# *Answer Key*
## *Part A*

1. What is the function of a flywheel?

   The function of a flywheel is to store energy during excess supply and to release energy during the period when the requirement of energy is more than supply (or) a flywheel controls the speed variations caused by the fluctuation of the engine turning moment during each cycle of operation.

2. Define coefficient of fluctuation of energy.

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

   **CE= Maximum fluctuation of energy /Work done per cycle**

3. Define maximum fluctuation of energy.

   Maximum fluctuation of energy is defined as the difference between maximum energy and minimum energy in a flywheel.

   **Maximum fluctuation of energy = Maximum energy – Minimum energy**

4. Give four applications of flywheel.
   i. Punching machines
   ii. Riveting machines
   iii. Shearing machines
   iv. Crushers

## *Part B*

**Problem 1:**

The turning moment diagram for a petrol engine is drawn to a scale of 1mm to 6Nm and the horizontal scale of 1mm to 1°.The turning moment repeat itself after every half revolution of the engine. The area above and below the mean torque line are 305, 710, 50,350,980 and 75mm$^2$. The mass of rotating parts is 40kg and a radius of gyration of 140mm.Calculate the coefficient of fluctuation of speed if the mean speed is 1500rpm.

**Solution:**

Let Flywheel KE at a = E

| | | | |
|---|---|---|---|
| at a | = E | | |
| at b | = **E+305** | | **(Max Energy)** |
| at c | = E+305-710 | = E-405 | |
| at d | = E-405+50 | = E-355 | |
| at e | = **E-355-350** | **= E-705** | **(Min Energy)** |
| at f | = E-705+980 | = E+275 | |
| at g | = E+275-275 | = E | |

Max Energy : E+305
Min Energy : E-705

Maximum Fluctuation of energy:

$\Delta E$ = Max Energy- Min Energy

= E+305-(E-705)

**$\Delta E$ = 1010 $mm^2$**

**Scale:**

1mm = 6 Nm

1mm = 1°

1$mm^2$ in turning moment diagram

= (1*π/180) *6

= 0.10Nm

1010$mm^2$ = 105.77 Nm

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

$= mk^2\omega^2 C_s$

$\omega = 2\pi N/60$

$C_s = \Delta E / mk^2\omega^2$

$= 105.77/ (40*0.14^2*(2\pi*1500/60))$

= 0.0034

**$C_s$ = 0.34%**

**Problem 2:**

The intercepted areas between the output torque curve and the mean resistance line of a turning moment diagram for a multi cylinder engine, taken in order from one end are as follows:-0.35,4.10,-2.85,3.25,-3.35,2.60,-3.65,2.85,-2.6 sq cm. The diagram drawn into a scale of 1cm=700Nm and 1cm = 45°. The engine speed is 900rpm and the fluctuation of speed is not to exceed 2% of the mean speed. Find the suitable diameter and cross section of the flywheel rim if the safe centrifugal stress is limited to 7MPa. The density of the material is 7200kg/$m^3$. The rim is rectangular with the width 2 times the thickness. Neglect the effect of arms.

**Solution:**

Let Flywheel KE at a = E

| | | |
|---|---|---|
| at a | = E | |
| at b | = E-0.35 | **E-0.35 (Min Energy)** |
| at c | = E-0.35+4.10 | E+3.75 |
| at d | = E+3.75-2.85 | E+0.9 |
| at e | = E+0.9+3.25 | **E+4.15 (Max Energy)** |
| at f | = E+4.15-3.35 | E+0.8 |
| at g | = E+0.8+2.60 | E+3.4 |
| at h | = E+3.4-3.65 | E-0.25 |
| at i | = E+2.85-0.25 | E+2.6 |
| at j | = E+2.6-2.6 | E |

Max Energy : E+4.15

Min Energy : E-0.35

Maximum Fluctuation of energy:

$\Delta E$ = Max Energy- Min Energy

= E+4.15-(E-0.35)

**$\Delta E$ = 4.5 $cm^2$**

**Scale:**

1cm = 700 Nm

1cm = 45°

1mm$^2$ in turning moment diagram

= (45*π/180) *700

= 549.78 Nm

4.5cm$^2$ = 2474.01Nm

$\sigma = \rho\upsilon^2$

$7*10^6 = 7200*\upsilon^2$

$\upsilon$ = 31.18m/s

$\upsilon$ = πDN/60

31.18 = (π*D*900)/60

D = 0.66m

ω = 2 πN/60

=(2*π*900)/60

= 94.25 rad/s

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

$= mk^2\omega^2 C_s$

2474 = $(m*0.33^2*94.25^2*18)$

m = 0.14kg

m = πDAρ

= π*D*b*t*ρ

0.14 = $\pi*0.66*2t^2*7200$

**t = 0.218mm**

**b = 0.436mm**

**Problem 3:**

The turning moment diagram for a petrol engine is drawn to a scale of 1mm to 500Nm and the horizontal scale of 1mm to 3°.The turning moment repeat itself after every half revolution of the engine. The area above and below the mean torque line are 260,-580, 80, -380,870 and -250mm$^2$. The mass of rotating parts is 55kg and a radius of gyration of 2.1m. Calculate the coefficient of fluctuation of speed if the mean speed is 1600rpm.

**Solution:**

Let Flywheel KE at a = E

| | | | |
|---|---|---|---|
| at a | = E | | |
| at b | = **E+260** | | **(Max Energy)** |
| at c | = E+260-580 | =E-320 | |
| at d | = E-320+80 | = E-240 | |
| at e | = E-240-380 | **= E-620** | **(Min Energy)** |
| at f | = E-620+870 | = E+250 | |
| at g | = E+250-250 | = E | |

Max Energy : E+260

Min Energy : E-620

Maximum Fluctuation of energy:

ΔE = Max Energy- Min Energy

= E+260-(E-620)

**ΔE = 880 mm$^2$**

**Scale:**

1mm = 500 Nm

1mm = 3°

1mm$^2$ in turning moment diagram

= (3*π/180) *500

= 26.18

880mm$^2$ = 23038 Nm

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

= $mk^2\omega^2 C_s$

$\omega$ = 2 $\pi$N/60

$C_s$ = $\Delta E/ mk^2\omega^2$

= 23038/ (55*2.1$^2$*(2 $\pi$*1600/60))

= 0.0034

**$C_s$ = 0.34%**

**Problem 4:**

The engine is running at a speed of 480rpm. The intercepted areas between the output torque curve and the mean resistance line of a turning moment diagram for a multi cylinder engine, taken in order from one end are as follows 1.1,-1.32,1.53,-1.66,1.97,-1.62sq cm. Design the flywheel if the total fluctuation of speed is not to exceed 10rpm and the centrifugal stress in the rim is $5*10^5$ N/m$^2$ .You may assume the breadth is approximately 2.5 times of the thickness and 90% of the Moment iof Inertia is due to the rim. The density of the material is 7250 kg/m$^{3.}$

**Solution:**

Let Flywheel KE at a = E

| | | |
|---|---|---|
| at a | = E | |
| at b | = E+1.1 | E+1.1 |
| at c | = E+1.1-1.32 | E-0.22 |
| at d | = E-0.22+1.53 | E+1.31 |
| at e | = E+1.31-1.66 | E-0.35 (Min Energy) |
| at f | = E-0.35+1.97 | E+1.62(Min Energy) |
| at g | = E+1.62-1.62 | E |

Max Energy : E+1.62

Min Energy : E-0.35

Maximum Fluctuation of energy:

$\Delta E$ = Max Energy- Min Energy

= E+1.62-(E-0.35)

**$\Delta E$ = 1.97 cm$^2$**

**Scale:**

1cm = 2000 Nm

1cm = 36°

1mm$^2$ in turning moment diagram

= (36*π/180) *2000

= 1256.64Nm

4.5cm$^2$ = 2475.58Nm

$\sigma$ = $\rho\upsilon^2$

5*10^5=7250* $\upsilon^2$

$\upsilon$ = 8.30m/s

$\upsilon$ =πDN/60

8.30 = (π*D*480)/60

D = 0.33m

$\omega$ = 2 πN/60

=(2*π*480)/60

= 50.27 rad/s

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

$= mk^2\omega^2 C_s$

$2475.6 = (m*(0.33/2)^2*50.27^2*10)$

$m = 3.60kg$

$m = \pi D A \rho$

$= \pi*D*b*t*\rho$

$3.60 = \pi*0.33*2.5t^2*7250$

**$t = 138mm$**

**$b = 277mm$**