RGIT FE-SAHYOG

Module 1: System of Forces

Q1. What is a force and what are its basic characteristics?

Answer: A force is an external agency that tends to change the state of rest or motion of a body. Its characteristics are magnitude, direction, line of action, and point of application.

Q2. What is meant by a system of forces?

Answer: A system of forces is a group of two or more forces acting on a body at the same time.

Memory Tip: Many forces acting together on one body form a system.

Q3. How are force systems classified?

Answer: Force systems are commonly classified as coplanar/non-coplanar and concurrent/non-concurrent, with special cases like parallel forces and couples.

Memory Tip: First check "plane" (coplanar or 3D), then "meeting" (concurrent or not).

Q4. What is the principle of transmissibility of forces?

Answer: The principle of transmissibility states that the external effect of a force on a rigid body is unchanged if the force is moved along its line of action.

Memory Tip: Same line, same effect, for a rigid body.

Q5. What is meant by composition and resolution of forces?

Answer: Composition of forces means replacing several forces by a single resultant, while resolution means splitting one force into two or more components.

Memory Tip: "Compose" = many to one; "resolve" = one to many.

Q6. State the parallelogram law of forces.

Answer: When two forces acting at a point are represented in magnitude and direction by two adjacent sides of a parallelogram, their resultant is represented by the diagonal through that point.

Memory Tip: Two sides meet, diagonal beats.

Q7. How is the resultant of two perpendicular forces found?

Answer: For two perpendicular forces P and Q, the resultant R is $R = \sqrt{P^2 + Q^2}$, and the angle θ is $tan\theta = Q/P$.

Key Formulae: $R = \sqrt{P^2 + Q^2}$; $tan\theta = \frac{Q}{P}$.

Memory Tip: Think of a right triangle with sides P and Q.

Q8. What is a coplanar concurrent force system? Give an example.

Answer: In a coplanar concurrent force system, all forces lie in the same plane and their lines of action intersect at a common point; for example, forces acting at a pin joint.

Memory Tip: "Co" = same plane, "concurrent" = same point.

Q9. How do you find the resultant of coplanar concurrent forces using components?

Answer: Resolve each force into x and y components, add all components to get ΣF_x and ΣF_y, then $R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$ and $tan\theta = \Sigma F_y / \Sigma F_x$.

Key Formulae: $R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $tan\theta = \frac{\Sigma F_y}{\Sigma F_x}$.

Memory Tip: Sum components first, then use Pythagoras.

Q10. Define the moment of a force about a point and give its formula.

Answer: The moment of a force about a point is the turning effect and equals the product of the force and the perpendicular distance from the point to the line of action of the force.

Key Formula: $M = F \times d$, where F = force, d = perpendicular distance.

Memory Tip: Moment = Force × distance (perpendicular only).

Q11. What is a couple and what is its moment?

Answer: A couple consists of two equal and opposite parallel forces separated by a distance; its moment is $M = F \times d$ and is the same about any point in the plane.

Key Formula: $M_{couple} = F \times d$.

Memory Tip: Couple gives pure rotation, no net force.

Q12. State Varignon's theorem of moments.

Answer: Varignon's theorem states that the moment of a resultant force about a point equals the algebraic sum of the moments of the component forces about the same point.

Memory Tip: "Moment of resultant = sum of moments."

Q13. What is meant by a general coplanar force system and how is its resultant found?

Answer: A general coplanar force system has forces with arbitrary lines of action in a plane; its resultant is found by reducing to a single force and a single couple using ΣF_x, ΣF_y, and ΣM.

Memory Tip: Combine all forces (x, y) and all moments.

Q14. Explain the concept of equivalent force-couple system.

Answer: An equivalent force-couple system replaces a given system by a single force along a chosen line of action plus a couple whose moment equals the original system's resultant moment.

Memory Tip: Shift a force → add a couple.

Q15. What is a non-coplanar concurrent force system? How is its resultant obtained?

Answer: In a non-coplanar concurrent system, forces act in 3D but meet at one point; the resultant is found by resolving each force into x, y, and z components and summing to get ΣF_x, ΣF_y, and ΣF_z.

Key Formulae: $R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2 + (\Sigma F_z)^2}$.

Memory Tip: Same idea as 2D components, but with one extra axis.

Module 2: Centroid

Q1. What is a centroid of a plane lamina?

Answer: The centroid of a plane lamina is the point where the entire area can be considered to be concentrated for geometrical purposes.

Memory Tip: Centroid = "geometrical center" of area.

Q2. How is centroid different from center of gravity?

Answer: Centroid refers to the geometrical center of an area, while center of gravity is the point where the weight of a body may be assumed to act; for uniform thickness and density they coincide.

Memory Tip: Area → centroid; weight → center of gravity.

Q3. What are the coordinates of the centroid of a rectangle of width b and height h?

Answer: The centroid lies at the intersection of diagonals, at $(b/2, h/2)$ measured from one corner.

Key Formulae: $\bar{x} = b/2$; $\bar{y} = h/2$.

Memory Tip: Midpoint in both directions.

Q4. Where is the centroid of a right triangle located relative to its base and height?

Answer: The centroid of a right triangle lies at one-third of the base and one-third of the height measured from the right-angled corner.

Key Formulae: $\bar{x} = b/3$; $\bar{y} = h/3$ from the right angle.

Memory Tip: Triangle centroid → "one-third rule".

Q5. Give the centroid location of a semicircular area of radius R.

Answer: The centroid of a semicircle lies on its axis of symmetry at a distance $4R/(3\pi)$ from the center of the circle, towards the flat side.

Key Formula: $\bar{y} = \frac{4R}{3\pi}$ from the center along the symmetry axis.

Memory Tip: Remember 4 over 3π for semicircles.

Q6. Which formula is used to find the centroid of a composite area made of simple shapes?

Answer: Centroid coordinates are found using area-weighted averages: $\bar{x} = \frac{\Sigma A_i x_i}{\Sigma A_i}$ and $\bar{y} = \frac{\Sigma A_i y_i}{\Sigma A_i}$.

Key Formulae: $\bar{x} = \frac{\Sigma A_i x_i}{\Sigma A_i}$; $\bar{y} = \frac{\Sigma A_i y_i}{\Sigma A_i}$.

Memory Tip: Multiply area with its centroid coordinate, then divide by total area.

Q7. In centroid problems, what are x_i and y_i?

Answer: x_i and y_i are the coordinates of the centroid of the i-th simple shape measured from the chosen reference axes.

Memory Tip: Each small part has its own centroid coordinates.

Q8. How do you handle holes (cut-outs) while finding centroid of a lamina?

Answer: Treat the area of the hole as negative in the summation, using $A_i < 0$ for cut-outs in the centroid formulas.

Memory Tip: Hole = negative area.

Q9. Why are reference axes important in centroid calculations?

Answer: Reference axes define the coordinate system so that the centroid coordinates of each basic shape can be measured consistently for the summations.

Memory Tip: Fix axes before any calculation.

Q10. For a symmetric composite section about a vertical axis, what can you say about the x-coordinate of its centroid?

Answer: The x-coordinate of the centroid lies on the axis of symmetry, so $\bar{x}$ equals the x-coordinate of the symmetry axis.

Memory Tip: Symmetry pulls centroid onto the symmetry line.

Q11. State the centroid coordinates for a full circular lamina of radius R.

Answer: The centroid of a full circle is at its center, so its coordinates equal the coordinates of the center.

Memory Tip: For a complete circle, center = centroid.

Q12. How does shifting the reference axes affect centroid coordinates?

Answer: If reference axes shift, the numerical values of centroid coordinates change accordingly, but the physical location of the centroid in the body remains the same.

Memory Tip: Changing origin changes numbers, not the point.

Q13. What is the use of centroid in engineering applications?

Answer: Centroids are used in analysis of bending, deflection, and stability of structures, and in calculating moments of inertia of sections.

Memory Tip: Centroid is the "anchor point" for many structural formulas.

Q14. In a T-section, why is the centroid usually closer to the flange than to the web bottom?

Answer: Because the flange has a larger area concentrated near the top, pulling the centroid upward toward itself.

Memory Tip: Larger area "attracts" the centroid.

Module 3: Equilibrium of Force System and Friction

Q1. What is equilibrium of a rigid body?

Answer: A rigid body is in equilibrium when it is at rest or moving with constant velocity under the action of forces, so that the net force and net moment on it are zero.

Memory Tip: No net force, no net moment.

Q2. State the conditions of equilibrium for a coplanar concurrent system of forces.

Answer: For coplanar concurrent forces, equilibrium requires that the sum of horizontal forces and the sum of vertical forces are zero: $\Sigma F_x = 0$ and $\Sigma F_y = 0$.

Memory Tip: In 2D concurrency, moments need not be checked separately.

Q3. What additional condition is needed for equilibrium of a general coplanar force system?

Answer: For a general coplanar system, in addition to $\Sigma F_x = 0$ and $\Sigma F_y = 0$, the sum of moments about any point must also be zero, $\Sigma M = 0$.

Memory Tip: Three equations: two forces, one moment.

Q4. What is a free body diagram (FBD) and why is it important?

Answer: A free body diagram is a sketch of an isolated body with all external forces and reactions shown; it is essential for writing correct equilibrium equations.

Memory Tip: Always draw FBD before equations.

Q5. Name common types of supports and the reactions they offer.

Answer: Typical supports include a hinge or pin (two reaction components), a roller (one normal reaction), and a fixed support (two forces plus a moment reaction in 2D).

Memory Tip: More restraint → more reaction components.

Q6. For a rigid body in planar equilibrium, how many independent equilibrium equations are available?

Answer: There are three independent equations: $\Sigma F_x = 0$, $\Sigma F_y = 0$, and $\Sigma M = 0$.

Memory Tip: Two for force, one for moment.

Q7. What is a beam and how is it idealized in mechanics?

Answer: A beam is a long, slender structural member primarily subjected to transverse loads, idealized as a straight line that can take bending.

Memory Tip: Think of beams as line elements carrying loads.

Q8. What are the common types of beams?

Answer: Common types are simply supported beams(pin + roller), cantilever beams, and overhanging or compound beams.

Memory Tip: Simply supported (both ends), cantilever (one fixed), overhanging (beyond support).

Q9. How do you determine reactions at supports of a simply supported beam with a single point load at midspan?

Answer: Draw FBD, take moments about one support to find the other reaction, then use $\Sigma V = 0$ for the remaining reaction.

Q10. What types of loads are usually considered on beams in this subject?

Answer: Typically point (concentrated) loads, uniformly distributed loads (UDL), and sometimes uniformly varying loads (UVL) are considered.

Memory Tip: Point, UDL, and UVL are the standard three.

Q11. In a compound beam, how is overall equilibrium enforced?

Answer: Each span or part is analyzed with FBD, but the support reactions at common supports are shared; equilibrium equations are written for the whole system to solve unknown reactions.

Memory Tip: Treat the structure as a connected set but keep joint reactions consistent.

Q12. State the laws of dry friction.

Answer: For dry friction, friction force is proportional to normal reaction up to a maximum value, acts opposite to motion or impending motion, and the limiting friction is independent of apparent area and roughly independent of sliding speed.

Key Formula: $F_{max} = \mu N$, where μ is coefficient of friction, N is normal reaction.

Memory Tip: Friction ∝ normal, not area.

Q13. What is the coefficient of friction and coefficient of static friction?

Answer: The coefficient of friction is the ratio of limiting friction to normal reaction; for static friction, $\mu_s = F_{max}/N$.

Key Formula: $\mu = \frac{F_{max}}{N}$.

Memory Tip: It is just "friction over normal".

Q14. Define angle of friction and give its relation with coefficient of friction.

Answer: The angle of friction is the angle between the resultant reaction and the normal reaction at the limiting state; it satisfies $tan\phi = \mu$.

Key Formula: $tan\phi = \mu$.

Memory Tip: Angle of friction converts μ into an angle.

Q15. What is the angle of repose? How is it related to the coefficient of friction?

Answer: Angle of repose is the maximum inclination of a plane at which a body just begins to slide down; for limiting equilibrium, $tan\theta = \mu$.

Key Formula: $tan\theta = \mu$.

Memory Tip: At just-start-to-slide angle, tan equals μ.

Q16. Define cone of friction.

Answer: The cone of friction is a right circular cone generated by the resultant reaction at limiting friction when the direction of impending motion varies around the normal; its semi-vertical angle equals the angle of friction.

Memory Tip: All possible limiting reactions form a cone.

Q17.Define static friction and kinetic friction.

Answer: Static friction resists the start of motion between surfaces; kinetic friction resists motion when surfaces slide relative to each other.

Module 4: Kinematics of Particle and Rigid Bodies

Q1. What is kinematics and how does it differ from kinetics?

Answer: Kinematics is the study of motion without considering forces, while kinetics relates motion to the forces causing it.

Memory Tip: Kinematics = "how it moves"; kinetics = "why it moves".

Q2. Define displacement, velocity, and acceleration of a particle.

Answer: Displacement is the change in position, velocity is the rate of change of displacement with time, and acceleration is the rate of change of velocity with time.

Memory Tip: Position → displacement → velocity → acceleration.

Q3. Write the relation between acceleration and velocity for motion with variable acceleration as a function of position.

Answer: For variable acceleration $a(x)$, the relation is $a = v\frac{dv}{dx}$.

Key Formula: $a = v\frac{dv}{dx}$.

Memory Tip: Combine chain rule: $a = \frac{dv}{dt} = \frac{dv}{dx}\frac{dx}{dt}$.

Q4. For motion in a plane curve, how are the tangential and normal components of acceleration defined?

Answer: Tangential acceleration a_t is along the path and equals rate of change of speed; normal acceleration a_n is towards the center of curvature and equals v^2/ρ where ρ is radius of curvature.

Key Formulae: $a_t = \frac{dv}{dt}$; $a_n = \frac{v^2}{\rho}$.

Memory Tip: Tangential changes speed, normal changes direction.

Q5. Write the expressions for velocity and acceleration in terms of rectangular components for plane motion.

Answer: If $x(t)$ and $y(t)$ define motion, then velocity components are $v_x = dx/dt$ and $v_y = dy/dt$; acceleration components are $a_x = d^2x/dt^2$ and $a_y = d^2y/dt^2$.

Key Formulae: $\vec{v} = v_x\hat{i} + v_y\hat{j}$; $\vec{a} = a_x\hat{i} + a_y\hat{j}$.

Memory Tip: Differentiate position for velocity, differentiate again for acceleration.

Q6. For a particle moving in a circle of radius r with speed v, what is its normal acceleration?

Answer: The normal or centripetal acceleration is $a_n = v^2/r$ directed towards the center of the circle.

Key Formula: $a_n = \frac{v^2}{r}$.

Memory Tip: Faster motion or tighter circle → larger v^2/r.

Q7. What is general plane motion of a rigid body?

Answer: General plane motion is a combination of translation and rotation in a single plane, so different points of the rigid body trace different paths in that plane.

Memory Tip: It includes both sliding and spinning together.

Q8. What is centripetal acceleration?

Answer: Centripetal acceleration is the acceleration directed toward the center of a circular path that keeps an object moving in a circle.

Memory Tip: "Centripetal" means center-seeking acceleration in circular motion.

Q9. Define instantaneous center of rotation (ICR) for a plane motion.

Answer: The instantaneous center of rotation is a point in or out of the body about which the body appears to rotate at a given instant.

Memory Tip: At that instant, motion is pure rotation about ICR.

Q10. Define instantaneous center of rotation (ICR) for a plane motion.

Answer: Projectile motion is the curved motion of a body thrown in air under gravity only.

Memory Tip: Thrown object + only gravity → parabolic path.

Q11. How do you find velocity of a point on a link using ICR?

Answer: First locate the ICR, then use $v = \omega r$, where r is the distance from the ICR to the point and ω is the angular velocity of the link.

Key Formula: $v = \omega r$.

Memory Tip: Velocity is always perpendicular to the line from ICR.

Q12. In a two-link mechanism, how is ICR located for a given link?

Answer: For each link, extend or draw perpendiculars to the velocity directions of two points; their intersection gives the ICR for that link at that instant.

Memory Tip: Intersection of perpendiculars to velocities gives the ICR.

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Module 5: Kinetics of Particle

Q1. What is kinetics of a particle?

Answer: Kinetics studies the relation between forces acting on a particle and the resulting motion (acceleration) of the particle.

Memory Tip: Kinetics connects force and motion.

Q2. State Newton's second law of motion in mathematical form.

Answer: Newton's second law states that the resultant force on a particle equals mass times its acceleration, $\Sigma\vec{F} = m\vec{a}$.

Key Formula: $\Sigma\vec{F} = m\vec{a}$.

Memory Tip: Force = mass × acceleration.

Q3. What is D'Alembert's principle?

Answer: D'Alembert's principle states that by adding an inertia force $-m\vec{a}$ to the real forces, a dynamic problem can be treated as a static equilibrium problem.

Key Formula: $\Sigma\vec{F} - m\vec{a} = 0$.

Memory Tip: Convert dynamics to statics by adding fictitious inertia force.

Q4. Define inertia force and its direction.

Answer: Inertia force is a fictitious force equal in magnitude and opposite in direction to $m\vec{a}$; it acts opposite to the actual acceleration of the particle.

Memory Tip: Inertia resists acceleration.

Q5.What is impulse-momentum principle?

Answer: The impulse-momentum principle states that impulse applied to an object equals the change in its momentum.

Memory Tip: Impulse changes momentum instantly.

Q6. Define linear momentum of a particle.

Answer: Linear momentum is the product of mass and velocity of a particle, $\vec{p} = m\vec{v}$.

Key Formula: $\vec{p} = m\vec{v}$.

Memory Tip: Momentum = "mass in motion".

Q7. What is impulse and how is it related to change in momentum?

Answer: Impulse is the product of force and the time interval of its action (or integral of force over time); it equals the change in linear momentum.

Key Formula: $\vec{I} = \int \vec{F}\, dt = \Delta\vec{p}$.

Memory Tip: Impulse creates momentum change.

Q8. State the law of conservation of linear momentum.

Answer: The law says that if the net external impulse on a system is zero, the total linear momentum of the system remains constant.

Memory Tip: No external impulse → momentum conserved.

Q9. Define coefficient of restitution for a one-dimensional impact.

Answer: Coefficient of restitution e is the ratio of relative speed of separation to relative speed of approach along the line of impact.

Key Formula: $e = \frac{v_2 - v_1}{u_1 - u_2}$ (for direct impact, with proper sign convention).

Memory Tip: "Separation over approach".

Q10. What is direct central impact?

Answer: Direct central impact occurs when colliding bodies move along the line joining their centers before and after impact.

Memory Tip: Motion and line of centers are the same line.

Q11. For a perfectly elastic direct impact between two smooth spheres, what values does coefficient of restitution take and what is conserved?

Answer: For perfectly elastic impact, $e = 1$; both linear momentum and kinetic energy are conserved.

Memory Tip: Elastic → $e = 1$, energy conserved.

Q12. For a perfectly inelastic impact (bodies stick together), what is the value of e and what is conserved?

Answer: For perfectly inelastic impact, $e = 0$; linear momentum is conserved but kinetic energy is not conserved.

Memory Tip: Inelastic → stick → $e = 0$.

Q13. Two bodies of masses m_1 and m_2 moving with velocities u_1 and u_2 collide directly and then move with velocities v_1 and v_2. Write equations using conservation of momentum and coefficient of restitution.

Answer: Use: $\Sigma p_{before} = \Sigma p_{after}$ and definition of e.

Worked Solution:

- Momentum: $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$.
- Restitution: $e = \frac{v_2 - v_1}{u_1 - u_2}$.

  Key Formulae: Momentum and restitution equations above.

  Memory Tip: Always write two equations: momentum and restitution.

Q14. How is loss of kinetic energy in an inelastic collision determined?

Answer: Compute total kinetic energy before and after collision using $\frac{1}{2}mv^2$, then subtract: loss = KE_before − KE_after.

Key Formula: $\Delta KE = \frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2 - (\frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2)$.

Memory Tip: Loss is just "before minus after".

Q15. What is oblique central impact?

Answer: Oblique central impact is when the line of centers is the line of impact, but the velocities have components not only along but also perpendicular to this line.

Memory Tip: Resolve velocities into along-line and perpendicular components.

Q16. In oblique impact between smooth spheres, what happens to the components of velocity perpendicular to the line of impact?

Answer: The components of velocity perpendicular to the line of impact remain unchanged by the impact.

Memory Tip: Only along-line components are affected by restitution.

Module 6: Introduction to Robot Kinematics

Q1. What is a robot in the context of engineering mechanics?

Answer: A robot is a reprogrammable mechanical device capable of moving its links and end-effector to perform tasks automatically.

Memory Tip: Robot = programmable mechanical worker.

Q2. What is meant by robot kinematics?

Answer: Robot kinematics deals with the motion of robot links and joints without considering the forces or torques that cause the motion.

Memory Tip: Kinematics = geometry of motion of the robot.

Q3. Define degree of freedom (DOF) of a robot.

Answer: Degree of freedom is the number of independent joint variables or parameters required to define the robot's configuration.

Memory Tip: DOF = independent motions.

Q4. How many DOF are generally needed for a robot arm to reach any position and orientation in 3D space?

Answer: Typically, 6 DOF are needed: 3 for position and 3 for orientation of the end-effector.

Memory Tip: Think 3 (x, y, z) + 3 rotations.

Q5. What is a homogeneous transformation matrix and why is it used in robot kinematics?

Answer: A homogeneous transformation matrix is a 4×4 matrix that represents rotation and translation together; it is used to transform coordinates of points from one frame to another in a compact way.

Memory Tip: One matrix handles both rotation and shift.

Q6. Write the general form of a 4×4 homogeneous transformation matrix.

Answer: It consists of a 3×3 rotation submatrix R, a 3×1 position vector p, and last row $[0.$

Key Form (symbolic):

$$T = [R\ p\ 0\ 1]$$

Memory Tip: Top-left = rotation, top-right = position, bottom row = [0 0 0 1].

Q7. What are Denavit–Hartenberg (D–H) parameters?

Answer: D–H parameters are a set of four parameters ($\theta_i, d_i, a_i, \alpha_i$) used to systematically describe the relative position and orientation between successive joint frames in a serial robot.

Memory Tip: Remember the four: joint angle, offset, link length, twist.

Q8. Name the four D–H parameters and state what each represents.

Answer: θ_i: joint angle (rotation about z_{i-1}); d_i: link offset (translation along z_{i-1}); a_i: link length (translation along x_i); α_i: link twist (rotation about x_i).

Memory Tip: Two rotations (θ, α), two translations (d, a).

Q9. What is forward kinematics of a robot manipulator?

Answer: Forward kinematics is the process of computing the position and orientation of the end-effector from known joint variables using transformation matrices.

Memory Tip: Joints → end-effector pose.

Q10. How is the overall transformation from base to end-effector obtained using D–H parameters?

Answer: Individual homogeneous transformation matrices for each joint are formed using D–H parameters and then multiplied in order to get the base-to-end-effector transformation.

Memory Tip: Overall T = product of link transforms.

Q11. What is the significance of using coordinate frames in robot mechanics?

Answer: Assigning coordinate frames to links and joints simplifies describing motion, writing transformation matrices, and performing systematic computations.

Memory Tip: Frames turn geometry into matrices.

Q12. In a 2-DOF serial robot with purely revolute joints (R–R), what are the joint variables?

Answer: The joint variables are the two joint rotation angles, typically denoted by θ_1 and θ_2.

Memory Tip: Revolute → angles are variables.

Q13. What is meant by workspace of a robot?

Answer: Workspace is the region in space that the robot's end-effector can reach, considering its link lengths and joint limits.

Memory Tip: Workspace = reachable volume.