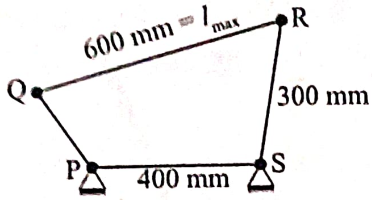
31. Ans: (d)

Sol:



To obtain C-R mechanism $l_{min(shortest\ time)}$ must be adjacent to fixed link per class I linkage.

So PQ = 80 mm (l_{min})

$80 + 600 < 400 + 300$

any other option will violate Grashof's condition.

32. Ans: (a)

Sol: The different kinematic pairs that are possible are,

1 double crank,

2 double rocker,

3 crank rocker.

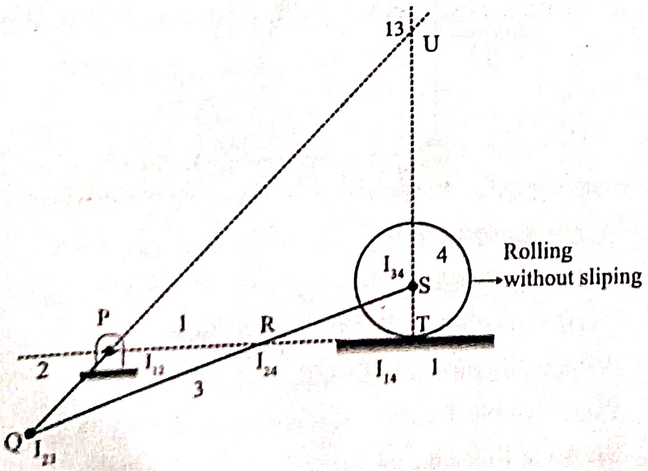
33. Ans: (c)

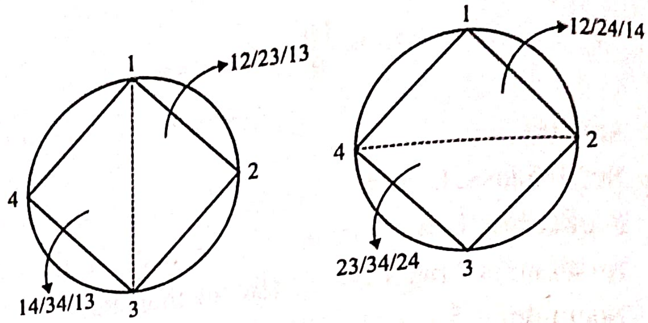
Sol:

1. Quick return mechanism used in shaper is "Crank and slotted lever Quick return mechanism"
2. As " Link 2" is fixed in a single slider chain as shown in figure, above mechanism results.

34. Ans: (a)

Sol:





n = 4

$\text{No. of instantaneous centers} = \dfrac{4(4-1)}{2} = 6$

All points P, Q, R, S, T and U are I-centers of mechanism.

35. Ans: 120

Sol: Crank length (r) = 30 mm

Stroke length (2r) = 2 × 30 = 60 mm

Distance covered by piston in one revolution

$= 2 \times \text{stroke length} = 2 \times 60 = 120 \text{ mm}$

Time taken for 1 rev = 1 sec

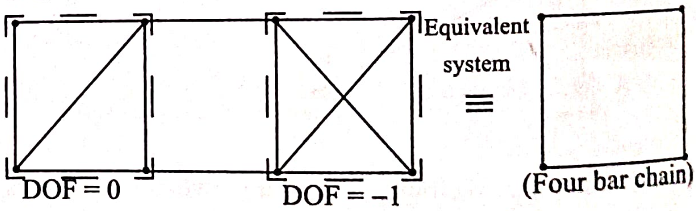
Average velocity of piston

$$= \frac{\text{Distance covered in 1 rev}}{\text{time taken in 1 rev}} = \frac{120}{1}$$

= 120 mm/sec

36. Ans: (c)

Sol:



Hence non-rigid.

Two Marks Solutions

01. Ans: (b)

Sol: In a pure rolling the I – centre lies at the point of contact at the given instant.

In sliding motion, the I – centre lies at infinity in a direction perpendicular to the path of motion of slider. As for three centers in line theorem, in both rolling and sliding motion the I – center lies in between point of contact and in the direction of the centre of sliding i.e. perpendicular to the sliding direction.

02. Ans (c)

Sol: Grubler's equation $F = 3\,(N-1) - 2P_1 - P_2$

F = degrees of freedom

N = total number of links in a mechanism

P_1 = number of pairs having one degree of freedom

P_2 = number of pairs having two degree of freedom (Higher pairs)

Above mechanism have 5 joint pairs which have one degree of freedom = $(P_1) = 5$

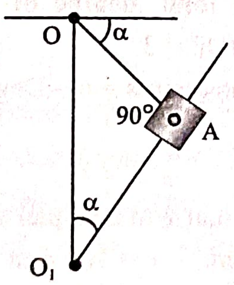
There is No class II pairs $(P_2) = 0$,

Number of links N = 5

$\therefore\ F = 3\,(5-1) - 2\times 5 = 2$

03. Ans: (b)

Sol:



$$\sin\alpha = \frac{OA}{OO_1} = \frac{2}{4} = \frac{1}{2}$$

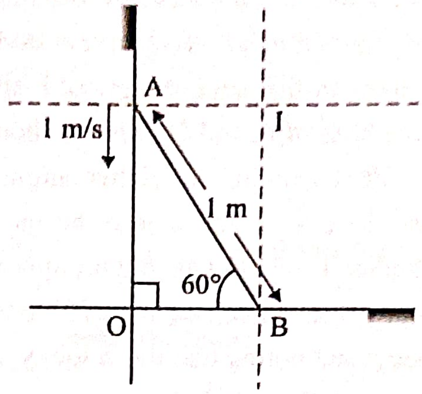
$\Rightarrow \alpha = 30°$

$$QRR = \frac{180+2\alpha}{180-2\alpha} = \frac{180+60}{180-60}$$

$\Rightarrow$ QRR = 2

04. Ans: (a)

Sol:



$V_a = 1$ m/s

V_a = Velocity along vertical direction

V_b = Velocity along horizontal direction

So instantaneous center of link AB will be perpendicular to A and B respectively i.e at I

$$IA = OB = \cos\theta = 1\times\cos 60° = \frac{1}{2}\,m$$

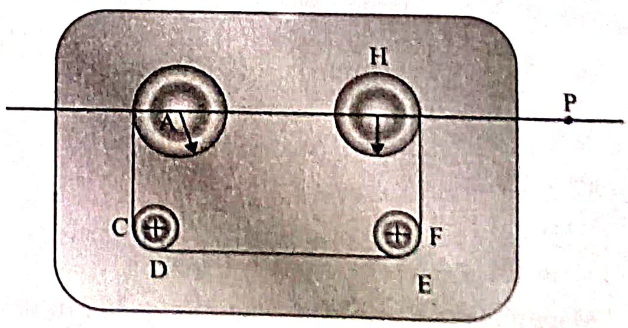
$$IB = OA = \sin\theta = 1\times\sin 60° = \frac{\sqrt{3}}{2}\,m$$

$$V_a = \omega \times IA$$

$$\Rightarrow \omega = \frac{V_a}{IA} = \frac{1}{V_2} = 2\ \text{rad/sec}$$

05. Ans: (c)

Sol: Consider the three bodies the bigger spool (Radius 20), smaller spool (Radius 10) and the frame. They together have three I centers, I centre of big spool with respect to the frame is at its centre A and that of the small spool with respect to the frame is at its centre H. The I centre for the two spools P is to be located.



As for the three centers in line theorem all the three centers should lie on a straight line implies on the line joining of A and H more over as both the spools are rotating in the same direction, P should lie on the same side of A and H. Also it should be close to the spool running at higher angular velocity. Implies close to H and it is to be on the right of H. Whether P belongs to bigger spool or smaller spool its velocity must be same. As for the radii of the spools and noting that the velocity of the tape is same on both the spools

$$\omega_H = 2\omega_A$$

$\therefore$ $AP.\omega_A = HP\omega_H$ and

$$AP = AH + HP \Rightarrow HP = AH$$

06. Ans: (c)

Sol: $V_{BA} = V_B - V_A = r_B\omega - r_A\omega = \omega\ (r_B - r_A)$

Both are in the direction of motion

The relative velocity is in the direction of motion of B.

07. Ans: (d)

Sol: $f_{BA} = f_B - f_A = r_b\omega^2 - r_a\omega^2 = (r_b - r_a)\ \omega^2$

Being centripetal, the direction is towards the centre of rotation

i.e., from Z to O

08. Ans: (a)

Sol: The block has linear velocity along the axis of the link which is in angular motion hence it has coriolis acceleration give by 2 Vω

Given: N = 120 rpm

$$\omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 120}{60} = 12.566 \text{ rad/ sec}$$

$V = 12$ m/s

$a^{cor} = 2V\omega$

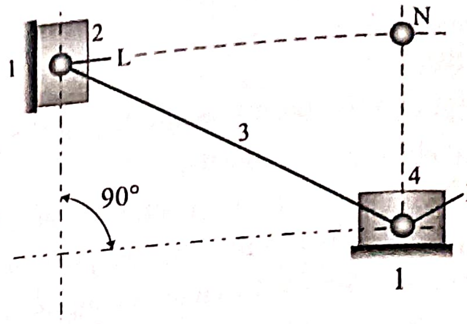
$= 2 \times 12.566 \times 12$

$= 301.5$ m/sec^2

Magnitude of Coriolis acceleration = 302 m/sec^2

09. Ans: (d)

Sol:



By considering the links 1, 2 and 4 as for three centers in line theorem, I_{12}, I_{14} and I_{24} lies on a straight line I_{12} is at infinity along the horizontal direction while I_{14} is at infinity along vertical direction hence I_{24} must be at infinity

10. Ans: (c)

Sol: (P) Scott-Russel mechanism-straight line motion

(Q) Geneva mechanism – intermittent motion

(R) Off-set slider crank mechanism-Quick return motion

(S) Scotch yoke mechanism- simple Harmonic motion

11. Ans: (c)

Sol: For revolute joint, degree of freedom is 1 and constrained DOF = 5

For cylindrical joint, degree of freedom is 2 and constrained DOF = 4

For spherical joint, degree of freedom is 3 and constrained DOF = 3

[Degree of constraints = 6 – Degree of freedom]

12. Ans: (b)

Sol: Calculate AB that will be equal to 260 mm

L = 260 mm, P = 160 mm

S = 60 mm Q = 240 mm

L + S = 320; P + Q = 400

$\therefore L + S < P + Q$

It is a Grashof's chain

Link adjacent to the shortest link is fixed

$\therefore$ Crank – Rocker Mechanism.

13. **Ans: (b)**

Sol: $O_2A \parallel O_4B$

Then linear velocity is same at A and B.

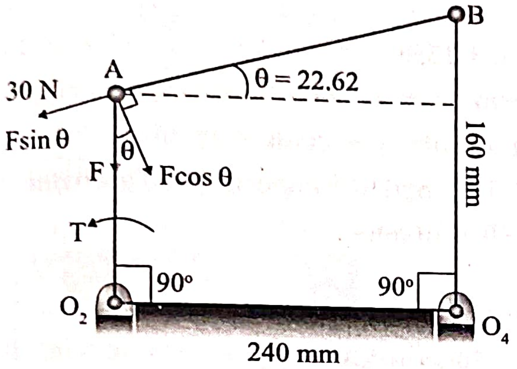
$\therefore \omega_2 \times O_2A = \omega_4 \times O_4B$

$\therefore 8 \times 60 = \omega_4 \times 160$

$\Rightarrow \omega_4 = 3$ rad/sec

14. **Ans: (c)**

Sol:



$\tan\theta = \dfrac{100}{240} \Rightarrow \theta = 22.62°$

As centre of mass falls at O_2

$m\bar{r}\omega^2 = 0 \quad (\because \bar{r} = 0)$

$\alpha = 0$ (Given)

Inertia torque = 0

Since torque on link O_2A is zero, the resultant force at point A must be along O_2A.

$\Rightarrow F\sin 22.62 = 30$

$\Rightarrow F = \dfrac{30}{\sin 22.62} = 78$ N

The magnitude of the joint reaction at O_2=F=78 N

15. **Ans: (d)**

Sol:
- Higher kinematic pair → Line contact
- Lower kinematic pair → Surface contact
- Quick return mechanism → Shaper
- Mobility of a linkage → Grubler's equation

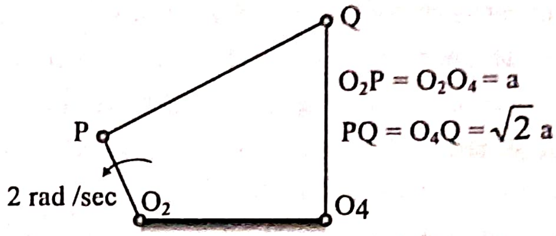
16. **Ans: (a)**

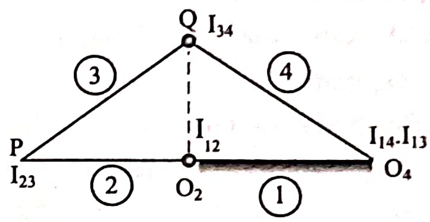
Sol: Crank is possible only in case of Grashof's chain ($l + s < p + q$) and special Grashof's chain ($l + s = p + q$).

Hence $l + s \le p + q$

17. **Ans: (c)**

Sol: $\angle O_4O_2P = 180°$ Sketch the position diagram for the given input angle and identify the Instantaneous Centers.





I_{13} is obtained by joining I_{12} I_{23} and I_{14} I_3

$\dfrac{\omega_3}{\omega_2} = \dfrac{I_{12}I_{23}}{I_{13}I_{23}} = \dfrac{a}{2a}$

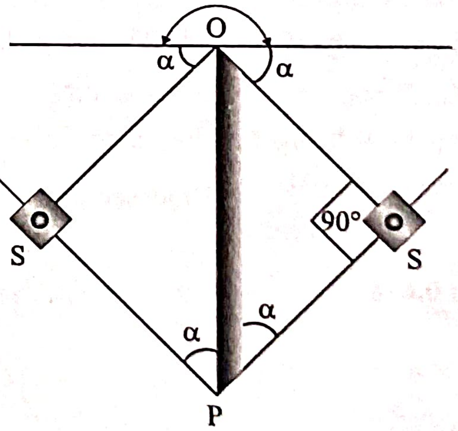
$\dfrac{\omega_3}{2} = \dfrac{1}{2} \Rightarrow \omega_3 = 1$ rad/ sec

Alternate Method:

The position diagram is isosceles right angle triangle and the velocity triangle is similar to the position diagram

18. **Ans: (a)**

Sol:



$QRR = \dfrac{180 + 2\alpha}{180 - 2\alpha} = \dfrac{2}{1} \Rightarrow \alpha = 30°$

$\sin\alpha = \dfrac{OS}{OP} \Rightarrow OS = \dfrac{OP}{2} = 250$ mm

19. Ans: (b)

Sol: Maximum speed during forward stroke occurs when PQ is perpendicular to the line of stroke of the tool i. e. PQ, OS & OQ are in straight line

$\Rightarrow V = 250 \times 2 = 750 \times \omega_{PQ}$

$\Rightarrow \omega_{PQ} = \frac{2}{3}$

20. Ans: (b)

Sol:

- Continuous relative rotation → Grashof's law
- Velocity and acceleration → Kennedy's theorem
- Mobility → Grubler's criterion
- Dynamic–static analysis → D'Alembert's principle

21. Ans: (d)

Sol: As for the given dimensions the mechanism is in a right angle triangle configuration and the crank AB is perpendicular to the lever CD. The velocity of B is along CD only which is purely sliding component

∴ Velocity of the slider

$= AB \times \omega_{AB} = 10 \times 250 = 2.5$ m/sec

22. Ans: (d)

Sol: As both the links AB and CD are perpendicular to the fixed link AD.

So the velocity of AB and CD are equal.

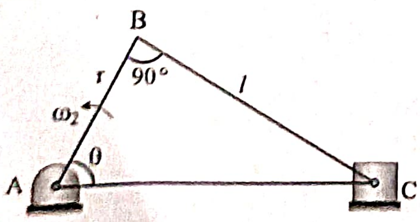
$\Rightarrow V_{BA} = V_{CD}$

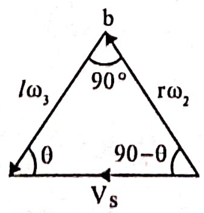
$\Rightarrow \omega_{AB} \times AB = \omega_{CD} \times CD$

$\Rightarrow \omega_{CD} = \frac{1 \times AB}{1.5 \times AB} = \frac{2}{3}$ rad/sec

23. Ans: 0.618

Sol:





(Velocity diagram)

Refer the configuration diagram and velocity diagram

$$\tan\theta = \frac{\ell}{r} = \frac{240}{60} \Rightarrow \theta = 76^\circ$$

$$\frac{r\omega_2}{\sin\theta} = \frac{V_s}{\sin 90^\circ}$$

$$\Rightarrow V_s = \frac{r\omega_2}{\sin 76} = 618 \text{ mm/sec}$$

$$= 0.618 \text{ m/sec}$$

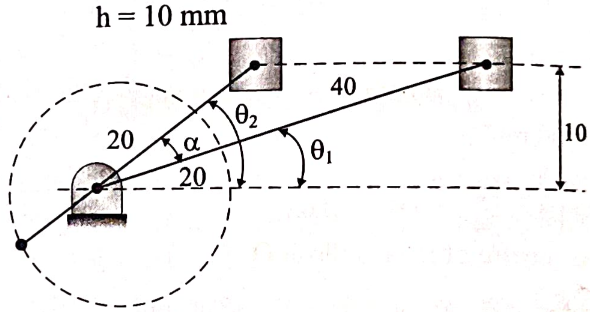
24. Ans: 1.2558

Sol: Two extreme positions are as shown in figure below.

Let r = radius of crank = 20 mm

l = length of connecting rod = 40 mm

h = 10 mm



$$\theta_1 = \sin^{-1}\left(\frac{h}{\ell + r}\right) = \sin^{-1}\left(\frac{10}{60}\right) = 9.55^\circ$$

$$\theta_2 = \sin^{-1}\left(\frac{h}{\ell - r}\right) = \sin^{-1}\left(\frac{10}{20}\right) = 30^\circ$$

$\alpha = \theta_2 - \theta_1 = 20.41^\circ$

Quick return ratio,

$$(\text{QRR}) = \frac{180 + \alpha}{180 - \alpha} = 1.2558$$

25. Ans: 115 to 120

Sol: Acceleration of the slider

$$f_{max} = r\omega^2\left(1 + \frac{1}{n}\right) = 2r\omega^2$$

$$= 2 \times 0.3 \times 14^2 = 117.6 \text{ m/sec}^2$$

26. Ans: (c)

Sol: Number of links, L = 6

Number of joints, J = 7 (class – I)

Degrees of freedom, dof = 3(L – 1) – 2J

$= 3 \times 5 - 2 \times 7 = 1$

27. Ans: 1400

Sol: $V_A = 80$ m/s, $V_B = 140$ m/s,

AB = 300 mm = 0.3 m

$V_{BA} = V_B - V_A = (O_2B \times \omega_2) - (O_2A \times \omega_2)$

$\Rightarrow 60 = (O_2B - O_2A) \times \omega_2$

$\Rightarrow 60 = 0.3 \times \omega_2$

$\Rightarrow \omega_2 = 200$ rad/sec

$V_B = OB \times \omega_2 \Rightarrow OB = \dfrac{140}{200} = 0.7$ m

Diameter $= 2 \times O_2B = 0.7 \times 2 = 1.4$ m = 1400 mm

28. Ans: (c)

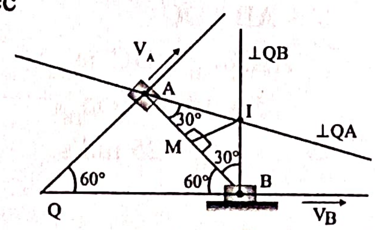
Sol: $QRR = \dfrac{180+\theta}{180-\theta} = \dfrac{180+20}{180-20} = 1.25$

29. Ans: 1 (range 0.95 to 1.05)

Sol: Locate the I-centre for the link AB as shown in fig.

M is the mid point of AB

Given, $V_A = 2$ m/sec



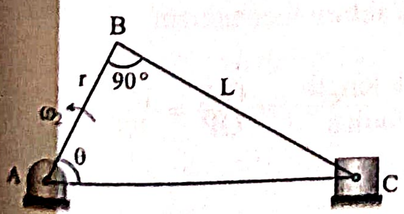
$V_A = IA.\omega \Rightarrow \omega = \dfrac{V_A}{IA}$

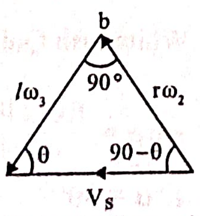
$V_M = IM.\omega = IM\dfrac{V_A}{IA} = \dfrac{IM}{IA}.V_A$

$= \sin 30°.V_A = \dfrac{1}{2}.2 = 1$ m/sec

30. Ans: 0.267

Sol: $V_{slider} = 1$ m/sec, r = 3 m, L = 4 m





V_S
(Velocity diagram)

Refer the configuration diagram and velocity diagram

$\tan\theta = \dfrac{L}{r} = \dfrac{4}{3} = 1.33 = n$

$\theta = 53.13°$

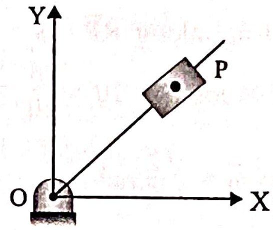
$V_{slider} = \dfrac{r\omega_2}{\sin\theta} = \dfrac{r\omega_2}{\sin 53.13} = 1.25\, r\omega_2$

$1 = 1.25 \times 3 \times \omega_2$

$\omega_2 = \dfrac{1}{3 \times 1.25} = 0.267$ rad/sec

31. Ans: 243. 3

Sol:



r = 100 mm = 0.1 m

Uniform angular velocity = ω = 20 rad/s

Angular acceleration, α = 0

Uniform sliding velocity = $V_S = 6$ m/s

∴ Sliding acceleration $f^S = 0$

Coriolis acceleration, $f^c = 2V\omega = 2 \times 6 \times 20$

$= 240$ m/sec² ⊥ /r to OP

Centripetal acceleration $= r\omega^2 = 0.1 \times 20^2$

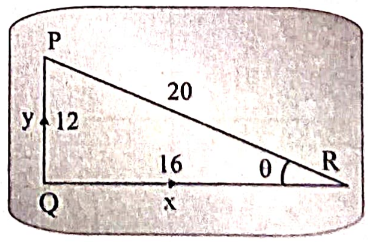
$= 40$ m/sec² towards the center of rotation

Resultant acceleration $= \sqrt{(f^c)^2 + (f^{cor})^2}$

$= \sqrt{40^2 + 240^2} = 243.3$ m/s²

32. Ans: (d)

Sol:

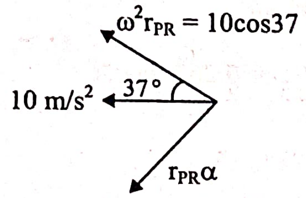


Given that,

$\bar{a}_{RP} = 10$ m/s² ∠180°

$\tan\theta = \frac{12}{16} \Rightarrow \theta = 37^\circ$

Acceleration of R with respect to P is in negative x –direction i.e., along $\overrightarrow{RQ}$



Component of $\vec{a}_R$ along $\overline{RP}$ is

$$\omega^2 r_{PQ} = 10 \times \cos 37 = 10 \times \frac{16}{20} = 8 \text{ m/s}^2$$

$$\omega^2 = \frac{8}{20} \Rightarrow \omega = \sqrt{\frac{2}{5}} \text{ rad/s}$$

Component of $\vec{a}_{RP}$ perpendicular to $\overrightarrow{RP}$ is

$$\alpha r_{RP} = 10\sin 37 = 10 \times \frac{12}{20} = 6 \text{ m/s}^2$$

$$\alpha = \frac{6}{20} = \frac{3}{10} \text{ rad/s}^2$$

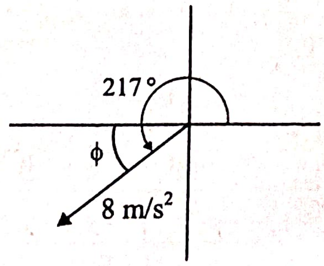
Acceleration $\vec{a}_{RQ}$ is given by

$$\vec{a}_{RQ} = \vec{a}_R - \vec{a}_Q = \vec{a}_R$$

$$a_R = \sqrt{(\omega^2 r_{RQ})^2 + (\alpha r_{RQ})^2}$$

$$= \sqrt{\left(\frac{2}{5} \times 16\right)^2 + \left(\frac{3}{10} \times 16\right)^2} = 8 \text{ m/s}^2$$

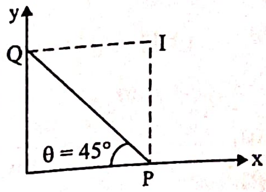
$$\tan\phi = \left(\frac{\alpha r_{RQ}}{\omega^2 r_{RQ}}\right) = \frac{\left(\frac{3}{10}\right)}{\left(\frac{2}{5}\right)} \Rightarrow \phi = 37^\circ$$



∴ Acceleration R is 8 m/s² at 217° from x-axis i.e., $8 \angle 217^\circ$ m/s²

33. Ans: (a)

Sol:



Using Instantaneous centre method

$$\therefore V_P = IP \times \omega = U$$

$$V_Q = IQ \times \omega = V$$

$$\frac{V}{U} = \frac{IQ \times \omega}{IP \times \omega} = \frac{L\cos 45}{L\sin 45} = 1$$

$$\therefore V = U = 5 \text{ m/s}$$

34. Ans: (a)

Sol: AB = 5 cm, AD = 4 cm, DC = 2 cm, $\omega_{AB} = 10$ rad/s,

$\because$ AB || DC

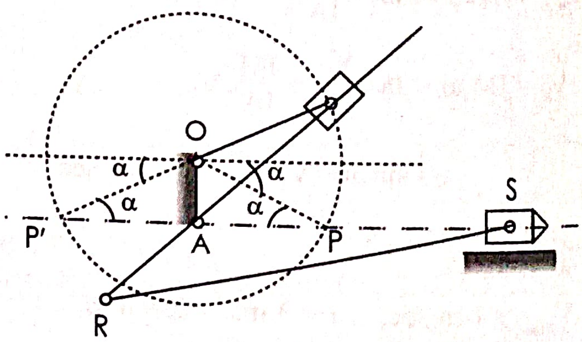
$\therefore$ AB. ω_{AB} = DC. ω_{DC}

$5 \times 10 = 2 \times \omega_{DC}$

$\Rightarrow \omega_{DC} = 25$ rad/s

35. Ans: (2)

Sol:



Whitworth Quick return mechanism

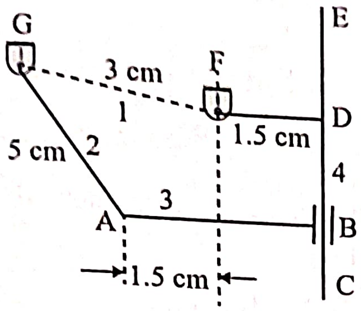
$$\sin\alpha = \frac{\text{fixed link length}}{\text{crank radius}} = \frac{OA}{OP} = \frac{150}{300} = \frac{1}{2}$$

$$\alpha = 30^\circ$$

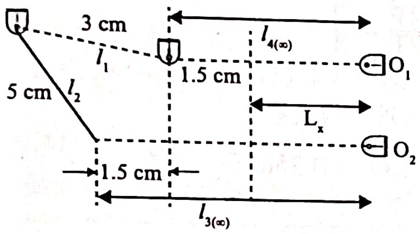
$$QRR = \frac{180 + 2\alpha}{180 - 2\alpha} = \frac{180 + 2 \times 30^\circ}{180 - 2 \times 30^\circ} = 2$$

36. Ans: (a)

Sol: The given mechanism is



As we know sliding pair is a special case of turning pair with infinite lengths link. So the equivalent diagram has been drawn below. Since two parallel lines meets at infinite point O_1 and O_2 are same.



$l_1 = 3$ cm

Shortest link, $l_2 = 5$ cm

$l_3 = l_{3(\infty)} = L_\infty + 3 \rightarrow$ longest link

$l_4 = l_{4(\infty)} = L_\infty + 1.5$

For Grashof's rule to satisfy

$l_1 + l_3 \leq l_2 + l_4$

$\Rightarrow \; 3 + L_\infty + 3 \leq 5 + L_\infty + 1.5$

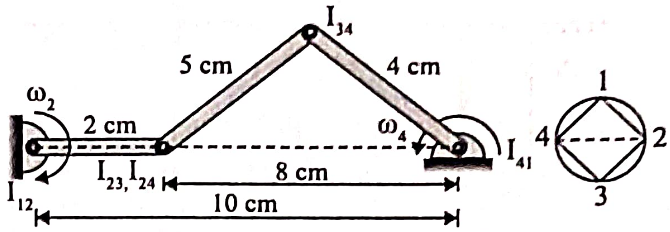
$\Rightarrow \; 6 \leq 6.5$

LHS is less than RHS.

Hence, Grashof's rule is satisfied in this mechanism. Since shortest link is fixed. It will be a double crank mechanism.

37. Ans: 1.25

Sol:



Number of links = 4

Number of I-centers = $4c_2 = 6$

$\omega_2 = 5$ rad/s, $\omega_4 = ?$.

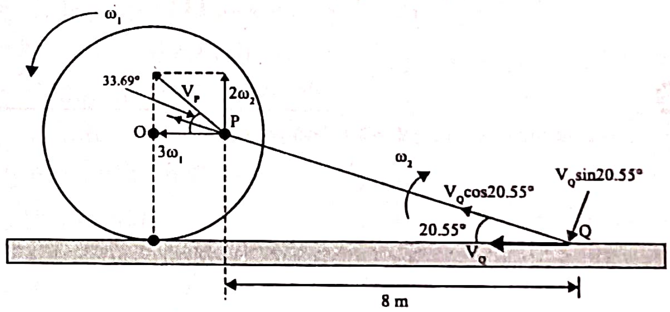
For $V_{I_{24}} = I_{12}I_{24}\omega_2 = I_{14}I_{24}\omega_4$

$= 2\times5 = 8\times\omega_4$

$\omega_4 = 1.25$ rad/sec

38. Ans: (d)

Sol:



$PQ = \sqrt{3^2+8^2} = \sqrt{73}$ m

$V_P = \sqrt{3^2+2^2}\,\omega_1 = \sqrt{13}\,\omega_1$ m/sec

$\theta = \tan^{-1}\left(\frac{2}{3}\right) = 33.69°$

As the bar PQ is rigid

$V_P\cos(33.69° - 20.55°) = V_Q\cos(20.55°)$

$\sqrt{13}\,\omega_1\cos(13.14°) = V_Q\cos(20.55°)$

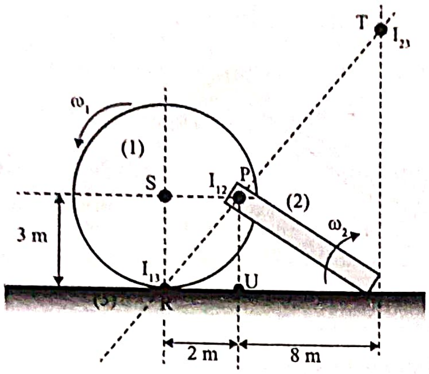
$\Rightarrow V_Q = 3.75\,\omega_1$

$$\omega_2 = \frac{V_P\sin13.14° + V_Q\sin20.55°}{PQ}$$

$$\omega_2 = \frac{\sqrt{13}\,\omega_1\sin13.14° + 3.75\omega_1\sin20.55°}{\sqrt{73}}$$

$\Rightarrow \omega_2 = 0.25\omega_1$

Alternative Method:

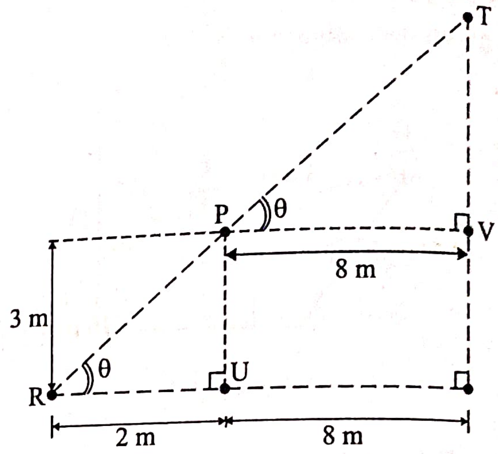


Let us take fixed link (ground) as link no. (3). The I-centres are I_{12}, I_{23} & I_{13}, must be on same line as per Keneddy's theorem for continuous relative motion.

Thus we can write using Kenndy's theorem,

$$\omega_1 (I_{12} - I_{13}) = \omega_2 (I_{12} - I_{23})$$

$$\frac{\omega_2}{\omega_1} = \left(\frac{I_{12}, I_{23}}{I_{12}, I_{13}}\right) = \frac{RP}{PT} \quad \text{........ (1)}$$



Now from geometry,

ΔRUP & ΔPTV are similar triangles, hence

$$\Rightarrow \frac{RP}{PT} = \frac{RU}{PV}$$

$$\frac{RP}{PT} = \frac{2}{8} = 0.25$$

Putting in eq. (1).,

$$\frac{\omega_2}{\omega_1} = 0.25$$

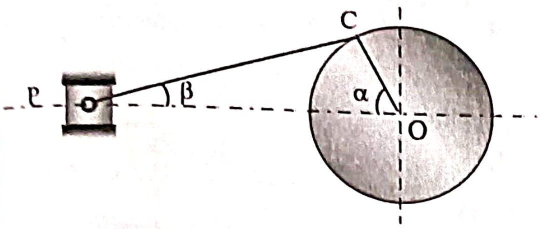
$$\Rightarrow \quad \omega_2 = 0.25\omega_1$$

Chapter 2

Dynamic Analysis of single slider - Crank Mechanism

Two Marks Questions

01. The cross head velocity in the slider crank mechanism, for the position shown in figure is **(GATE–ME-97)**

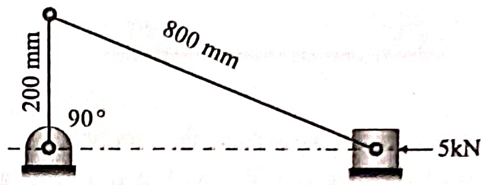


(a) $V_C\cos\left(90-\overline{\alpha+\beta}\right)\cos\beta$
(b) $V_C\cos\left(90-\overline{\alpha+\beta}\right)\sec\beta$
(c) $V_C\cos\left(90-\overline{\alpha-\beta}\right)\cos\beta$
(d) $V_C\cos\left(90-\overline{\alpha-\beta}\right)\sec\beta$
Where V_C is the linear velocity of the crank pin.

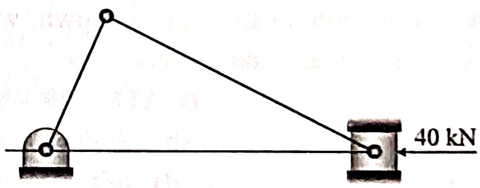
02. Consider the triangle formed by the connecting rod and the crank of an IC engine as the two sides of the triangle. If the maximum area of this triangle occurs when the crank is 75°, the ratio of connecting rod length to crank radius is **(GATE–ME-98)**
(a) 5 (b) 4 (c) 3.73 (d) 3

03. A slider crank mechanism has slider mass of 10 kg, stroke of 0.2 m and rotates with a uniform angular velocity of 10 rad/s. The primary inertia forces of the slider are partially balanced by a revolving mass of 6 kg at the crank, placed at a distance equal to crank radius. Neglect the mass of connecting rod and crank. When the crank angle (with respect to slider axis) is 30°, the unbalanced force (in Newton) normal to the slider axis is ______ **(GATE–ME-14)**

04. A slider crank mechanism with crank radius 200 mm and connecting rod length 800 mm is shown. The crank is rotating at 600 rpm in the counterclockwise direction. In the configuration shown, the crank makes an angle of 90° with the sliding direction of the slider, and a force of 5 kN is acting on the slider. Neglecting the inertia forces, the turning moment on the crank (in kN-m) is **(GATE – 16 – SET – 1)**



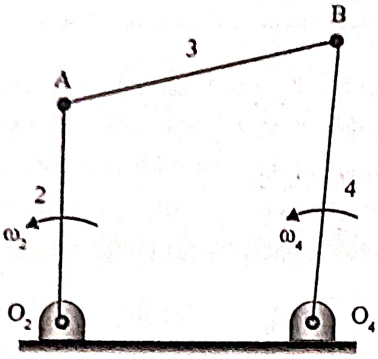
05. A slider crank mechanism is shown in the figure. At some instant, the crank angle is 45° and a force of 40 N is acting towards the left on the slider. The length of the crank is 30 mm and the connecting rod is 70 mm. Ignoring the effect of gravity, friction and inertial forces, the magnitude of the crankshaft torque (in Nm) needed to keep the mechanism in equilibrium is ______ (correct to two decimal places). **(GATE – 18 – SET – 1)**



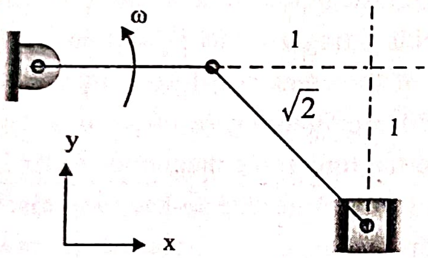
06. A four bar mechanism is shown in the figure. The link numbers are mentioned near the links. Input link 2 is rotating anticlockwise with a constant angular speed ω_2. Length of different links are:

$$O_2O_4 = O_2A = L,$$
$$AB = O_4B = \sqrt{2}L,$$

The magnitude of the angular speed of the output link 4 is ω_4 at the instant when link 2 makes an angle of 90° with O_2O_4 as shown. The ratio $\frac{\omega_4}{\omega_2}$ is ______ (round off to two decimal places). **(GATE – 19 – SET – 2)**



07. The crank of a slider-crank mechanism rotates counter-clockwise (CCW) with a constant angular velocity ω, as shown. Assume the length of the crank to be r,



Using exact analysis, the acceleration of the slider in the y-direction, at the instant shown, where the crank is parallel to x-axis, is given by

(GATE – 19 – SET – 2)

(a) $-\omega^2 r$ (b) $-2\omega^2 r$
(c) $\omega^2 r$ (d) $2\omega^2 r$

KEY & Detailed Solutions

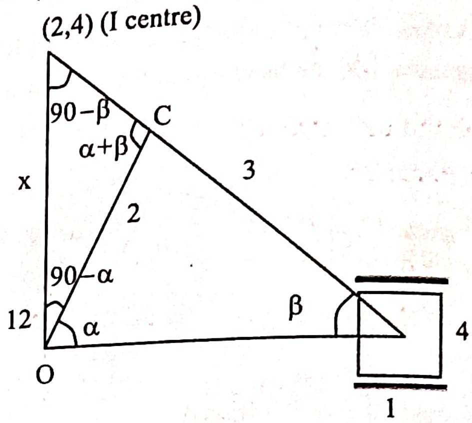
TWO MARKS QUESTIONS

01. (b)	02. (c)	03. 30 N	04. 1	05. 1.11
06. 0.789	07. (c)			

Two Marks Solutions

01. Ans: (b)

Sol:



$OC = r$

Velocity of slider, $V_s = (12-24)\times\omega_2$

$V_s = x\times\omega_2$

$$\frac{x}{\sin(\alpha+\beta)} = \frac{r}{\sin(90-\beta)}$$

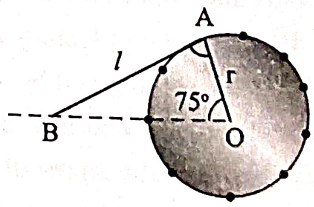
$$x = \frac{r\sin(\alpha+\beta)}{\sin(90-\beta)}$$

$$\therefore V_S = r\,\omega_2\sin(\alpha+\beta).\sec\beta$$
$$= V_c\sin(\alpha+\beta)\times\sec\beta$$

$$\therefore V_S = V_C\cos(90-\overline{\alpha+\beta}).\sec\beta$$

02. Ans: (c)

Sol:



$$\Delta = \frac{1}{2}(AB)(AO)\sin A^\circ$$

Area will be maximum when $A = 90°$

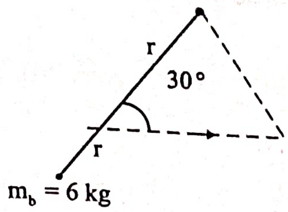
Where ∠OAB is a right angled triangle.

Ratio of connecting rod length to crank radius,

$$\frac{\ell}{r} = \tan 75^\circ = 3.732$$

03. Ans: 30 N

Sol:



Crank radius = stroke/2 = 0.1 m,

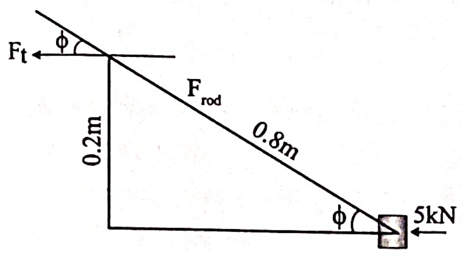
ω = 10 rad/sec

Unbalanced force along perpendicular to the line of stroke = $m_b r\omega^2 \sin 30°$

$= 6 \times (0.1) \times (10)^2 \sin 30° = 30$ N

04. Ans: 1 (range 0.9 to 1.1)

Sol:



Given $F_p = 5$ kN

$$F_{rod} = \frac{F_p}{\cos\phi}$$

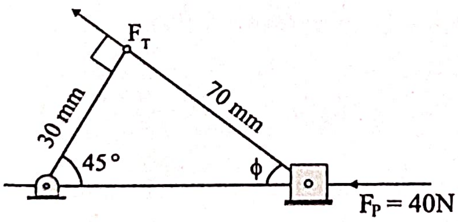
$F_t = F_{rod}\cos\phi$

$\Rightarrow F_t = 5$ kN

Turning moment = $F_t.r = 5 \times 0.2 = 1$ kN-m

05. Ans: 1.11

Sol:



$$F_T = F_P.\frac{\sin(\theta+\phi)}{\cos\phi}$$

But $\theta = 45°$

$$n = \frac{\ell}{r} = \frac{70}{30} = 2.333$$

$$\sin\phi = \frac{\sin\theta}{n} = \frac{\sin 45°}{2.333}$$

$\therefore \phi = 17.64°$

$$\therefore F_T = 40 \times \frac{\sin(45+17.64)}{\cos(17.64)}$$

$= 37.278$ N

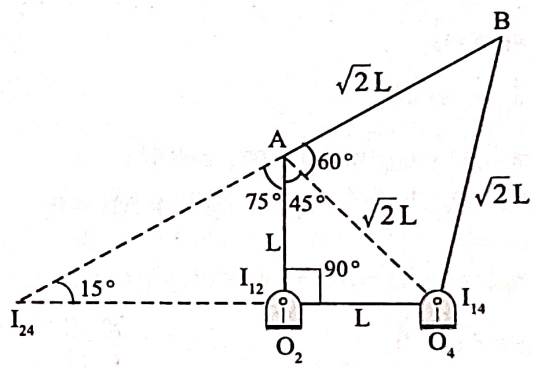
$\therefore$ Torque on crank $T = F_T \times r$

$= 37.278 \times 0.03$ N-m

$\therefore \quad T = 1.1183$ N-m

06. Ans: 0.789

Sol:



$O_2A = O_2O_4 = L$

$AB = O_4B = L\sqrt{2}$

$\omega_2 I_{12}I_{24} = \omega_4 I_{14}I_{24}$

$$\frac{\omega_4}{\omega_2} = \frac{I_{12}I_{24}}{I_{14}I_{24}}$$

From triangle O_2AI_{24},

$$\frac{I_{12}I_{24}}{\sin 75} = \frac{L}{\sin 15}$$

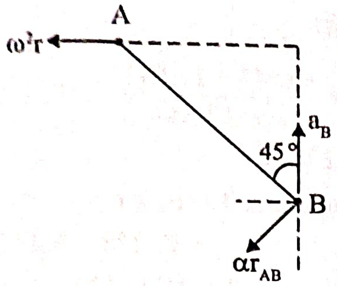
$$I_{12}I_{24} = L\frac{\sin 75}{\sin 15} = 3.73L$$

$I_{14}I_{24} = 3.73L + L = 4.73L$

$$\frac{\omega_4}{\omega_2} = \frac{I_{12}I_{24}}{I_{14}I_{24}} = \frac{3.73L}{4.73L} = 0.789$$

07. Ans: (c)

Sol:



Since the velocity of the point A and B are parallel

$\omega_{AB} = 0$.

$$\vec{a}_B = \vec{a}_A + \vec{a}_{AB}$$

$$\vec{a}_B = a_a\hat{j}$$

$$\vec{a}_A = -\omega^2 r\hat{i}$$

$$\vec{a}_{AB} = -\alpha r_{AB}\sin 45\hat{i} - \alpha r_{AB}\cos 45\hat{j}$$

($\because$ $\omega^2 r_{AB}$ along link AB = 0)

$$a_B\hat{j} = -\omega^2 r\hat{i} - (\alpha\hat{i} + \alpha\hat{j}) = -(\omega^2 r + \alpha)\hat{i} - \alpha\hat{j}$$

$\omega^2 r + \alpha = 0$

$\alpha = -\omega^2 r$

$a_B = -\alpha = -(-\omega^2 r) = \omega^2 r$

Chapter 3 Gear & Gear Trains

One Mark Questions

01. In spur gears having involute teeth, the product of circular pitch and diametral pitch is____
(GATE–ME-94)

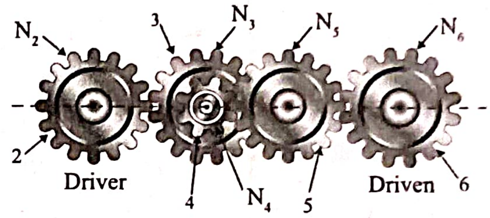
02. A 1.5 kW motor is running at 1440 rev/min. It is to be connected to a stirrer running at 36 rev/min. The gearing arrangement suitable for this application is
(GATE–ME-00)
(a) differential gear (b) helical gear
(c) spur gear (d) worm gear

03. Tooth interference in an external involute spur gear pair can be reduced by **(GATE–ME-10)**
(a) decreasing center distance between gear pair
(b) decreasing module
(c) decreasing pressure angle
(d) increasing number of gear teeth

04. The following are the data for two crossed helical gears used for speed reduction:
Gear I: Pitch circle diameter in the plane of rotation 80 mm and helix angle 30°.
Gear II: Pitch circle diameter in the plane of rotation 120 mm and helix angle 22.5°.
If the input speed is 1440 rpm. The output speed in rpm is **(GATE–ME-12)**
(a) 1200 (b) 900 (c) 875 (d) 720

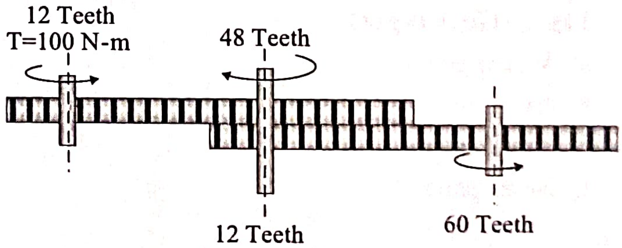
05. Which one of the following is used to convert a rotational motion into a translational motion?
(GATE–ME-14)
(a) Bevel gears
(b) Double helical gears
(c) Worm gears
(d) Rack and pinion gears

06. A gear train is made up of five spur gears as shown in the figure. Gear 2 is driver and gear 6 is driven member. N_2, N_3, N_4, N_5 and N_6 represent number of teeth on gears 2, 3, 4, 5, and 6 respectively. The gear(s) which act(s) as idler(s) is/are
(GATE –15 –Set 3)



(a) Only 3 (b) Only 4
(c) Only 5 (d) both 3 and 5

07. A frictionless gear train is shown in the figure. The leftmost 12-teeth gear is given a torque of 100 N-m. The output torque from the 60-teeth gear on the right in N-m is **(GATE – 18 – SET – 2)**

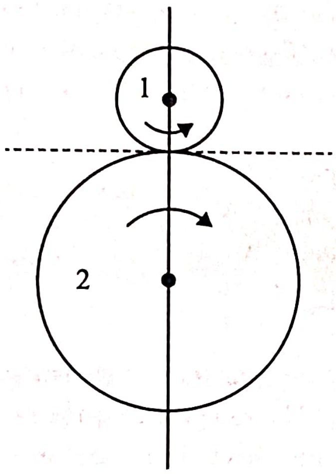


(a) 5 (b) 20 (c) 500 (d) 2000

08. A spur gear with 20° full depth teeth is transmitting 20 kW at 200 rad/s. The pitch circle diameter of the gear is 100 mm. The magnitude of the force applied on the gear in the radial direction is
(GATE – 19 – SET – 1)
(a) 0.36 kN (b) 1.39 kN (c) 0.73 kN (d) 2.78 kN

09. A spur gear has pitch circle diameter D and number of teeth T. The circular pitch of the gear is
(GATE – 19 – SET – 2)
(a) $\frac{T}{D}$ (b) $\frac{D}{T}$ (c) $\frac{2\pi D}{T}$ (d) $\frac{\pi D}{T}$

10. Two meshing spur gears 1 and 2 with diametral pitch of 8 teeth per mm and an angular velocity ratio $|\omega_2|/|\omega_1|=1/4$, have their centers 30 mm apart. The number of teeth on the driver (gear 1) is _______. (Answer in integer) **(GATE_ME-23)**



Two Marks Questions

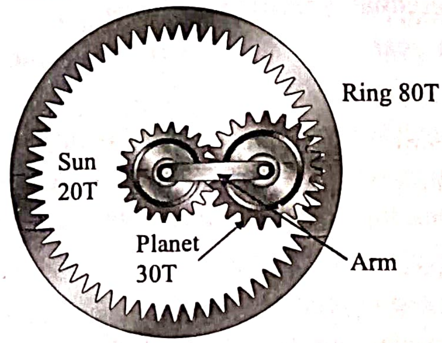
01. **List I (Gear types)**
   a. Worm gears
   b. Cross helical gears
   c. Bevel gears
   d. Spur gears

   List II (Applications)
   1. Parallel shafts
   2. Non-parallel, intersecting shafts
   3. Non-parallel, non intersecting shafts
   4. Large speed ratios **(GATE–ME-95)**

02. The arm OA of an epicylic gear train shown in Fig. revolves counter clockwise about O with an angular velocity of 4 rad/s. Both gears are of same size. The angular velocity of gear C, if the sun gear B is fixed, is **(GATE–ME-95)**

(a) 4 rad/s (b) 8 rad/s (c) 10 rad/s (d) 12 rad/s

03. The sun gear in the figure is driven clockwise at 100 rpm. The ring gear is held stationary. For the number of teeth shown on the gears, the arm rotations at **(GATE–ME-01)**



(a) 0 rpm (b) 20 rpm
(c) 33.33 rpm (d) 66.67 rpm

04. Match the items in columns I and II **(GATE–ME-06)**

Column I
P. Addendum
Q. Instantaneous center of velocity
R. Section modulus
S. Prime circle

Column II
1. Cam
2. Beam
3. Linkage
4. Gear

	P	Q	R	S
(a)	4	2	3	1
(b)	4	3	2	1
(c)	3	2	1	4
(d)	3	4	1	2

Data for Q.Nos. 05 & 06 are given below.

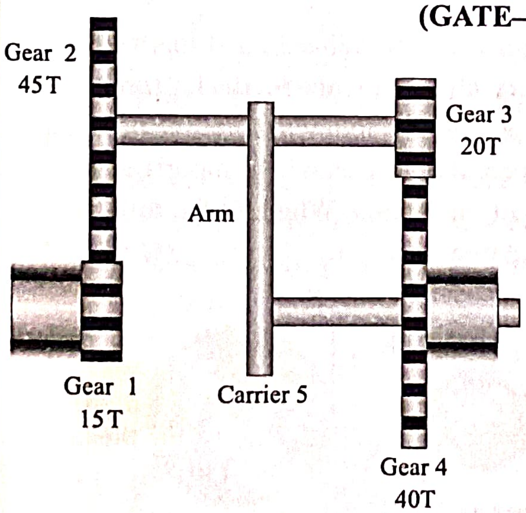
The overall gear ratio in a 2 stage speed reduction gear box (with all spur gears) is 12. The input and output shafts of the gear box are collinear. The counter-shafts which is parallel to the input and output shafts has a gear (Z_2 teeth) and pinion (Z_3 = 15 teeth) to mesh with pinion (Z_1 = 16 teeth) on the input shaft and gear (Z_4 teeth) on the output shaft respectively. It was decided to use a gear ratio of 4 with 3 module in the first stage and 4 module in the second stage. **(GATE-ME-03)**

05. Z_2 and Z_4 are
(a) 64 and 45 (b) 45 and 64
(c) 48 and 60 (d) 60 and 48

06. The centre distance in the second stage is
(a) 90 mm (b) 120 mm
(c) 160 mm (d) 240 mm

Common Data for Q.Nos. 07 & 08

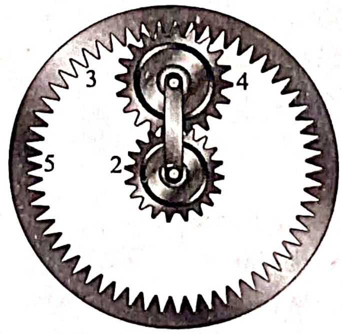
A planetary gear train has four gears and one carrier. Angular velocities of the gears are ω_1, ω_2, ω_3 and ω_4 respectively. The carrier rotates with angular velocity ω_5. **(GATE–ME-06)**



07. What is the relation between the angular velocities of Gear 1 and Gear 4?
(a) $\frac{\omega_1-\omega_5}{\omega_4-\omega_5}=6$ (b) $\frac{\omega_4-\omega_6}{\omega_1-\omega_5}=6$
(c) $\frac{\omega_1-\omega_2}{\omega_4-\omega_5}=-\left(\frac{2}{3}\right)$ (d) $\frac{\omega_2-\omega_5}{\omega_4-\omega_5}=-\left(\frac{8}{9}\right)$

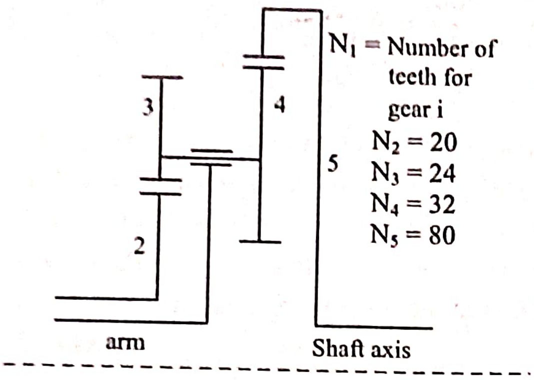
08. For ω_1 = 60 rpm clockwise (CW) when looked from the left, what is the angular velocity of the carrier and its direction so that Gear 4 rotates in counter clockwise (CCW) direction at twice the angular velocity of Gear 1 when looked from the left? **(GATE–ME-06)**
(a) 130 rpm, CW
(b) 223 rpm, CCW
(c) 256 rpm, CW
(d) 156 rpm, CCW

09. An epicyclic gear train is shown schematically in the figure. The sun gear 2 on the input shaft is a 20 teeth external gear. The planet gear 3 is a 40 teeth external gear. The ring gear 5 is a 100 teeth internal gear. The gear 5 is fixed and the gear 2 is rotating at 60 rpm CCW (CCW = counter- clockwise and CW = clockwise). The arm 4 attached to the output shaft will rotate at **(GATE–ME-09)**



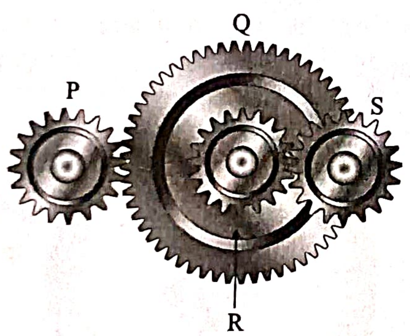
(a) 10 rpm CCW
(b) 10 rpm CW
(c) 12 rpm CCW
(d) 12 rpm CW

10. For the epicyclic gear arrangement shown in the figure, ω_2 = 100 rad/s clockwise (CW) and ω_{arm} = 80 rad/s counter clockwise (CCW). The angular velocity ω_5 (in rad/s) is **(GATE–ME-10)**



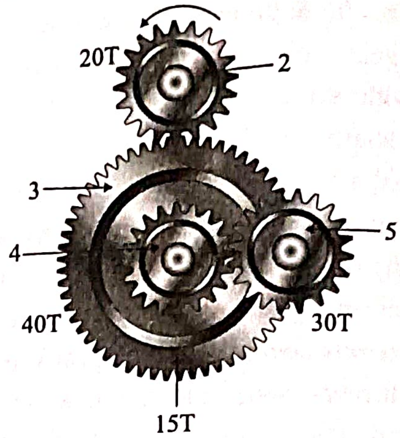
(a) 0 (b) 70 CW
(c) 140 CCW (d) 140 CW

11. A compound gear train with gears P, Q, R and S has number of teeth 20, 40, 15 and 20 respectively. Gears Q and R are mounted on the same shaft as shown in the figure below. The diameter of the gear Q is twice that of the gear R. If the module of the gear R is 2 mm, the center distance in mm between gears P and S is **(GATE–ME-13)**



(a) 40 (b) 80 (c) 120 (d) 160

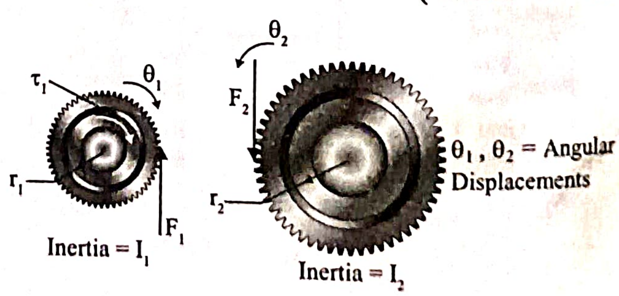
12. Gear 2 rotates at 1200 rpm in counter clockwise direction and engages with Gear 3. Gear 3 and Gear 4 are mounted on the same shaft. Gear 5 engages with Gear 4. The numbers of teeth on Gears 2, 3, 4 and 5 are 20, 40, 15 and 30, respectively. The angular speed of Gear 5 is **(GATE–ME-14)**



(a) 300 rpm counter clockwise
(b) 300 rpm clockwise
(c) 4800 rpm counter clockwise
(d) 4800 rpm clockwise

13. It is desired to avoid interference in a pair of spur gears having a 20° pressure angle. With increase in pinion to gear speed ratio, the minimum number of teeth on the pinion **(GATE–ME- 14)**
(a) increases
(b) decreases
(c) first increases and then decreases
(d) remains unchanged

14. A pinion with radius r_1, and inertia I_1 is driving a gear with radius r_2 and inertia I_2. Torque τ_1 is applied on pinion. The following are free body diagrams of pinion and gear showing important forces (F_1 and F_2) of interaction. Which of the following relations hold true? **(GATE –15 –Set 1)**



(a) $F_1 \neq F_2;\ \tau_1 = I_1\ddot{\theta}_1;\ F_2 = I_2\dfrac{r_1}{r_2^2}\ddot{\theta}_1$

(b) $F_1 = F_2;\ \tau_1 = \left[I_1 + I_2\left(\dfrac{r_1}{r_2}\right)^2\right]\ddot{\theta}_1;\ F_2 = I_2\dfrac{r_1}{r_2^2}\ddot{\theta}_1$