CBCS SCHEME

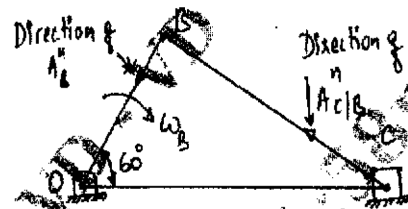
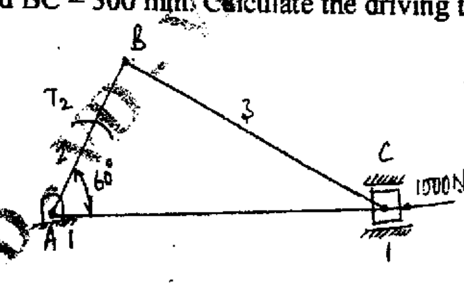
USN | | | | | | | | | | |

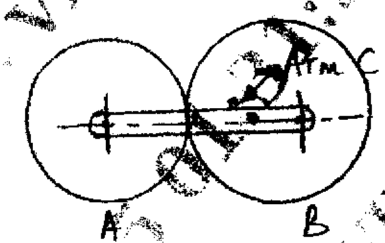
BME503

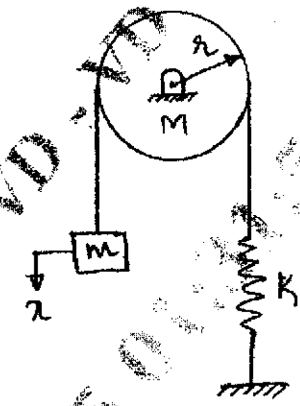
Fifth Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025
Theory of Machines

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	Define : (i) Kinematic link (ii) Kinematic pair (iii) Kinematic chain (iv) Mechanism (v) Machine.	10	L1	CO1
	b.	Briefly explain the following inversions : (i) Beam engine (ii) Watt's straight line mechanism	10	L1	CO1
		OR			
Q.2	a.	In a slider crank mechanism, the crank OB = 30 mm and connecting rod BC = 120 mm. The crank rotates at a uniform speed of 300 rpm clockwise. For the crank position as shown in Fig. Q2 (a) ; find (i) Velocity of Piston C and angular velocity of connecting rod BC (ii) Acceleeration of piston C and angular acceleration of connecting rod BC.  Fig. Q2 (a)	10	L3	CO1
	b.	If the crank and connecting rod are 150 mm and 600 mm long respectively and the crank rotates at a uniform speed of 100 rpm closckwise; determine the angular velocity and angular acceleration of connecting rod and velocity of the piston by using Raven's approach. The angle which the crank makes with the inner dead center is 30°.	10	L3	CO1
		Module – 2			
Q.3	a.	With a neat sketch, explain the following : (i) Equillibrium of Three force members (ii) Equillibrium of Four force members.	10	L1	CO2
	b.	For a slider crank mechanism as shown in Fig. Q3 (b), the force applied to the piston is 1000 N when the crank is at 60° from IDC. Given AB = 100 mm and BC = 300 mm. Calculate the driving torque T_2.  Fig. Q3 (b)	10	L3	CO2

		OR			
Q.4	**a.**	Explain : (i) Dynamic force analysis. (ii) D'Alembert's principle.	10	L1	CO2
	b.	A punching machine punches 38 mm holes in 32 mm thick plate requires 7 N-m/mm^2 of sheared area and punches one hole in every 10 sec. The mean speed is of the flywheel given is 25 m/sec. The punch has a stroke of 100 mm. Find : (i) Power required to drive the machine. (ii) Mass of the flywheel, if total fluctuation of speed is not to exceed 2%.	10	L3	CO2
		Module – 3			
Q.5	**a.**	Define the following gear terminologies : (i) Pitch circle. (ii) Pitch circle diameter. (iii) Addendum (iv) Dedendum (v) Module.	10	L1	CO3
	b.	A pinion having 30 teeth drives a gear having 80 teeth. The profile of the gears is involute with 20° pressure angle, 12 mm module and 10 mm addendum. Find the length of path of contact and length of arc of contact.	10	L3	CO3
		OR			
Q.6	**a.**	Derive with usual notations ; an expression for velocity ratio of compound gear trains.	10	L2	CO3
	b.	In an Epicyclic gear train, an arm carries two gears A and B having 36 and 45 teeth respectively. If the arm rotates at 150 rpm in anticlockwise direction about centre of gear A which is fixed as shown in Fig. Q6 (b); then determine speed of gear B. If the gear A instead of being fixed makes 300 rpm in clockwise direction, what will be the speed of gear B? Use Tabular method.  Fig. Q6 (b)	10	L3	CO3
		Module – 4			
Q.7	**a.**	A shaft carries 4 masses A, B, C, D in parallel planes in this order along its length. The masses at B and C are 18 kg and 12.5 kg respectively. Each of B and C has an eccentricity of 60 mm. The masses at A and D have an eccentricity of 80 mm. The angle between B and C is 100° and in between B and A is 190°, both being measured in same direction. The axial distance between A and B is 100 mm and in between B and C is 200 mm. For the shaft to be in complete balance, determine magnitude of masses at A and D as well as the angular position of mass at D.	10	L3	CO4
	b.	A four cylinder vertical engine has cranks 150 mm long. The planes of rotation of the 1st, 2nd and 4th cranks are 400 mm, 200 mm and 200 mm respectively from 3rd crank and their reciprocating masses are 50 kg, 60 kg and 50 kg respectively. Find the mass of the reciprocating parts of 3rd cylinder and relative angular positions of the cranks in order that the engine may be in complete primary balance.	10	L3	CO4

		OR			
Q.8	**a.**	Define the following terminologies : (i) Sensitiveness (ii) Stability (iii) Hunting (iv) Effort (v) Power.	**10**	**L1**	**CO4**
	b.	A Porter governor has equal arms each of 250 mm long and pivoted on the axis of rotation. Each flyball has a mass of 5 kg and the mass of central sleeve is 15 kg. The radius of rotation of the flyball is 150 mm when the governor begins to lift and 200 mm when the governor is at maximum speed. Find the minimum, maximum speeds and the range of speed of the governor.	**10**	**L3**	**CO4**
		Module – 5			
Q.9	**a.**	Define the following types of vibrations : (i) Free vibration. (ii) Forced vibration (iii) Damped vibration. (iv) Undamped vibration (v) Longitudinal vibration.	**10**	**L1**	**CO5**
	b.	Determine the natural frequency of the spring mass pulley system as shown in Fig. Q9 (b).  Fig. Q9 (b)	**10**	**L3**	**CO5**
		OR			
Q.10		Explain the following : **a.** Rotating unbalance. **b.** Reciprocating unbalance. **c.** Vibration isolation **d.** Critical speed.	**20**	**L2**	**CO5**

* * * * *

VTU QUESTION PAPER SOLUTIONS DEC. 2024/JAN 2025

Fifth Semester BE/BTech. Degree Examination Dec. 24/Jan 25

THEORY OF MACHINES [BME503]

MODULE - 1

Q. 1. a. Definition of,

i) Kinematic Link: It is a each part of mechanism that have relative motion with ~~rep~~ respect to the mating part.

ii) Kinematic Pair: Kinematic pair is a joint of two links (rigid bodies) having relative motions between them.

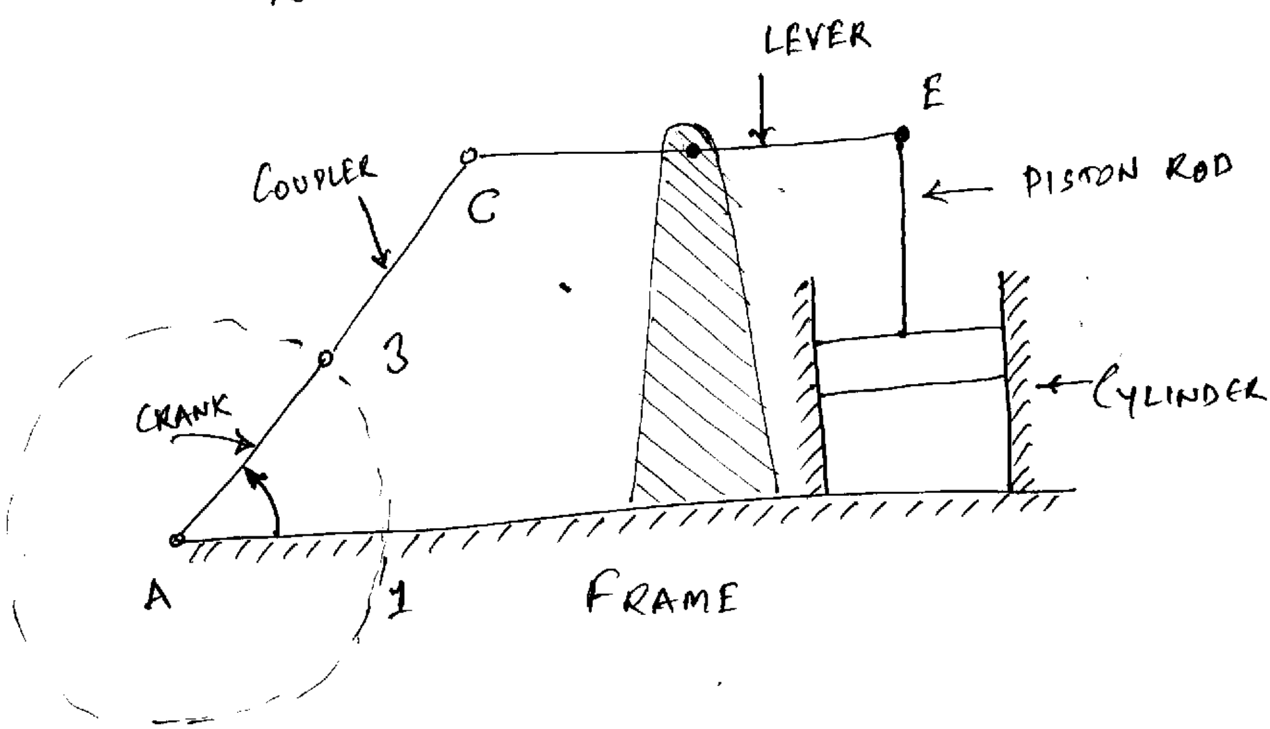
iii) Kinematic Chain: It is an assembly of links in which the relative motion of the links is possible and the motion of each relative to other is definite.

iv) Mechanism: It is combination of number of bodies assembled in such a way that the motion of one causes constrained and predictable motion to others.

v) Machine: It is a mechanism or combination of mechanisms which apart from imparting definite motions to the parts, also transmits and modifies the available mechanical energy into some kind of mechanical work.

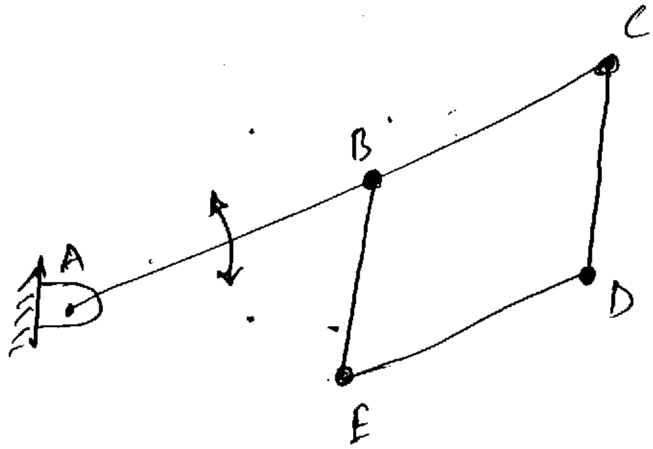
Q. 1. b) EXPLAINATION OF INVERSIONS

i) BEAM ENGINE :



Beam engine is a mechanism that is an example of Crank and Lever mechanism. In the diagram Link 2 is the crank and Link 4 is a lever. When the crank rotates about the fixed centre A, the lever oscillates about the fixed centre D. The end of lever CDE is connected to a piston rod which reciprocates due to the rotation of the crank. The purpose of this mechanism is to convert rotary motion to reciprocating motion.

ii) WATT'S STRAIGHT LINE MECHANISM:



Watt's straightline mechanism, invented by James Watt, is a fourbar linkage mechanism that approximates a straight-line motion. It is a crossed fourbar chain where the coupler link traces a path that includes a portion resembling straight line.

This mechanism originally used in steam engines to guide the piston rod near a straight path.

Q 2. a) Solution:

$$\omega_B = \frac{2\pi N_B}{60} = 31.416 \text{ rad/sec}$$

$$V_B = \omega_B \times OB = 0.9425 \text{ m/s or } 942.5 \text{ mm/s}$$

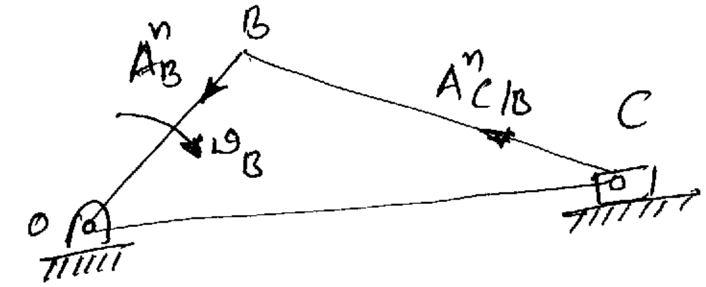
Velocity, $V_{C/B} = 2.4 \times 20 = 48$ cm/s or 0.48 m/s

Velocity of piston, $V_C = OC \times \text{scale} = 92$ cm/s
$= 0.92$ m/s [ANS (i)]

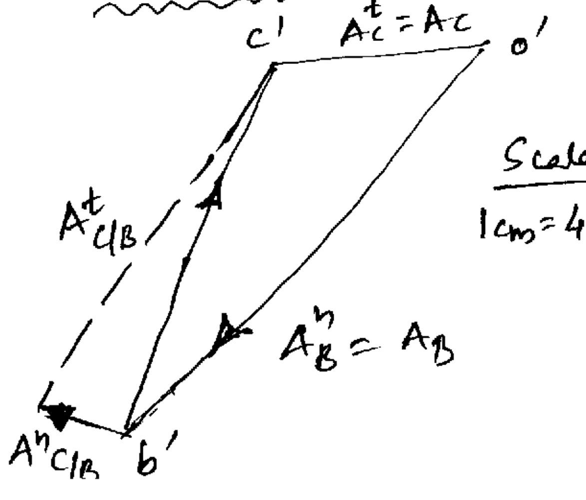
Angular velocity of connecting rod $BC = \omega_{BC}$

$$\omega_{BC} = \frac{V_{C/B}}{CB} = \frac{0.48}{0.12} = 4 \text{ rad/s}$$ [Ans. (ii)]

Space Diagram:

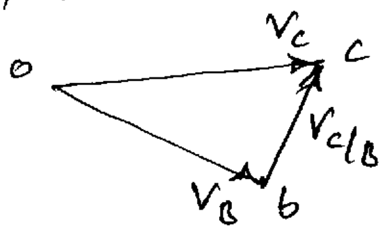


Acceleration Diagram:



Scale
1 cm = 4 cm/s²

Velocity Diagram:



$$A^n_B = \frac{V_B^2}{OB} = 29.6 \ m/s^2$$

$$A^n_{C/B} = \frac{V_{C/B}^2}{CB} = 1.92 \ m/s^2$$

Acceleration of piston, $A_C = o'c' \times scale = 10.8 \ m/s^2$

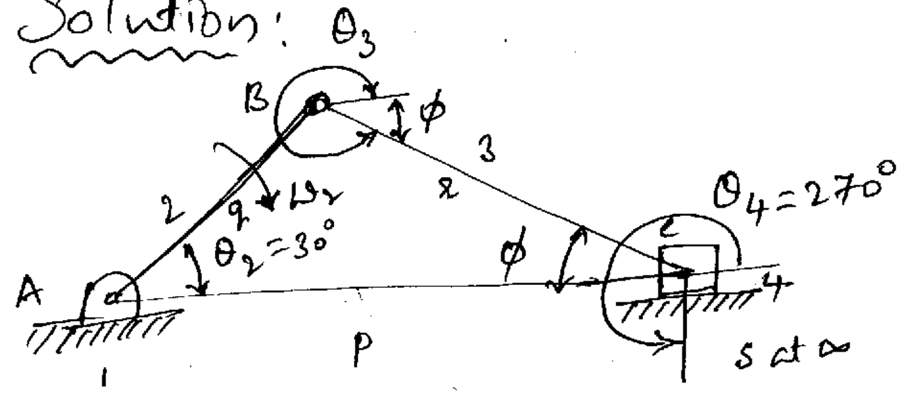
Angular Acceleration of ~~piston~~ connecting rod BC,

$$\alpha_{BC} = \frac{A^t_{C/B}}{CB} = 216.67 \ rad/s^2$$

[Ans (iii)]

Q. 2 b)

Solution:



$$\omega_2 = \frac{2\pi N_2}{60} = -10.472 \text{ Rad/s}$$

$$\frac{\sin\theta_2}{r} = \frac{\sin\phi}{q} \Rightarrow \phi = 7.1808° \text{ \& } \theta_3 = 352.82°$$

$$\omega_3 = -\frac{q\cos\theta_2}{r\cos\theta_3} \times \omega_2 = 2.285 \text{ Rad/s.}$$

$$\alpha_3 = \frac{\omega_3}{\omega_2} \times \alpha_2 + \frac{q\omega_2^2\sin\theta_2 + r\omega_3^2\sin\theta_3}{r\cos\theta_3}$$

$\alpha_3 = 13.16$ Rad/s²

$R_v = 956.767$ & $I_v = 0$

∴ V_p = Velocity of piston $= \sqrt{R_v^2 + I_v^2} = 0.957$ m/s [ANS]

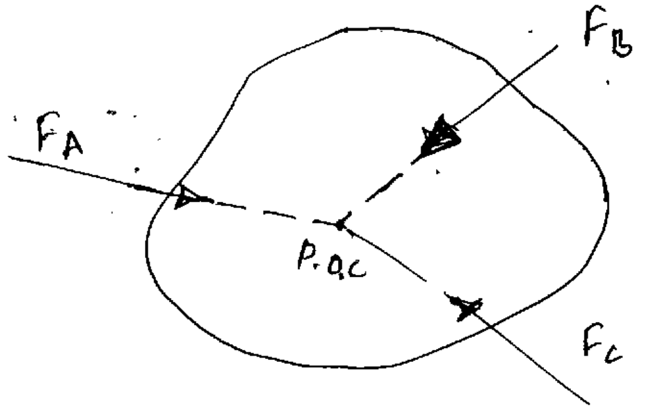
$R_a = -16366.886$ & $I_A = 0$

∴ Acceleration of Piston; $A_p = \sqrt{R_a^2 + I_a^2}$

$A_p = -16.37$ m/s [ANS.]

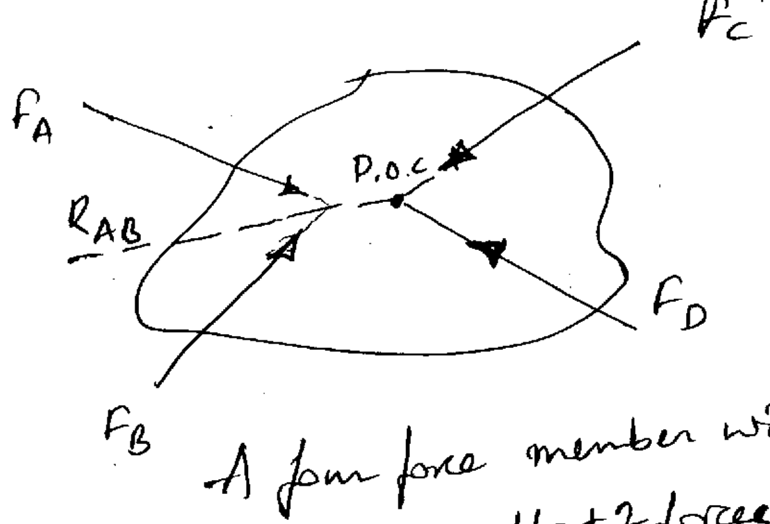
Q. 3 a)

(i) EQUILIBRIUM OF THREE FORCE MEMBERS:



The three force member will be in equilibrium when the lines of action of three forces once extended must meet at a single point which is called point of concurrency.

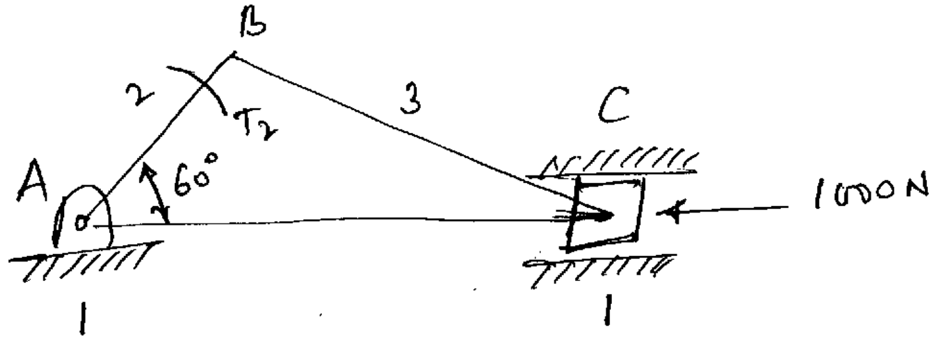
(ii) EQUILIBRIUM OF FOUR FORCE MEMBER:



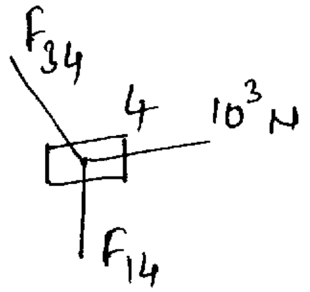
A four force member will be in equilibrium when resultant 2 forces (R_{AB}) and lines of actions of F_C & F_D meet at a single point known as Point of Concurrency.

Q. 3. b) SLIDER CRANK MECHANISM

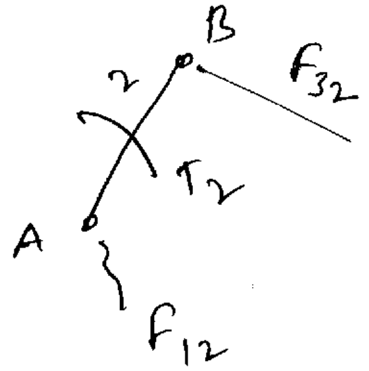
Solution:

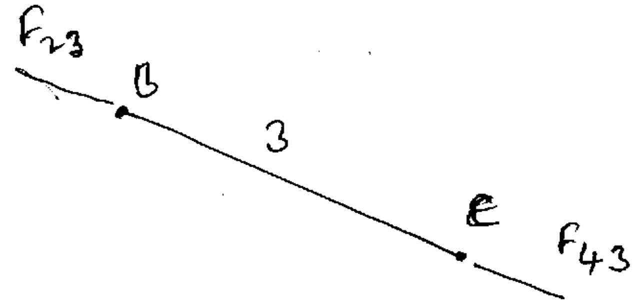


SPACE DIAGRAM

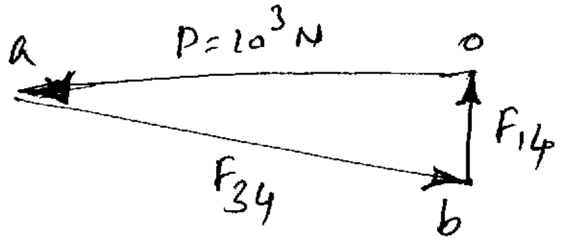


Free Body Diagrams



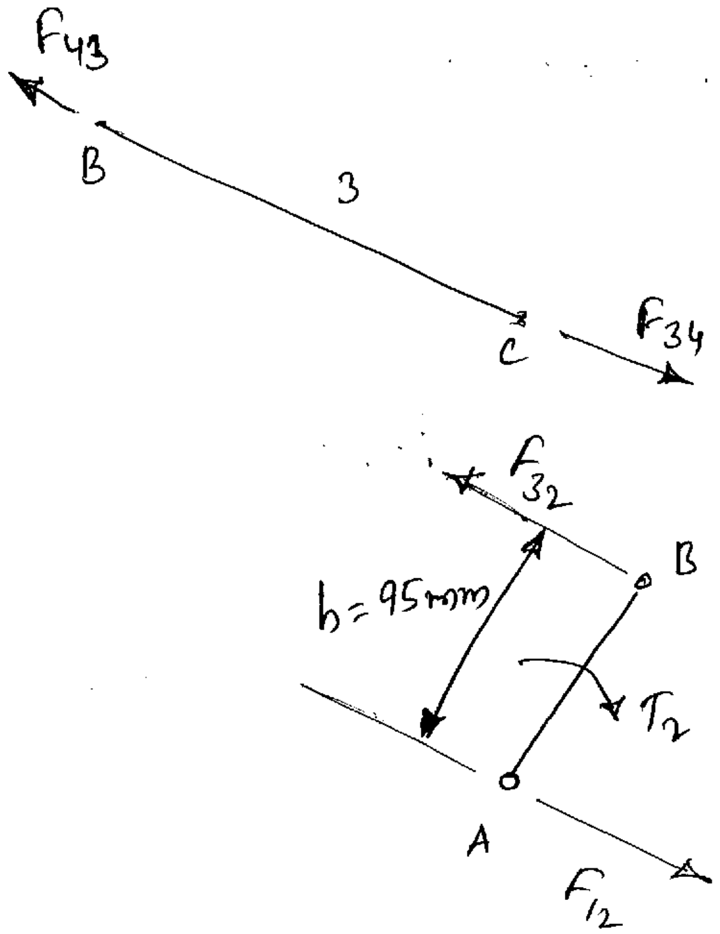


FORCE POLYGON: (Scale : 1cm = 100 N)



$F_{34} = ab \times Scale$
$= 1050\ N.$

$F_{14} = ob \times Scale$
$= 300\ N.$



Thus,

Torque, $T_2 = F_{12} \times h$

$= 99750$ N-mm or

$= 99.75$ N-m. [ANS.]

Q. 4. a)

(i) DYNAMIC FORCE ANALYSIS:

Dynamic force analysis is a method used to determine forces acting on machine components, considering not only external forces but also inertia due to acceleration.

The inertia forces arise from the resistance of a body to changes in its motion (acceleration & deceleration). They are directly proportional to the mass and acceleration of the body.

Dynamic force analysis involves determining the forces acting on machine components considering both external loads and inertia forces.

(ii) D'ALEMBERT'S PRINCIPLE :

D'Alemberts' principle states that a system of particles is in dynamic equilibrium if sum of the forces acting on it, including inertial forces, is zero for any virtual displacement consistent with constraints.

It provides an alternative way to express Newton's second Law by introducing the concept of Inertial forces (mass times acceleration, but with reversed sign). This allows treating dynamic problems as equivalent to static equilibrium problems that simplifies the analysis.

Q. 4 b) PUNCHING MACHINE.

Solution:

Workdone / Sheared area = 7 N-m/mm²

Workdone / hole = $7 \times \pi d t$ = 26741.24 N-m

Workdone / min = $\frac{\text{Workdone}}{\text{hole}} \times \frac{\text{hole}}{\text{min}}$

= 160447.42 N-m/min

(i) Power, P = $\frac{\text{Workdone/min}}{60 \times 10^3}$ = 2.674 kW

[ANS]

(ii) Actual time taken to punch a hole = 1.6 sec.

Maximum energy supplied

e_{max} = 22462.65 N-m

$e_{max} = \frac{K_s M v^2}{100}$

$22462.65 = \frac{3 \times M \times 25^2}{100}$

∴ Mass of flywheel, M = 1198 kg

[ANS.]

Q. 5 a) Definitions:

(i) Pitch Circle: The pitch circle is an imaginary reference circle on a gear wheel. It is a circle, that, if it were a smooth friction wheel, would transmit the same motion as the actual gear teeth. When two gears mesh, their pitch circles are tangent to each other at a point called pitch point.

(ii) Pitch Circle diameter: It is the diameter of an imaginary reference circle on a gear.

(iii) Addendum: The addendum is the radial distance from the pitch circle to the top of the gear tooth (the addendum circle)

(iv) Dedendum: It is the radial distance from the pitch circle to the bottom of gear tooth surface.

(v) Module: It is the ratio of pitch circle diameter to the number of teeth ($m = D/N$)

Q. 5 b)

Solution:

$r = \frac{mt}{2} = \frac{12 \times 30}{2} = 180\,mm$

$R = \frac{mT}{2} = \frac{12 \times 80}{2} = 480\,mm$

$r_A = r + \text{Addendum} = 180 + 10 = 190\,mm$

$R_A = R + \text{Addendum} = 480 + 10 = 490\,mm$

Length of the path of Approach } $K_P = \sqrt{R_A^2 - R^2\cos^2\phi} - R\sin\phi$

$K_P = 27.3$ mm.

Length of the path of recess } $P_L = \sqrt{r_A^2 - r^2\cos^2\phi} - r\sin\phi$

$P_L = 25$ mm

Thus, Length of path of Contact, $K_L = K_P + P_L$
$= 52.3\,mm$

Now,

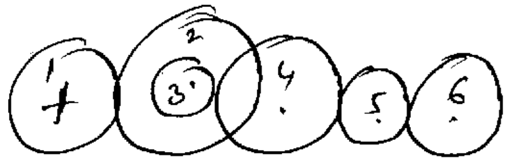
Length of Arc of Contact } $= \frac{\text{Length of path of contact}}{\cos\phi}$

$= \frac{52.3}{\cos 20^\circ}$

Length of arc of Contact $= 55.66$ mm

[Ans.]

Q. 6. a) DERIVATION FOR VELOCITY RATIO :



$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \; ; \quad \frac{N_3}{N_4} = \frac{T_4}{T_3} \quad \frac{N_5}{N_6} = \frac{T_6}{T_5}$$

Velocity ratio, $\frac{N_1}{N_2} \times \frac{N_3}{N_4} \times \frac{N_5}{N_6} = \frac{T_2}{T_1} \times \frac{T_4}{T_3} \times \frac{T_6}{T_5}$

∴ Velocity ratio N_1/N_6

$$\text{i.e., } \frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}$$

Q 6. b)

Solution:

	Arm C	Gear A	Gear B
1. Gear A rotates through +1 rev.	0	+1	$-\frac{T_A}{T_B}$
2. Gear A rotates through +x rev.	0	+x	$-\frac{T_A}{T_B}x$
3. Add y rev. to all elements	+y	+y	+y
4. Total motion	+y	x+y	$y-\frac{T_A}{T_B}x$

Now, Speed of Gear B: $y = 150$ rpm

$x+y=0$, $x=-y=-150$ rpm

(i) $\therefore N_B = y - \frac{T_A}{T_B}x = 150 - (-150)\frac{36}{45}$

$N_B = +270$ rpm **Ans**

(ii) $x+y=-300$: $x=-300-y=-300-150$

$x = -450$ rpm

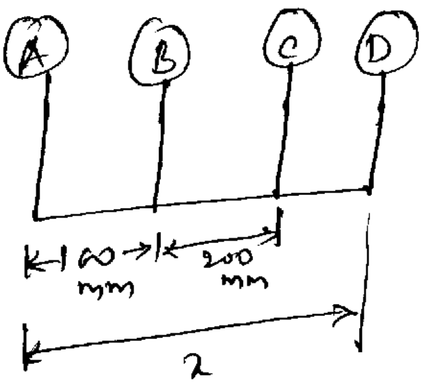
$N_B = y - x\frac{T_A}{T_B} = 150 - (-450)\times 36/45$

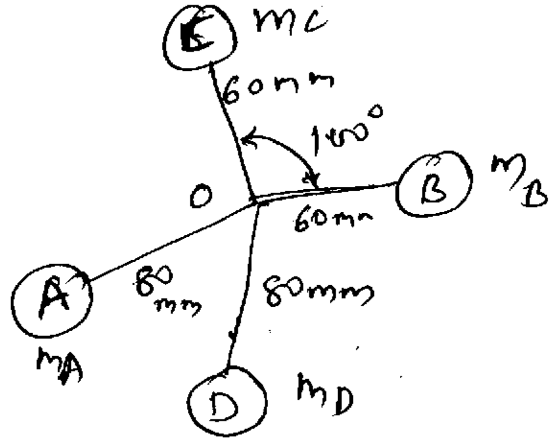
$N_B = +510$ rpm **Ans.**

Q. 7 a)

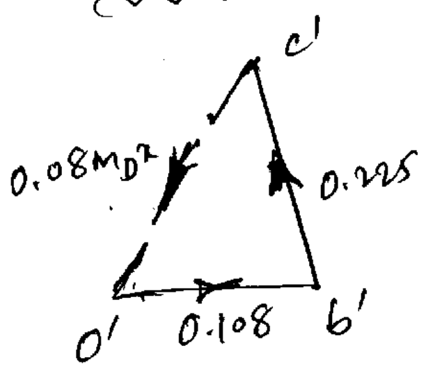
Solution:

PLANE	m	r	m×r	l	m×r×l
A (R.P.)	m_A	0.08 m	$0.08 m_A$	0	0
B	18 kg	0.06 m	1.08	0.1	0.108
C	12.5 kg	0.06 m	0.75	0.3	0.225
D	m_D	0.08 m	$0.08 m_D$	x	$0.08 m_D x$

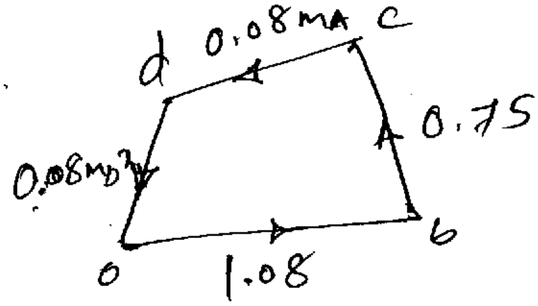




COUPLE POLYGON



FORCE POLYGON



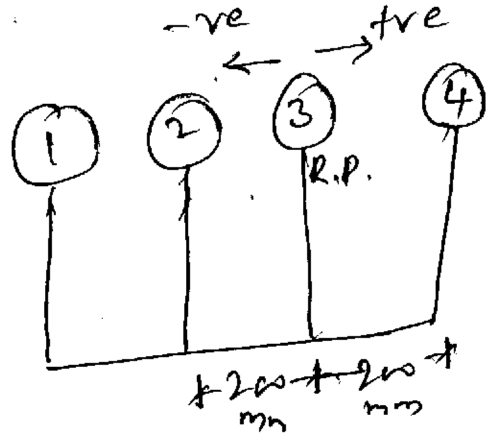
$m_A = \underline{9.625\ kg}$; $m_D = \underline{8.125\ kg}$

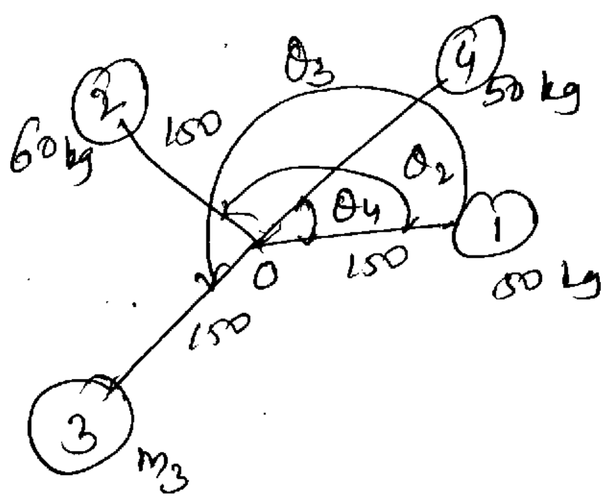
$\theta_D = \underline{251^\circ}$ [ANS.]

Q. 7. b)

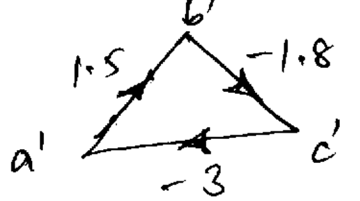
Solution :

PLANE	m	r	m×r	l	m.r.l
1	50 kg	0.15m	7.5	-0.4m	-3
2	60 kg	0.15m	9	-0.2m	-1.8
3 (R.P.)	m_3	0.15m	$0.15m_3$	0m	0
4	50 kg	0.15m	7.5	0.2m	1.5

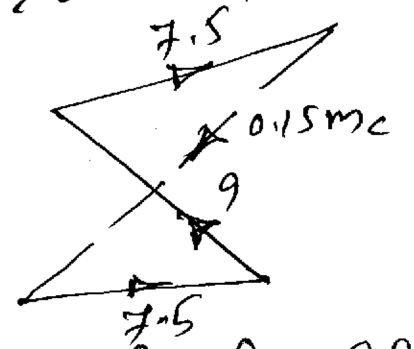




Force Polygon :



Couple Polygon



Answers: $\theta_2 = 160^\circ$; $\theta_4 = 26^\circ$; $\theta_3 = 227^\circ$

$m_3 = \underline{60 \text{ kg}}$ (Ans.)

Q. 8. a) DEFINITIONS:

i) SENSITIVENESS: (S)

Sensitiveness is defined as the ratio of the difference between the maximum and minimum equilibrium speeds to the mean equilibrium speed.

If, N_1 = Minimum equilibrium speed
N_2 = Maximum equilibrium speed
N = Mean equilibrium speed $= (N_1 + N_2)/2$

then, $S = (N_2 - N_1)/N$

ii) STABILITY: It is the ability to maintain constant & steady engine speed without undesirable oscillations or "hunting".

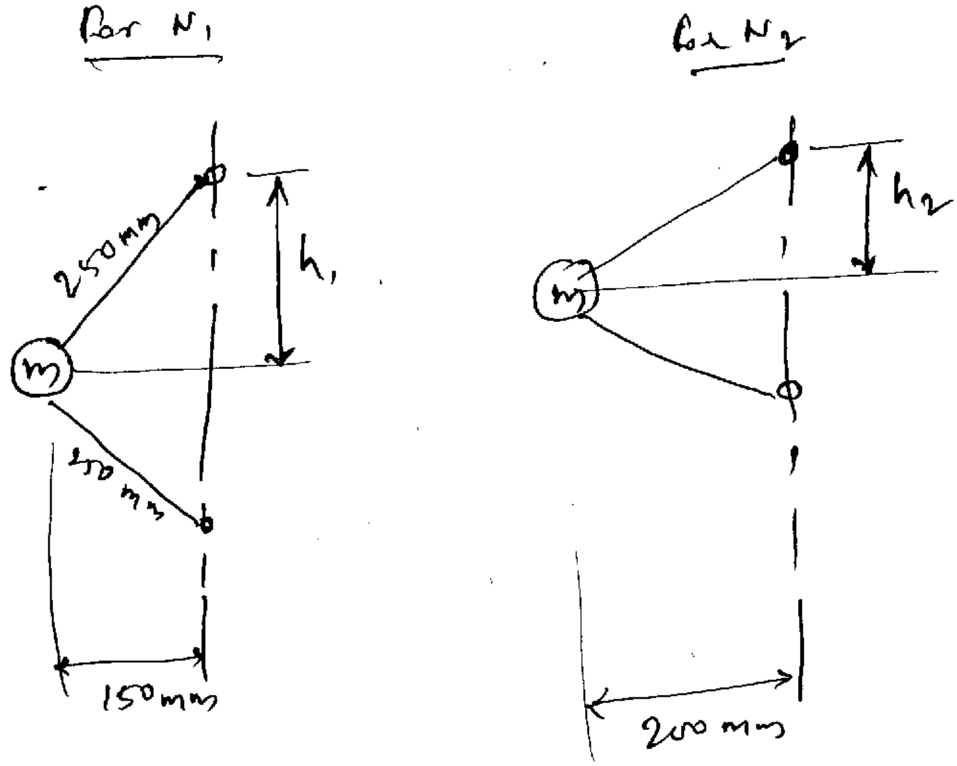
iii) HUNTING: In mechanical Governors hunting is an continuous & undesirable oscillation or fluctuation of the engine speed above and below its desired mean speed.

(iv) EFFORT: Effort of governor is defined as a mean force exerted by the governor on the sleeve for a given percentage change in speed or lift of the sleeve.

(v) POWER: Power of Governor is work done at the sleeve for a given change in engine speed. It quantifies the governors ability to perform the necessary control action, which is to move the throttle valve or fuel control mechanism.

Q. 8. b)

Solution: [Porter Governor]



$h_1 = 0.2\,m$; $N_1^2 = \frac{m+M}{m} \times \frac{895}{h_1}$

So, $N_1 = 133.8$ rpm.

$h_2 = 0.15\,m$; $N_2^2 = \frac{m+M}{m} \times \frac{895}{h_2}$

$N_2 = 154.5$ rpm.

Range of Speed } $R = N_2 - N_1 = 154.5 - 133.8$

$R = 20.7$ rpm

[Ans.]

Q. 9. a) DEFINITIONS:

i) Free Vibrations: These are the oscillations of a system when it is disturbed from its equilibrium position and then allowed to vibrate naturally without any further external force or excitation.

ii) Forced Vibrations: Forced vibrations occur when a mechanical system is continuously subjected to an external, time-varying force or excitation.

iii) Damped Vibration: It is an oscillatory motion of a system where the amplitude of the oscillations gradually decrease over time due to the presence of energy-dissipating force.

iv) Undamped Vibration: It is the oscillation of a system where there are no energy-dissipating forces present.

v) Longitudinal Vibration: It is a type of oscillatory motion where the particles of medium vibrate parallel to the direction of wave propagation or the axis of vibrating object.

Q. 9. b)

Solution:

Total Energy of the system = Constant.

i.e., $(KE)_{Mass} + (KE)_{Pulley} + (KE)_{Spring} = \text{Constant}$.

$$\frac{1}{2} m r^2 \dot{\theta}^2 + \frac{1}{2} I \dot{\theta}^2 + \frac{1}{2} K r^2 \theta^2 = \text{constant}.$$

Upon differentiation,

$$\frac{1}{2} \cdot 2 m r^2 \dot{\theta} \ddot{\theta} + \frac{1}{2} \cdot 2 I \dot{\theta} \ddot{\theta} + \frac{1}{2} \cdot 2 K r^2 \theta \cdot \dot{\theta} = 0$$

$$(m r^2 + I) \ddot{\theta} + (K r^2) \theta = 0$$

$$(m r^2 + \frac{1}{2} M r^2) \ddot{\theta} + (K r^2) \theta = 0$$

$$(m + \frac{1}{2} m) \ddot{\theta} + (K) \theta = 0$$

We know that,

$$\omega_n = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{m + \frac{1}{2} M}} = \sqrt{\frac{2K}{2m + M}}$$

Also, $$\boxed{f_n = \frac{1}{2\pi} \omega_n = \frac{1}{2\pi} \sqrt{\frac{K}{2m + M}} \text{ Hz.}}$$

Hence, the Natural frequency.

Q. 10.

a) ROTATING UNBALANCE:

It is common and critical issue in rotating machinery. It occurs when the mass distribution of a rotating component is not uniform around its axis of rotation.

When an unbalanced rotor spins, the unevenly distributed mass creates a centrifugal force that doesnot pass through the centre of rotation. This force, which rotates with the rotor, continuously pulls the rotating component in different directions through each revolution. This rotating force acts as a periodic excitation on the machine's bearings and structure, leading to the forced vibration.

Q 10. b) RECIPROCATING UNBALANCE:

It is an undesirable inertia forces & couples generated by the linear (back & forth) motion of components in machine. Unlike rotating unbalance which is caused by uneven mass distribution

Causes of reciprocating Unbalance:

- Piston Motion
- Connecting rod oscillations
- Non-sinusoidal motion

Types of reciprocating Unbalance:

1. Primary Unbalanced forces: It is the component of inertia force oscillates at the same frequency as engine speed.
2. Secondary Unbalanced force: This component oscillates at the twice the frequency of the engines rotational speed.

Q. 10. c). VIBRATION ISOLATION: It is the process of reducing the transmission of vibrations from one component of the system to another. Vibration isolation is an important aspect since it causes many detrimental effects like,

i) Reduced equipment life span
ii) Decreased performance & efficiency
iii) Increased noise levels.
iv) Compromised safety
v) Human Discomfort.

The concept of vibration isolation include,

- Natural frequency
- Resonance
- Transmissibility
- Damping

Types of Vibration Isolation:

- Active Vibration Isolation
- Passive Vibration Isolation.

Q 10. d) CRITICAL SPEED :

The critical speed of rotating machinary component (particularly a shaft) is a fundamental concept in mechanical engineering and rotordynamics. It refers to rotational speed at which the components' operating frequency coincides with one of its natural frequencies of vibration.

The phenomenon of this coincidence is called as resonance. At a critical speed the following conditions prevail,

i) Resonance.
ii) Whirling / Bending Vibration
iii) Infinite deflection
iv) Increased forces.
v) Noise & Instability

Types of Critical Speeds:

i) Lateral /Bending Critical Speed

ii) Torsional critical Speed.

iii) Axial Critical Speed

Factors Affecting Critical Speed:

- Shaft ~~stiffness~~ (k) Stiffness
- Mass (m)
- Shaft length (L)
- Shaft diameter (D)
- Bearing support Conditions.
- Mass distribution
- Material properties.

(BB Patil)

HOD
Mechanical Engineering
KLS Vishwanathrao Deshpande
Institute of Technology
Haliyal-581329