UNIT-IV

ENERGY STORING ELEMENTS AND ENGINE COMPONENTS

PART - A

1. **Why springs are used in the machine? (Dec 2010)**

   Springs are used in the machines to provide cushioning effect or reduce the effect of shock or impact loading.

2. **State any two functions of springs. (Dec 2006)**

   To measure forces in spring balance, meters and engine indicators.

   To store energy.

3. **What is surge in springs? (May 2013)**

   The material is subjected to higher stresses which may cause early fatigue failure. This effect is called as spring surge.

4. **What is meant by semi elliptical leaf spring? (May 2014)**

   The spring consists of number of leaves which are held together by U- clips. The long leaf fastened to the supported is called master leaf. Remaining leaves are called graduated leaves.

5. **What is the purpose of flywheel that is used in an IC engine? (Dec 2013)**

   A flywheel is a heavy rotating mass which is placed between the power source and the driven member to act as a reservoir of energy. The primary function of flywheel is to act as an "energy accumulator". It will absorb energy when demand is less than the supply of energy and will release it when the demand is more than the energy being supplied.

6. **How does the function of flywheel differ from that of governor? (Dec 2012)**

Governor regulates the mean speed of an engine when there are variations in the load, e.g. when the load on the engine increases, it becomes necessary to increase the supply of working fluid. On the other hand, when the load decreases, less working fluid is required. The governor automatically controls the supply of working fluid to the engine with the varying load condition and keeps the mean speed within certain limits.

Flywheel does not maintain a constant speed, it simply reduces the fluctuation of speed. In other words, a flywheel controls the speed variations caused by the fluctuation of the engine turning moment during each cycle of operation. It does not control the speed variations caused by the varying load.

7. Define the co-efficient of fluctuation of speed in case of flywheel. (Nov 2014)

When the fly wheel absorbs energy, its speed increases and when it releases the energy, its speed decreases. N_1 and N_2 be the maximum and minimum speeds and N is the average speed.

The difference between the maximum and minimum speeds during a cycle is called the maximum fluctuation of speed. The ratio of the maximum fluctuation of speed to the mean speed is called coefficient of fluctuation of speed.

$$C_s \text{ or } K_s = (N_1 - N_2) / N$$

8. Under what circumstances Bellevellie springs used? (Dec 2010)

When large force is applied and deflection must be small. When space availability is small.

9. Distinguish between close coiled and open coiled springs. (Nov 2014)

Open coiled spring;

The wires are coiled such that there is a gap between the two consecutive turns. Helix angle is larger than 10^0.Both torsional and bending stresses are significant.

Closed coiled spring:

The wires are coiled very closely, each turn is nearly at right angles to the axis of helix. Helix angle is smaller than 10^0. Torsional Stresses are predominant.

10. Mention any four types of springs. (May 2012)

Helical Spring	Conical Spring
Spiral Spring	Disc or Bellville Spring
Leaf Spring.	

11. Why leaf springs are made in layers instead of single plate? (Dec 2010)

Leaf springs are made in layers because,

1. To have equal stress
2. To achieve economical design

12. Define spring Index and stiffness. (DEC 2011)

The ratio of mean or pitch diameter to the diameter of wire for the spring is called spring index. Stiffness is the ratio of load to the deflection.

13. What are different styles of end for helical compression spring? (Nov 2009)

Plain end

Plain and ground

Squared

Squared and ground

14. Why piston end of a connecting rod kept smaller than the crank pin end? (Dec 2010)

The piston end of the connecting rod experiences less bending moment than crank end. Hence on the basis of beam of uniform strength the piston end of the connecting rod is smaller.

15. At what angle of the crank the twisting moment is maximum in the crankshaft? (Dec 2011)

The crank angle for maximum twisting moment lies between 250 and 350 from TDC for petrol engines and between 300 and 400 for diesel engine.

16. What are the forces acting on connecting rod? (April 2017)

The external forces acting on connecting rod are

1. Forces due to gas or steam pressure and inertia of reciprocating parts, 2. Inertia forces.

UNIT – IV

ENERGY STORING ELEMENTS AND ENGINE COMPONENTS

1. Design a helical spring for a spring loaded safety value for the following Conditions: Diameter of Value Seat is 65mm, operating pressure is 0.7 N/mm², Maximum pressure when the value blows off freely is 0.75 N/mm², Maximum lift of the value when the pressure rises from 0.7 to 0.75 N/mm² is 3.5mm, Maximum allowable stress is 550MPa, Modulus of rigidity = 84 kN/mm², Spring Index = 6. [MAY / JUNE 2012]

GIVEN DATA:

$D_v = 65\text{mm}$; $p_1 = 0.7\,\text{N/mm}^2$; $p_2 = 0.75\,\text{N/mm}^2$

$\delta = 3.5\text{mm}$; $[\tau] = 550\,\text{MPa} = 550\,\text{N/mm}^2$

$G = 84\,\text{kN/mm}^2 = 84 \times 10^3\,\text{N/mm}^2$; $C = \frac{D}{d} = 6$; $D = 6d$.

TO FIND: (1) Mean Diameter of Spring, D

(2) Wire Diameter, d.

(3) Number of Active Turns, n.

(4) Free Length of Spring, L_f

(5) Pitch of Coil.

SOLUTION:

I Forces acting on the Value:

P_1 = Tensile force acting on the spring before the Value lifts

$$P_1 = \frac{\pi}{4} D_v^2 p_1 = \frac{\pi}{4} \times 65^2 \times 0.7 = 2323\text{N}$$

P_2 = Maximum Tensile force acting on the Spring when the value blows off freely.

$$P_2 = \frac{\pi}{4} \times D_v^2 \times p_2 = \frac{\pi}{4} \times 65^2 \times 0.75 = 2489\,N$$

II Mean Diameter, D and Wire Diameter, d:

From DDB. P.No: 7.100 graph Corresponding to C=6 on the x-axis, the value of 'K' in Y-axis is 1.25.

$K = 1.25$

$K_s = K$ = Wahl's Stress factor

$$= \frac{4C-1}{4C-4} + \frac{0.615}{6}$$

$$= \frac{4\times6-1}{4\times6-4} + \frac{0.615}{6}$$

$$= 1.2525$$

$$\tau = K_s \frac{8PD}{\pi d^3} = \frac{K\, 8\, P_{max} D}{\pi d^3} = \frac{1.25 \times 8 \times 2489 \times 6\cancel{d}}{\pi d^{\cancel{3}2}}$$

$$= \frac{47536.39}{d^2} \le [\tau]$$

$$\therefore d^2 \ge \frac{47536.39}{550}$$

$$d \ge 9.2\,mm$$

From DDB. P.NO: 13.1, Select standard wire of size SWG 3/0 having diameter, d=9.45mm

$$D = 6 \times d = 6 \times 9.45 = 56.7\,mm$$

III Number of Turns of the Coil:

n = No. of active turns of the Coil.

DDB. P.No: 7.100

$$y = \delta = \frac{8PC^3n}{G.d}$$

Where P = Force which produces the deflection of 3.5mm

$= P_2 - P_1 = 2489 - 2323 = 166\text{N}$

$$3.5 = \frac{8 \times 166 \times 6^3 \times n}{84 \times 10^6 \times 9.45}$$

$\therefore n = 9.68$

$\simeq 10$

Tension Spring have loop on both ends

$\therefore n' = n + 1 = 10 + 1 = 11.$

IV Free Length of the Spring:

$L_F = n.d + (n-1)$

$= 10 \times 9.45 + (10-1) = 103.5\text{mm}$

V Pitch of Coil:

$$\text{Pitch} = \frac{L_F}{n-1} = \frac{103.5}{(10-1)} = 11.5\text{mm}$$

VI Spring Rate or Stiffness:

$$q = \frac{Gd}{8c^3.n} = \frac{84 \times 10^6 \times 9.45}{8 \times 6^3 \times 10}$$

$q = 45937.5$ N/mm

2. Design a Closed Coil helical Spring for a Service load ranging from 2250N to 2750N. The axial deflection of the spring for the load range is 6mm. Assume a spring index of 5. The permissible Shear Stress intensity is 420 MPa and modulus of rigidity is 84 kN/mm². Neglect the effect of Stress Concentration. [Nov/DEC 2014]

GIVEN DATA:

$P_1 = 2250N$; $P_2 = 2750N$; $\delta = 6mm$; $C = \frac{D}{d} = 5$

$\tau = 420\ MPa = 420 N/mm^2$; $G = 84\ kN/mm^2 = 84 \times 10^3 N/mm^2$

TO FIND:
1. Mean and Wire Diameter
2. Number of active turns
3. Free Length of the Spring.
4. Pitch of Coil.

SOLUTION:

I Mean and Wire Diameter of Spring:

$$\tau = k_s \frac{8PC}{\pi d^2} \quad \text{Where } P = P_{max} = P_2$$

$$420 = \frac{8 \times 2750 \times 5}{\pi d^2}$$

$$d^2 = \frac{8 \times 2750 \times 5}{\pi \times 420}$$

$$d = 9.13mm$$

From DDB. P.No: 13.1, Standard wire of size SWG 3/0 having diameter, $d = 9.49mm$

$D = 5 \times d = 5 \times 9.49 = 47.45mm$

$D_o = D + d = 56.94mm$; $D_i = D - d = 37.96mm$

III Number of Turns of the Coil:

$n =$ No. of active turns of the Coil.

DDB. P.No: 7.100

$$y = \delta = \frac{8PC^3n}{G.d}$$

Where $P =$ Force which produces the deflection of 3.5 mm

$= P_2 - P_1 = 2489 - 2323 = 166\,N$

$$3.5 = \frac{8 \times 166 \times 6^3 \times n}{84 \times 10^6 \times 9.45}$$

$\therefore n = 9.68$

$\simeq 10$

Tension Spring have loop on both ends

$\therefore n' = n+1 = 10+1 = 11.$

IV Free Length of the Spring:

$L_F = n.d + (n-1)$

$= 10 \times 9.45 + (10-1) = 103.5\,mm$

V Pitch of Coil:

$$\text{Pitch} = \frac{L_F}{n-1} = \frac{103.5}{(10-1)} = 11.5\,mm$$

VI Spring Rate or Stiffness:

$$q = \frac{Gd}{8C^3.n} = \frac{84 \times 10^6 \times 9.45}{8 \times 6^3 \times 10}$$

$q = 45937.5\ N/mm$

3. A helical Compression Spring made of oil tempered Carbon Steel is subjected to a load which varies from 500N to 1000N. The Spring index is 6 and the design factor of safety is 1.25. If the yield stress in Shear is 750 N/mm² and the endurance Stress in Shear is 350 N/mm². Find ① Size of the Spring wire ② Diameter of the Spring ③ Number of turns of the Spring ④ Free Length of the Spring. Take Compression of the spring at maximum load as 30mm. The modulus of rigidity is 80,000 N/mm². [NOV/DEC 2013]

<u>GIVEN DATA:</u>

$P_{min} = 500N$; $P_{max} = 1000N$; Factor of Safety, $n = 1.25$

$\tau_y = 750\ N/mm^2$; $\tau_o = 350\ N/mm^2$; $C = \frac{D}{d} = 6$

$\delta_{max} = 30mm$; $G = 80{,}000\ N/mm^2$

<u>TO FIND:</u> ① Mean Diameter, D and Wire Diameter, d.

② Number of turns of the spring, n

③ Free Length of the Spring, L_F.

<u>I. Mean Load, P_m and Variable Load, P_a:</u>

$$P_m = \frac{P_{max} + P_{min}}{2} = \frac{1000 + 500}{2} = 750N.$$

$$P_a = \frac{P_{max} - P_{min}}{2} = \frac{1000 - 500}{2} = 250N.$$

<u>II Mean Shear Stress, τ_m and Variable Shear Stress, τ_a:</u>

$$K = 1 + \frac{0.5}{C} = 1 + \frac{0.5}{6} = 1.08$$

$$\tau_m = \frac{K_s\, 8\, P_m\, D}{\pi d^3} = \frac{1.08 \times 8 \times 750 \times 6\cancel{d}}{\pi d^{\cancel{3}2}}$$

$$= \frac{12{,}376}{d^2}$$

$$\tau_a = \frac{K_s\, 8\, P_a \cdot D}{\pi d^3} = \frac{1.25 \times 8 \times 250 \times 6\cancel{d}}{\pi d^{\cancel{3}2}}$$

$$= \frac{4774.6}{d^2}$$

From DDB. P.No: 7.100, Corresponding to Spring Index, $c = 6$ in X-axis, the value of k in Y-axis is 1.25

<u>III Mean Diameter, D and Wire Diameter, d of Spring:</u>

From DDB. P.No: 7.102

$$\frac{1}{n} = \frac{\tau_m - \tau_a}{\tau_y} + \frac{2\tau_a}{\tau_o}$$

$$\frac{\tau_y}{n} = \tau_m - \tau_a + \frac{2\tau_a \tau_y}{\tau_o}$$

$$\frac{750}{1.25} = \frac{12376}{d^2} - \frac{4774.6}{d^2} + 2 \times \frac{4774.6 \times 750}{d^2 \times 350}$$

$$600 = \frac{28063.97}{d^2}$$

$$\therefore d = 6.83\,mm$$

From DDB. P.No: 13.1, Select a standard wire of size SWG having diameter, $d = 7.01\,mm$

$$d = 7.01\,mm$$

$D = C \times d = 6 \times 7.01 = 42.06\,mm$

$D \simeq 42\,mm$

III Number of Turns:

$$\delta = \frac{8 P D^3 . n}{G d^4}, \text{ where } P = P_{max}$$

$$30 = \frac{8 \times 1000 \times 42^3 \times n}{80 \times 10^3 \times 7^4}$$

$\therefore n = 9.7$

$\simeq 10$

$n' = n + 2 = 10 + 2 = 12$

IV Free Length, L_F:

$L_F = n'.d + \delta_{max} + 0.15\,\delta_{max}$

$= (12 \times 7) + 30 + (0.15 \times 30)$

$= 118.5\,mm$

V Stiffness, q:

$$q = k = \frac{G d^4}{8 D^3 . n} = \frac{80 \times 10^3 \times 7^4}{8 \times (42)^3 \times 10}$$

$= 32.4\,N/mm.$

4. A single cylinder double acting steam engine delivers 185 kW at 100 r.p.m. The maximum fluctuation of energy per revolution is 15 percent of the energy developed per revolution. The speed variation is limited to 1 percent

eitherway from the mean. The mean diameter of the rim is 2.4m. Design the flywheel

[NOV/DEC 2013]

GIVEN DATA:

$P = 185\,kW = 185 \times 10^3\,W$; $N = 100\,r.p.m$; $\Delta E = 15\%\,E$

$\Delta E = 0.15E$; $D = 2.4\,m$; $R = 1.2\,m$

$$N_1 - N_2 = 2\,\%\ \text{of}\ N$$

$$\frac{N_1 - N_2}{N} = 0.02$$

To FIND: (1) Mass, m

(2) Width of flywheel rim, b

Thickness of flywheel rim, t

(3) Diameter of Hub and Length of Hub.

SOLUTION:

I Maximum Fluctuation of Energy, ΔE:

E = Work Done or Energy Developed per Revolution

$$= \frac{P \times 60}{N} = \frac{185 \times 10^3 \times 60}{100} = 111\,000\ N\text{-}m.$$

$$\Delta E = 0.15E = 0.15 \times 111\,000 = 16\,650\ N\text{-}m.$$

II Mass of the Flywheel; m:

V = velocity of Flywheel

$$= \frac{\pi D N}{60} = \frac{\pi \times 2.4 \times 100}{60} = 12.57\,m/s$$

$$\Delta E = m \cdot v^2 \cdot C_s$$

$$16650 = m \times (12.57)^2 \times 0.02$$

$$\therefore m = \frac{16650}{3.16} = 5270\,kg$$

$$\boxed{m = 5270\ kg}$$

III Thickness, t and Width, b of Flywheel Rim:

Assume $b = 2t$

$A = b \times t = 2t \times t = 2t^2$

Mass, m = Area $\times$ length $\times$ Density

$m = 2t^2 \times \pi D \times \rho$

$5270 = 2t^2 \times \pi \times 2.4 \times 7200$

$5270 = 108588 t^2$

$t = 0.22 m$

$\boxed{t = 220 mm}$

$b = 2 \times t = 2 \times 220$

$\boxed{b = 440 mm}$

IV Diameter, d and Length, l of Hub:

$P = \frac{2\pi N T}{60}$

$\therefore T_{mean} = \frac{P \times 60}{2\pi N} = \frac{185 \times 10^3 \times 60}{2\pi \times 100} = 17664 N\text{-}m.$

Assume: Maximum Torque Transmitted by shaft is twice the mean Torque

$T_{max} = 2 \times T_{mean} = 2 \times 17664 N\text{-}m = 35.328 \times 10^6 N\text{-}mm$

Assume: $\tau = 40 MPa = 40 N/mm^2$

$T_{max} = \frac{\pi}{16} \tau d_1^3$

$35.328 \times 10^6 = \frac{\pi}{16} 40 \times d_1^3$

$\therefore d_1 = 165 mm$

d_1 = Diameter of Shaft

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Note: The diameter of hub is twice the diameter of the Shaft, d_1

$d = 2d_1 = 2 \times 165 = 330\,mm$

d = Diameter of Hub

$\boxed{d = 330\,mm}$

l = Length of Hub

$= b = 440\,mm$

$\boxed{l = 440\,mm}$

5. Design a Cast iron flywheel used for a four Stroke I.C Engine developing 180 kW at 240 r.p.m. The hoop or centrifugal Stress developed in the flywheel is 5.2 MPa, the total fluctuation of speed is to be limited to 3% of the mean Speed. The work done during the power Stroke is 1/3 more than the average work done during the whole Cycle. The maximum torque on the Shaft is twice the mean Torque. The density of Cast iron is 7220 kg/m³. [NOV/DEC 2014]

GIVEN DATA:

$P = 180\,kW = 180 \times 10^3\,W$; $N = 240\,r.p.m$; $\sigma_t = 5.2\,MPa$

$N_1 - N_2 = 3\%$ of N; $N_1 - N_2 = 0.03N$

$\sigma_t = 5.2 \times 10^6\,N/m^2$; $\rho = 7220\,kg/m^3$

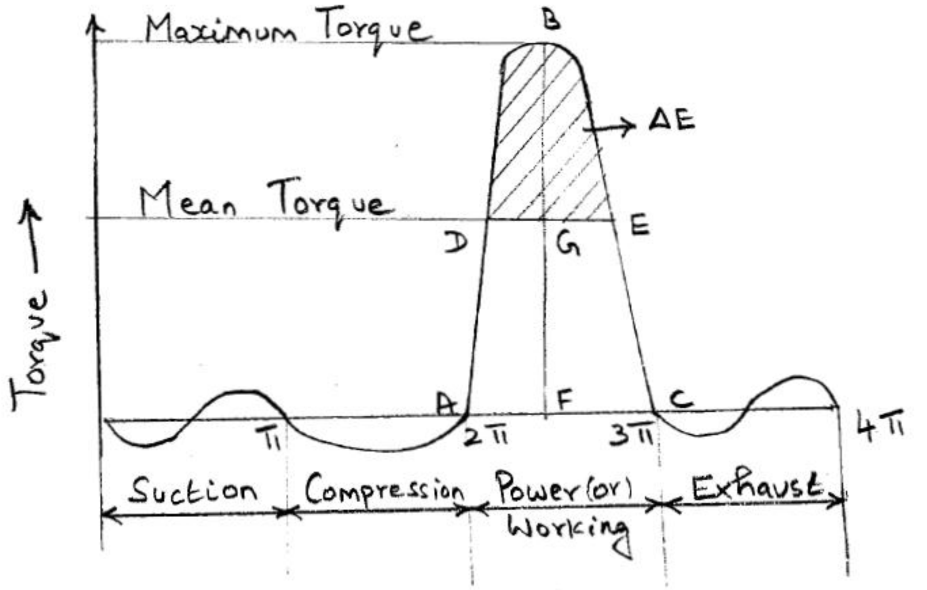
$\therefore \frac{N_1 - N_2}{N} = 0.03 = C_s$

To FIND: (1) Diameter of flywheel rim, D

(2) Mass of flywheel, m

(3) Width and Thickness of Flywheel rim.

(4) Diameter and Length of Hub.



SOLUTION:

I Maximum Fluctuation of Energy:

$$P = \frac{2\pi N T}{60}$$

$$\therefore T_{mean} = \frac{P \times 60}{2\pi N} = \frac{180 \times 10^3 \times 60}{2\pi \times 240} = 7161 \text{ N-m}.$$

Workdone per Cycle $= T_{mean} \times \theta = T_{mean} \times 4\pi$

$= 7161 \times 4\pi = 90\,000$ N-m

Method II : n = Number of working strokes per minute.

$$= \frac{N}{2} = \frac{240}{2} = 120$$

Workdone per Cycle $= \frac{P \times 60}{n} = \frac{180 \times 10^3 \times 60}{120} = 90{,}000$ N-m.

Work done during Power Stroke $= \frac{1}{3}$ greater than Work Done per cycle.

W.D during Power Stroke $=$ W.D/Cycle $+ \frac{1}{3}$ W.D/Cycle

$= 90{,}000 + \frac{1}{3} \times 90\,000$

$= 120\,000$ N-m

Work done during Power Stroke $= \frac{1}{2} \pi T_{max}$

$$120\,000 = \frac{1}{2} \pi T_{max}$$

$$T_{max} = 76\,384 \text{ N-m}$$

Height above mean Torque Line, BG

$$BG = BF - FG = T_{max} - T_{mean}$$

$$= 76\,384 - 7161 = 69\,223 \text{ N-m}$$

Geometrical Relation

Maximum Fluctuation of Energy, ΔE = Area of Triangle BDE

$$\frac{\text{Area of } \Delta BDE}{\text{Area of } \Delta ABC} = \frac{(BG)^2}{(BF)^2}$$

$$\therefore \Delta E = \text{Area of } \Delta ABC \times \left(\frac{BG}{BF}\right)^2$$

$$= 120\,000 \times \left(\frac{69223}{76384}\right)^2$$

$$\boxed{\Delta E = 98\,555 \text{ N-m}}$$

<u>II Diameter of Flywheel Rim:</u>

$$\sigma_t = \rho v^2$$

$$5.2 \times 10^6 = 7220 \times v^2$$

$$v^2 = \frac{5.2 \times 10^6}{7220}$$

$$v = 26.8 \text{ m/s}$$

$$v = \frac{\pi D N}{60}$$

$$26.8 = \frac{\pi \times D \times 250}{60}$$

$$\boxed{D = 2.04 \text{ m}}$$

III Mass of the Flywheel Rim, m:

ω = Angular speed of the Flywheel Rim

$$= \frac{2\pi N}{60} = \frac{2\pi \times 250}{60} = 25.14 \text{ rad/s.}$$

C_s = Coefficient of Fluctuation of Speed.

$$= \frac{N_1 - N_2}{N} = 0.03$$

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

$$98555 = m \cdot \left(\frac{2.04}{2}\right)^2 (25.14)^2 \times 0.03$$

$$m = \frac{98555}{19.73} = 4995 \text{ kg.}$$

$$\boxed{m = 4995 \text{ kg}}$$

IV Width, b and Thickness, t of Flywheel Rim.

Assume $b = 2t$

$$A = b \times t = b \times t = \text{Width} \times \text{Thickness}$$

$$= 2t \times t = 2t^2$$

$$m = A \times \pi D \times \rho$$

$$4995 = 2t^2 \times \pi \times 2.04 \times 7220$$

$$t^2 = \frac{4995}{92556}$$

$$t = 0.232 \text{ m} \simeq 0.235 \text{ m}$$

$$\boxed{t = 235 \text{ mm}}$$

$$b = 2 \times t = 2 \times 235$$

$$\boxed{b = 470 \text{ mm}}$$

V Diameter, d and Length, l of Hub:

$$T_{max} = 2 \times T_{mean} = 2 \times 7161 = 14322 \text{ N-m}$$
$$= 14322 \times 10^3 \text{ N-mm}$$

Assume $\tau = 40 MPa = 40 N/mm^2$

$$T_{max} = \frac{\pi}{16} \tau d_1^3$$

$$14322 \times 10^3 = \frac{\pi}{16} 40 \times d_1^3$$

$$d_1^3 = \frac{14322 \times 10^3}{7.855} = 1823 \times 10^3$$

$d_1 = 122$ mm

$d_1 \simeq 125$ mm

d_1 = diameter of Shaft.

d = Diameter of Hub

$= 2 \times d_1 = 2 \times 125$

$\boxed{d = 250mm}$

$\boxed{l = b = 470mm}$

l = Length of Hub

6. A multicylinder engine is to run at a Constant load at a speed of 600 r.p.m. On drawing the Crank effort diagram to a Scale of 1mm = 250N-m and 1mm = 3°, the areas in sq.mm above and below the mean torque line are as follows: +160, −172, +168, −191, +197, −162 sq.mm. The speed is to be kept within ±1% of the mean Speed of the engine. Calculate the necessary moment of Inertia of the flywheel. Determine suitable dimensions for Cast iron flywheel rim whose

breadth is twice its radial thickness. The density of Cast iron is 7250 kg/m³ and its working Stress in tension is 6 MPa. Assume that the rim Contributes 92% of the flywheel effect. [MAY/JUNE 2012]

GIVEN DATA:

$N = 600$ r.p.m ; 1mm = 250 N-m ; 1mm = 3°

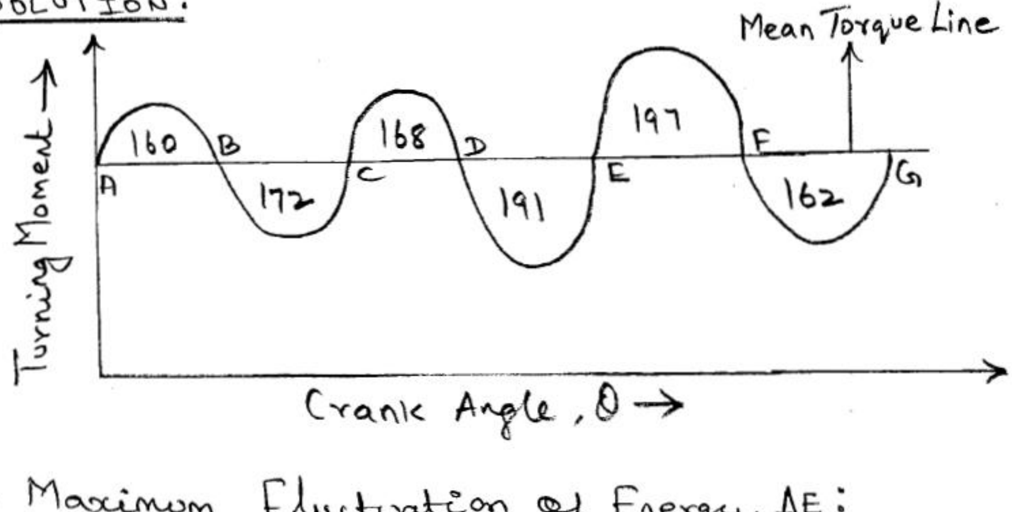
$N_1 - N_2 = \pm 1\%$ of N	$b = 2t$
$N_1 - N_2 = 2\%$ of N	$\rho = 7250$ kg/m³
$N_1 - N_2 = 0.02N$	Rim Contributes 92% of the Flywheel effect.
$\frac{N_1 - N_2}{N} = 0.02 = C_s$	

To FIND: (1) Moment of Inertia, I

(2) Mean Diameter of Flywheel, D.

(3) Width, b and Thickness of Flywheel Rim

SOLUTION:



I Maximum Fluctuation of Energy, ΔE:

Scale for Turning moment, 1mm = 250 N-m

Scale for Crank angle, 1mm = 3° = $\frac{\pi}{60}$ rad.

1 mm² on the Turning Moment Diagram $= 250 \times \frac{\pi}{60}$

$= 13.1$ N-m

Total Energy at A = E

Energy at B = E + 160

Energy at C = E + 160 − 172 = E − 12

Energy at D = E − 12 + 168 = E + 156

Energy at E = E + 156 − 191 = E − 35

Energy at F = E − 35 + 197 = E + 162

Energy at G = E + 162 − 162 = E

= E = Energy at A.

Maximum Energy = E + 162

Minimum Energy = E − 35

ΔE = Maximum Energy − Minimum Energy

$= (E+162) - (E-35) = 197\,mm^2$

$= 197 \times 13.1 = 2581\ N\text{-}m$

II Moment of Inertia, I of Flywheel:

$$\Delta E = m \cdot R^2 \omega^2 \cdot C_s = I \omega^2 C_s.$$

Where $\omega = \frac{2\pi N}{60} = \frac{2\pi \times 600}{60} = 62.84\ rad/s$

$$2581 = I\,(62.84)^2 \times 0.02$$

$$I = 32.7\ kg\text{-}m^2$$

III Mean Diameter of Flywheel, D:

$\sigma_t = 6MPa = 6\,N/mm^2 = 6 \times 10^6\ N/m^2$

$\sigma_t = \rho \cdot v^2$

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

$v^2 = \frac{6 \times 10^6}{7250}$

$v = 28.76\ m/s$

$$V = \frac{\pi D N}{60}$$

$$28.76 = \frac{\pi \times D \times 600}{60}$$

$$D = \frac{28.76}{31.42} = 0.915\,m$$

$$\boxed{D = 915\,mm}$$

IV Mass of the Flywheel, m:

E = Total Energy of the Flywheel

$$\Delta E = E \times 2C_s = E \times 2 \times 0.02$$

$$2581 = 0.04E$$

$$\therefore E = 64\,525\ N\text{-}m$$

$$E_{rim} = 0.92\,E = 0.92 \times 64525$$

$$E_{rim} = 59\,363\ N\text{-}m$$

$$E_{rim} = \frac{1}{2} m.v^2$$

$$59363 = \frac{1}{2} m \times (28.76)^2$$

$$m = \frac{59\,363}{413.6} = 143.5\,kg$$

$$\boxed{m = 143.5\,kg}$$

V Width, b & Thickness, t of flywheel rim:

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

$$143.5 = 2t \times t \times \pi \times 0.915 \times 7250$$

$$t^2 = \frac{143.5}{41686}$$

$$t = 0.0587$$

$$\simeq 0.06\,m$$

$$t = 60\,mm$$

$$b = 2t = 2 \times 60 = 120\,mm$$

$$\boxed{\begin{array}{l} t = 60\,mm \\ b = 120\,mm \end{array}}$$

7. Design a Connecting rod for an I.C. engine running at 1800 r.p.m and developing a maximum pressure of 31.5 N/mm². The diameter of the piston is 100mm; mass of the reciprocating parts per Cylinder 2.25kg; length of Connecting rod is 380mm; Stroke of piston is 190mm and Compression ratio = 16:1. Take a factor of Safety of 6 for the design. Take Length to diameter ratio of big end bearing as 1.3 and Small end bearing as 2 and the Corresponding bearing pressures as 10N/mm² and 15 N/mm². The density of material of the rod may be taken as 8000 kg/m³ and the allowable stress in the bolts 60N/mm² and in Cap as 80N/mm². The rod is to be of I-section for which you can Choose your own proportions. [NOV/DEC 2013]

GIVEN DATA:

$N = 1800$ r.p.m; $p = 31.5\,N/mm^2$; $d_p = 100mm$; $m_R = 2.25kg$

$N = 1800$ r.p.m; Compression Ratio $= 6:1$

$l = 380$ mm; Stroke $= 190$mm; Compression Ratio $= 6:1$

Factor of Safety, $n = 6$; $\frac{L_1}{D_1} = 1.3$; $\frac{L_2}{D_2} = 2$; $p_{b1} = 10N/mm^2$

$p_{b2} = 15N/mm^2$; $\rho = 8000\ kg/m^3$; $[\sigma_t]_{Bolt} = 60N/mm^2$

$[\sigma_b]_{Cap} = 80N/mm^2$

TO FIND: (1) Design Connecting Rod

(2) Dimensions of I Cross Section

SOLUTION:

I Material Selection:

From DDB. P.No: 1.17, 35 Mn2 Mo28 selected for Connecting rod

From DDB. P.No: 1.13, for 35 Mn2 Mo28 material

$\sigma_y = 54\ kgf/mm^2 = 540\ N/mm^2$

$\sigma_u = 70 - 85\ kgf/mm^2$

$= 80\ kgf/mm^2 = 800\ N/mm^2$

From DDB. P.No: 1.17, 40 Ni2 Cr1 Mo28 Selected for Bolt.

From DDB. P.No: 1.15, $\sigma_y = 60\ kgf/mm^2 = 600\ N/mm^2$

$\sigma_u = 80 - 95\ kgf/mm^2$

$= 80\ kgf/mm^2 = 800\ N/mm^2$

II Factor of Safety, n:

From DDB P.No: 7.122

$n = 3$ to 6

Take $n = 6$

III Force on Connecting Rod, F_G:

DDB. P.No: 7.122

$$F_G = \frac{\pi}{4} d_p^2 \times p$$

$$= \frac{\pi}{4} \times (100)^2 \times 31.5$$

$$= 247400.42\ N$$

IV I-Section:

DDB. P.No: 7.122

$a = 11t^2$

$k_{xx}^2 = 3.18t^2$

$k_{xx} = 1.78t$

$I_{xx} = \frac{419}{12} t^4$

$Z_{xx} = \frac{419}{30} t^3$

where t = thickness of flange & web

V Web Thickness, t:

DDB. P.No: 7.122

$\sigma_y = 540 N/mm^2$

$n = 6$

$L_e = l = 380mm$

$k = k_{xx} = 1.78t$

$E = 2.1\times10^5 N/mm^2$

$F_a = F_G = 247400.2N$

$a = 11t^2$

$$\frac{F_a}{a} = \frac{\sigma_y}{n}\left[1 - \frac{\sigma_y}{4\pi^2 E}\left(\frac{L_e}{k}\right)^2\right]$$

$$\frac{247400.42}{11t^2} = \frac{540}{6}\left[1 - \frac{540}{4\pi^2\times2.1\times10^5}\left(\frac{380}{1.78t}\right)^2\right]$$

$$= \frac{540}{6}\left[1 - \frac{2.9685}{t^2}\right]$$

$$= 90 - \frac{267.165}{t^2}$$

$$\frac{247400.42}{11t^2} + \frac{267.165}{t^2} = 90$$

$$t^2 = \frac{22758.11}{90}$$

$$t = 15.9mm$$

$$\boxed{t = 16mm}$$

VI Dimensions of I-Section of the Connecting Rod:

$a = 11t^2 = 11 \times 16^2 = 2816\,mm^2$

$I_{xx} = \frac{419}{12} t^4 = \frac{419}{12} \times 16^4 = 2288298.66\,mm^4.$

$k_{xx} = 1.78t = 1.78 \times 16 = 28.48\,mm$

$Z_{xx} = \frac{419\,t^3}{30} = \frac{419 \times 16^3}{30} = 57207.46\,mm^3$

VII Bending Stress due to Inertia Forces:

DDB. P.No: 7.122

γ = Density = 8000 kg/m^3 = $8 \times 10^{-5}\,N/mm^3$.

r = Radius of Crank = $\frac{\text{Stroke}}{2}$

$= \frac{190}{2} = 95\,mm.$ | $[\sigma_b] = \frac{\sigma_y}{n} = \frac{540}{6} = 90\,N/mm^2$

$g = 9810\,mm/s.$

$\omega = \frac{2\pi N_{max}}{60} = \frac{2\pi \times 1800}{60} = 188.49$ rad/sec.

$$\sigma_{bmax} = \frac{\gamma a\, l^2 \omega^2 r}{9\sqrt{3} g\, Z_{xx}}$$

$$= \frac{8 \times 10^{-5} \times 2816 \times (380)^2 \times (188.49)^2 \times 95}{9\sqrt{3} \times 9810 \times 57207.46}$$

$= 12.55\,N/mm^2$

$\leq [\sigma_b]$

$\leq 90\,N/mm^2$

$\therefore$ Design is safe and satisfactory

VIII Design of Big End (or) Crank Pin Bearings:

$\frac{L_1}{D_1} = 1.3$; $P_{b1} = 10 N/mm^2$

$F_G = L_1 D_1 P_{b1}$

$247400.42 = 1.3 D_1 \times 10 \times D_1$

$$D_1^2 = \frac{247400.42}{13}$$

$$\boxed{D_1 = 137.95 \, mm}$$

$$L_1 = 1.3 \times D_1 = 1.3 \times 137.95$$

$$\boxed{L_1 = 179.33 \, mm}$$

IX Design of Small End (or) Wrist Pin (or) Gudgeon Pin Bearings:

$\frac{L_2}{D_2} = 2$; $P_{b2} = 15 N/mm^2$

$L_2 = 2 D_2$

$$F_G = L_2 D_2 P_{b2}$$

$247400.42 = 2 D_2 \cdot D_2 \, 15$

$$D_2^2 = \frac{247400.42}{(2 \times 15)}$$

$$\boxed{D_2 = 90.81 \, mm}$$

$$L_2 = 2 \times D_2 = 2 \times 90.81$$

$$\boxed{L_2 = 181.62 \, mm}$$

X Design of Bolts:

From DDB. P.No: 7.122

$F_i = m_R \times \omega^2 \times r \left[1 + \frac{r}{l}\right]$

m_R = Mass of Reciprocating parts in kg

= 2.25

r = Radius of Crank in metre.

= 95mm = 0.095M

l = 380mm = 0.38M

$F_i = 2.25 \times (188.49)^2 \times 0.095 \left(1 + \frac{0.095}{0.38}\right)$

= 9492.76N

Assume number of bolts to be 2.

$$[\sigma_t]_{Bolt} = \frac{F_i}{2 \times \frac{\pi}{4} d_c^2}$$

$$F_i = 2 \times \frac{\pi}{4} d_c^2 \times [\sigma_t]_{Bolt}$$

$$9492.76 = 2 \times \frac{\pi}{4} d_c^2 \times 60$$

$$d_c^2 = \frac{9492.76 \times 4}{2 \times \pi \times 60}$$

$$d_c = 10.03\,mm$$

For metric thread Nominal diameter $= \frac{d_c}{0.84}$

= 11.94mm

From DDB. P.No: 5.49

M12 Bolt is selected.

XI CAP THICKNESS (t_c):

$$M_{max} = \frac{F_i l_b}{6}$$

where l_b = Distance between Bolt Centres.

$$= D_1 + (2\times5) + (2\times d_c)$$
$$= 137.95 + 10 + (2\times12)$$
$$= 171.95\,mm$$

$$M_{max} = \frac{9492.76 \times 171.95}{6} = 272046.68\,N\text{-}mm$$

$$[\sigma_b]_{Cap} = \frac{M_{max}}{Z}, \text{ where } [\sigma_b]_{Cap} = 80\,N/mm^2$$

where $Z = \frac{1}{6} b t_c^2$

where b = width of Cap

$$= L_1 - (2\times5)$$
$$= 179.33 - (2\times5)$$
$$= 169.33\,mm$$

$$Z = \frac{1}{6} \times 169.33\, t_c^2$$
$$= 28.22\, t_c^2$$

$$[\sigma_b]_{Cap} = \frac{M_{max}}{Z}$$

$$80 = \frac{272046.68}{28.22\, t_c^2}$$

$$\therefore t_c^2 = 120.50$$

$$t_c = 10.97\,mm$$

$$\boxed{t_c \simeq 11\,mm}$$