

T_{mean} = *Mean torque, and*

θ = Angle turned (in radians), in one revolution.

= *2π, in case of steam engine and two stroke internal combustion* engines

= 4π. in case of four stroke internal combustion engines.

The mean torque (T_{mean}) in N-m may be obtained by using the following relation

$$T_{mean} = P / \omega$$

P = Power transmitted in watts,

N = Speed in r.p.m., and

ω = Angular speed in rad/s = $2 \pi N / 60$

The work done per cycle may also be obtained by using the following relation

$$\text{Work done per cycle} = \frac{P \times 60}{n}$$

where n = Number of working strokes per minute,

= N, in case of steam engines and two stroke internal combustion engines,

= N/2, in case of four stroke internal combustion engines.

Hoop Stress = $\rho \times v^2$

ρ = density of flywheel material

V = peripheral velocity

= **Π d N / 60**

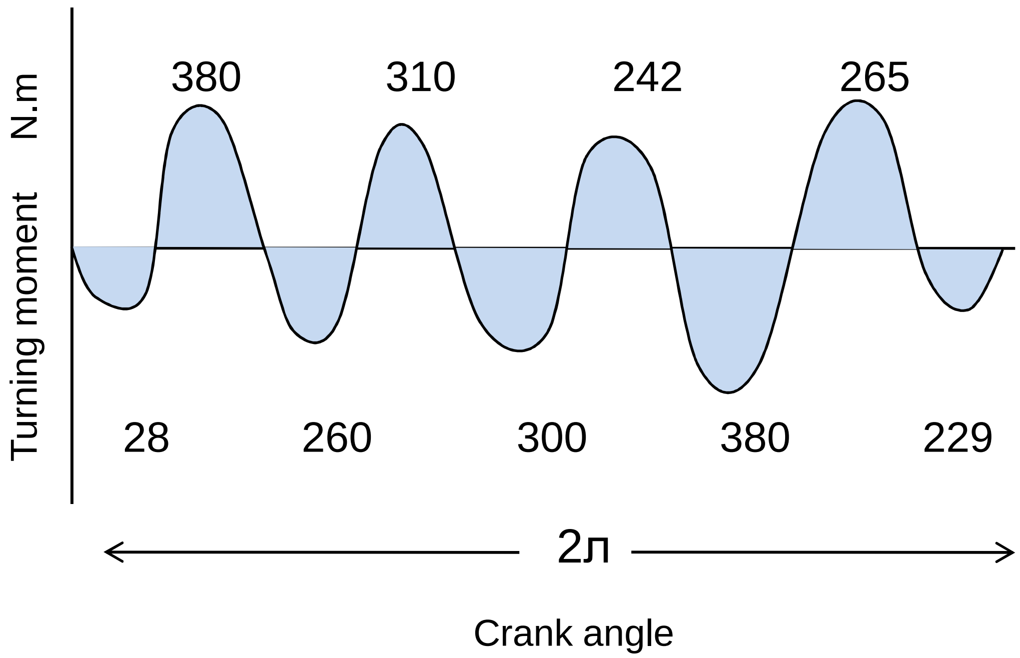
If b is width and t is thickness of the Rim having rectangular section,

Mass m = vol. X density

= (2Π r X A) X ρ

= 2Π r X (b X t) X ρ

Vertical axis : 1 mm = 650 N.m
Horizontal axis : 1 mm = 4.5 degree



Find out the mass of flywheel of radius 0.7 m , if the total fluctuation is +/- 1.8% of average speed and the avg. speed is 400 rpm.

N = 400 rpm

Average fluctuation = +/- $\frac{400 \times 1.8}{100}$

N_1 = 400 +

N_2 = 400 -

Coefficient of Fluctuation of Speed **Cs = 0.036**

Let the energy in the flywheel at *A = E,*

Emax = E + 402
Emin = E -36

Δ E = Maximum energy - Minimum energy = 438 mm^2

Convert this value by scale,

$438 \times 650 \times \frac{4.5 \times \pi}{180}$ N.m

$\Delta E = m K^2 \omega^2 Cs$ ***m= 725 .11 Kg***

Engine produces power of295 KW while rotating at 90 rpm. Co efficient of fluctuatuin = 0.1 and limited by +/- 5 % of average speed. Radius of gyresion is 2 m. Find out mass of fly wheel.

N = 90 rpm
P = 295 KW
$C_E = 0.1$
K = 2 m

Work done in 1 cycle = $\frac{P \times 60}{N}$ = 196.67 KN.m

Max energy fluctuation = ΔE = Work done in 1 cycle x C_E

= 19.667 KN.m
= 19667 Nm

$\Delta E = m K^2 \omega^2 Cs$

m = 553.5 Kg

A vertical double acting steam engine dedvelops 75 KW at 250 rpm. The maximum flactuation of energy is 30 % of work done.The maximum speed and minimum speeds are not vary more than 1 % on either side of mean speed. Find out mass of flywheel if radius of gyration is 0.6 m

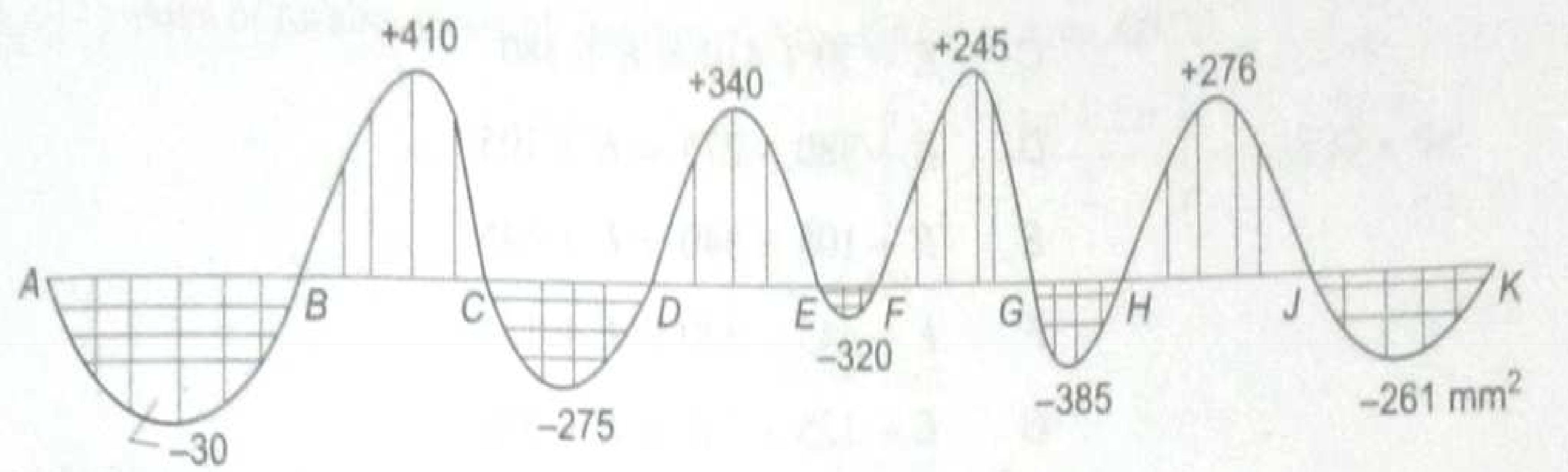
N = 250 rpm
P = 75 KW
ΔE *= 30% of WD*
k = 0.6 m
$C_s = 2 \times 0.01 = 0.02$

$$\text{Work done in 1 cycle} = \frac{P \times 60}{N} = 18000 \text{ N.m}$$

$$\text{Max energy fluctuation} = \Delta E = 0.30 \times \text{Work done in 1 cycle} = 5400 \text{ Nm}$$

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

The turning moment diagram for one revolution of a multi-cylinder engine is shown in Figure. The vertical and horizontal scales are: 1 mm = 600 Nm and 2.5° respectively.



The fluctuation of speed is limited to ±1.5% of mean speed, which is 250 rpm. The hoop stress in rim material is limited to 5.6 N/mm^2. Neglecting effect of boss and arms, determine the suitable diameter and cross-section of flywheel rim. Take density of rim material as 7200 kg/m^3 and width to be four times the thickness.

Given Data: $C_s = \pm 1.5$ % of mean speed $= 0.03$

$N = 250$ rpm $\quad$ б $= 5.6\ N/mm^2$

$\rho = 7200\ Kg/m^3$ $\quad$ $b = 4t$

Let the energy in the flywheel at *A = E,*

Emax = E + 445

Emin = E - 30

ΔE = Maximum energy - Minimum energy = 475 mm²

Convert this value by scale,

$$475 \times \left(600 \times \frac{2.5 \times л}{180}\right) \quad N.m$$

ΔE = 12435.47 Nm

Hoop Stress = $\rho \times v^2$

$V = \Pi D N / 60$

D = 2.1 m

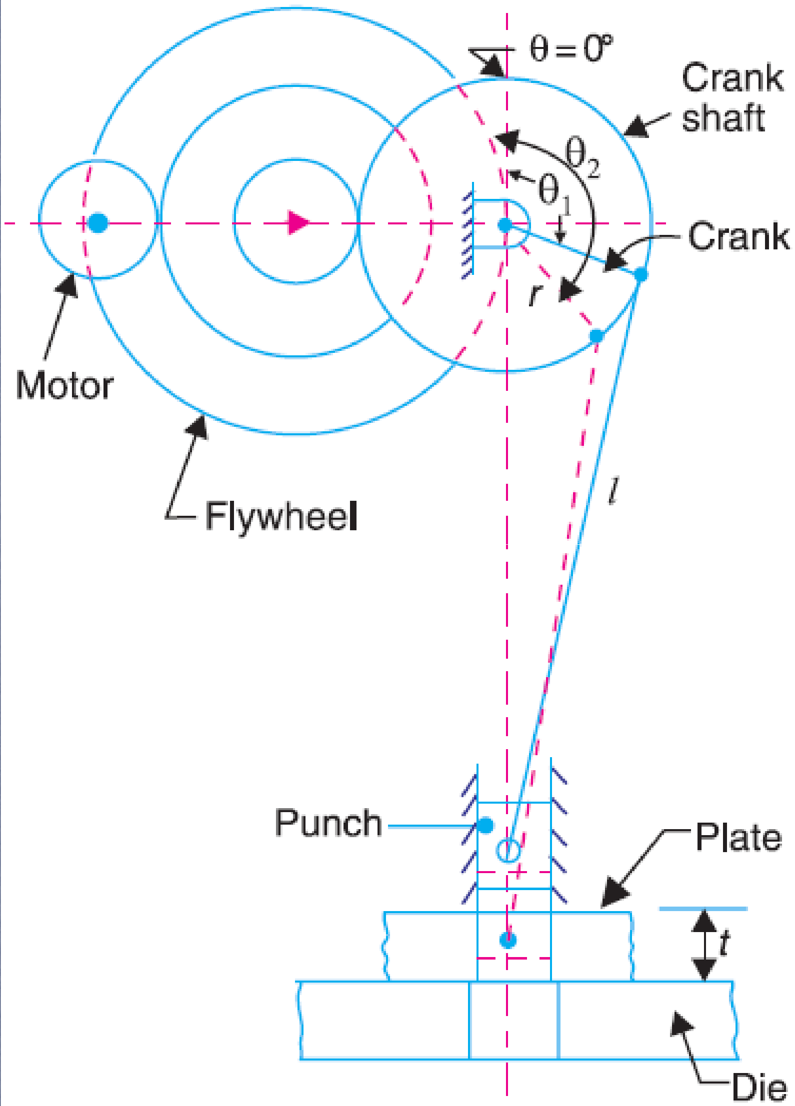
$\Delta E = m k^2 \omega^2 C_s$

m = 549.3 Kg

ρ = mass / Vol

$$= \frac{m}{\Pi D \times b \times t} = \frac{m}{\Pi D \times b \times 4b}$$

b = 215 mm and t = 53.7 mm



Flywheel in Punching Press

The load acts only during the rotation of the crank from $\theta = \theta_1$ to $\theta = \theta_2$, when the actual punching takes place and the load is zero for the rest of the cycle.

Unless a flywheel is used, the speed of the crankshaft will increase too much during $\theta = \theta_2$ to $\theta = 2\pi$ *or* $\theta = 0$ *and again from* $\theta = \theta_1$ to $\theta = \theta_2$, *because there is no load while input energy continues to be supplied.*

On the other hand, the drop in speed of the crankshaft is very large during the rotation of crank from **$\theta = \theta_1$ to $\theta = \theta_2$.**

Let E_1 be the energy required for punching a hole. This energy is determined by the size of the hole punched, the thickness of the material and the physical properties of the material.

Let d_1 = Diameter of the hole punched,

t_1 = Thickness of the plate, and

τ_u = Ultimate shear stress for the plate material.

$\therefore$ Maximum shear force required for punching,

$$F_S = \text{Area sheared} \times \text{Ultimate shear stress} = \pi d_1 . t_1 \tau_u$$

It is assumed that as the hole is punched, the shear force decreases uniformly from maximum value to zero.

$\therefore$ Work done or energy required for punching a hole,

$$E_1 = \frac{1}{2} \times F_s \times t$$

Assuming one punching operation per revolution, the energy supplied to the shaft per revolution should also be equal to E_1. The energy supplied by the motor to the crankshaft during actual punching operation,

$$E_2 = E_1\left(\frac{\theta_2 - \theta_1}{2\pi}\right)$$

$\therefore$ Balance energy required for punching

$$= E_1 - E_2 = E_1 - E_1\left(\frac{\theta_2 - \theta_1}{2\pi}\right) = E_1\left(1 - \frac{\theta_2 - \theta_1}{2\pi}\right)$$

This energy is to be supplied by the flywheel by the decrease in its kinetic energy when its speed falls from maximum to minimum. Thus maximum fluctuation of energy,

$$\Delta E = E_1 - E_2 = E_1\left(1 - \frac{\theta_2 - \theta_1}{2\pi}\right)$$

The values of θ_1 and θ_2 may be determined only if the crank radius (r), length of connecting rod (l) and the relative position of the job with respect to the crankshaft axis are known. In the absence of relevant data, we assume that

$$\frac{\theta_2 - \theta_1}{2\pi} = \frac{t}{2s} = \frac{t}{4r}$$

where t = Thickness of the material to be punched,

s = Stroke of the punch = $2 \times$ Crank radius = $2r$.

By using the suitable relation for the maximum fluctuation of energy (ΔE) as discussed in the previous articles, we can find the mass and size of the flywheel.

A punching press makes 25 holes of 20 mm diameter per minute in a plate 15 mm thick. This causes variation in the speed of flywheel attached to press from 240 to 220 rpm. The punching operation takes 2 seconds per hole. Assuming 6 Nm of work is required to shear 1 mm^2 of the area and frictional losses account for 15% of the work supplied for punching, determine (a) the power required to operate the punching press, and (b) the mass of flywheel with radius of gyration of 0.5 m.

Work required for punching one hole

= Area of shear in mm^2 x Work per mm^2

= π d t x6 = π x 20 x l5 x 6

= 5654.86 Nm

Accounting 15% for frictional losses, the actual work supplied

$$= \frac{5654.86}{0.85} = \mathit{6652.78\ Nm}$$

Total work required per minute for drilling 25 holes

= 6652.78 x 25 = 166319 Nm

$$\text{Power required} = \frac{166319}{60 \times 10^3} = 2.772 \text{ kW}$$

Energy supplied during the punching operation

= 2.772 x 1000 x 2 = 5544 Nm

Energy supplied by the flywheel, = *6652.78 - 5544 = 1108.78 Nm*

$$\Delta E = \frac{1}{2} I \left[\omega_1^2 - \omega_2^2 \right]$$

M = 87.92 Kg

Example *A punching press is driven by a constant torque electric motor. The press is provided with a flywheel that rotates at maximum speed of 225 r.p.m. The radius of gyration of the flywheel is 0.5 m. The press punches 720 holes per hour; each punching operation takes 2 second and requires 15 kN-m of energy. Find the power of the motor and the minimum mass of the flywheel if speed of the same is not to fall below 200 r. p. m.*

Solution. Given $N_1 = 225$ r.p.m ; $k = 0.5$ m ; Hole punched = 720 per hr; $E_1 = 15$ kN-m $= 15 \times 10^3$ N-m ; $N_2 = 200$ r.p.m.

Power of the motor

the total energy required per second

= Energy required / hole × No. of holes / s

$= 15 \times 10^3 \times 720/3600 = 3000$ N-m/s

∴ Power of the motor = 3000 W = 3 kW **Ans.** (∵ 1 N-m/s = 1 W)

Minimum mass of the flywheel

Let m = Minimum mass of the flywheel.

Since each punching operation takes 2 seconds, therefore energy supplied by the motor in 2 seconds,

$$E_2 = 3000 \times 2 = 6000 \text{ N-m}$$

∴ Energy to be supplied by the flywheel during punching or maximum fluctuation of energy,

$$\Delta E = E_1 - E_2 = 15 \times 10^3 - 6000 = 9000 \text{ N-m}$$

Mean speed of the flywheel,

$$N = \frac{N_1 + N_2}{2} = \frac{225 + 200}{2} = 212.5 \text{ r.p.m}$$

maximum fluctuation of energy (ΔE),

$$9000 = \frac{\pi^2}{900} \times m.k^2.N(N_1 - N_2)$$

$$= \frac{\pi^2}{900} \times m \times (0.5)^2 \times 212.5 \times (225 - 200) = 14.565\, m$$

∴ $m = 9000/14.565 = 618$ kg **Ans.**

**Success isn't how far you got,
but the distance you traveled from
where you started.**

So rise your level from right now….