14th Revised Edition 2008

Theory of Machines

R.S. KHURMI
J.K. GUPTA

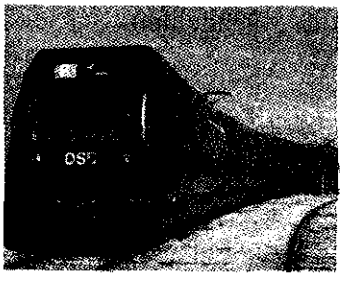
FREE CD
Containing e-Book

S. CHAND

CONTENTS

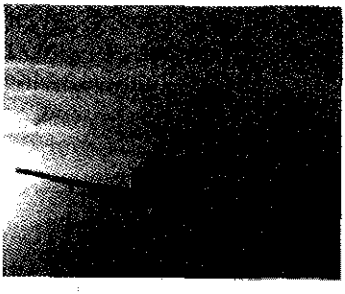
1. Introduction ...1–7

1. Definition. 2. Sub-divisions of Theory of Machines. 3. Fundamental Units. 4. Derived Units. 5. Systems of Units. 6. C.G.S. Units. 7. F.P.S. Units. 8. M.K.S. Units 9. International System of Units (S.I. Units). 10. Metre. 11. Kilogram. 12. Second. 13. Presentation of Units and their Values. 14. Rules for S.I. Units. 15. Force. 16. Resultant Force. 17. Scalars and Vectors. 18. Representation of Vector Quantities. 19. Addition of Vectors. 20. Subtraction of Vectors.



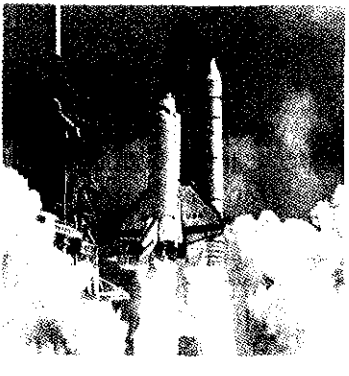
2. Kinematics of Motion ...8–23

1. Introduction. 2. Plane Motion. 3. Rectilinear Motion. 4. Curvilinear Motion. 5. Linear Displacement. 6. Linear Velocity. 7. Linear Acceleration. 8. Equations of Linear Motion. 9. Graphical Representation of Displacement with respect to Time. 10. Graphical Representation of Velocity with respect to Time. 11. Graphical Representation of Acceleration with respect to Time. 12. Angular Displacement. 13. Representation of Angular Displacement by a Vector. 14. Angular Velocity. 15. Angular Acceleration 16. Equations of Angular Motion. 17. Relation between Linear Motion and Angular Motion. 18. Relation between Linear and Angular Quantities of Motion. 19. Acceleration of a Particle along a Circular Path.



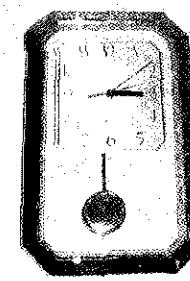
3. Kinetics of Motion ...24–71

1. Introduction. 2. Newton's Laws of Motion. 3. Mass and Weight. 4. Momentum. 5. Force. 6. Absolute and Gravitational Units of Force. 7. Moment of a Force. 8. Couple. 9. Centripetal and Centrifugal Force. 10. Mass Moment of Inertia. 11. Angular Momentum or Moment of Momentum. 12. Torque. 13. Work. 14. Power. 15. Energy. 16. Principle of Conservation of Energy. 17. Impulse and Impulsive Force. 18. Principle of Conservation of Momentum. 19. Energy Lost by Friction Clutch During Engagement. 20. Torque Required to Accelerate a Geared System. 21. Collision of Two Bodies. 22. Collision of Inelastic Bodies. 23. Collision of Elastic Bodies. 24. Loss of Kinetic Energy During Elastic Impact.



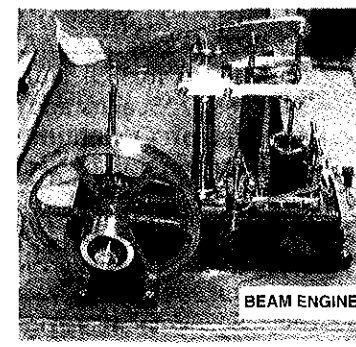
4. Simple Harmonic Motion ... 72–93

1. Introduction. 2. Velocity and Acceleration of a Particle Moving with Simple Harmonic Motion. 3. Differential Equation of Simple Harmonic Motion. 4. Terms Used in Simple Harmonic Motion. 5. Simple Pendulum. 6. Laws of Simple Pendulum. 7. Closely-coiled Helical Spring. 8. Compound Pendulum. 9. Centre of Percussion. 10. Bifilar Suspension. 11. Trifilar Suspension (Torsional Pendulum).



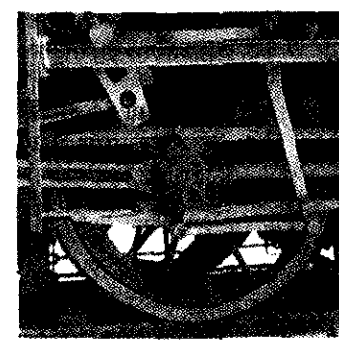
5. Simple Mechanisms ...94–118

1. Introduction. 2. Kinematic Link or Element. 3. Types of Links. 4. Structure. 5. Difference Between a Machine and a Structure. 6. Kinematic Pair. 7. Types of Constrained Motions. 8. Classification of Kinematic Pairs. 9. Kinematic Chain. 10. Types of Joints in a Chain. 11. Mechanism. 12. Number of Degrees of Freedom for Plane Mechanisms. 13. Application of Kutzbach Criterion to Plane Mechanisms. 14. Grubler's Criterion for Plane Mechanisms. 15. Inversion of Mechanism. 16. Types of Kinematic Chains. 17. Four Bar Chain or Quadric Cycle Chain. 18. Inversions of Four Bar Chain. 19. Single Slider Crank Chain. 20. Inversions of Single Slider Crank Chain. 21. Double Slider Crank Chain. 22. Inversions of Double Slider Crank Chain.



6. Velocity in Mechanisms (Instantaneous Centre Method) ...119–142

1. Introduction. 2. Space and Body Centrodes. 3. Methods for Determining the Velocity of a Point on a Link. 4. Velocity of a Point on a Link by Instantaneous Centre Method. 5. Properties of the Instantaneous Centre. 6. Number of Instantaneous Centres in a Mechanism. 7. Types of Instantaneous Centres. 8. Location of Instantaneous Centres. 9. Aronhold Kennedy (or Three Centres-in-Line) Theorem. 10. Method of Locating Instantaneous Centres in a Mechanism.



7. Velocity in Mechanisms (Relative Velocity Method) ...143–173

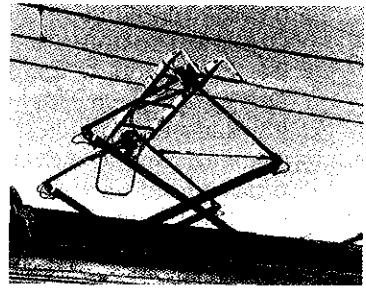
1. Introduction. 2. Relative Velocity of Two Bodies Moving in Straight Lines. 3. Motion of a Link. 4. Velocity of a Point on a Link by Relative Velocity Method. 5. Velocities in a Slider Crank Mechanism. 6. Rubbing Velocity at a Pin Joint. 7. Forces Acting in a Mechanism. 8. Mechanical Advantage.

8. Acceleration in Mechanisms ...174–231

1. Introduction. 2. Acceleration Diagram for a Link. 3. Acceleration of a Point on a Link. 4. Acceleration in the Slider Crank Mechanism. 5. Coriolis Component of Acceleration.

9. Mechanisms with Lower Pairs ...232–257

1. Introduction 2. Pantograph 3. Straight Line Mechanism. 4. Exact Straight Line Motion Mechanisms Made up of Turning Pairs. 5. Exact Straight Line Motion Consisting of One Sliding Pair (Scott Russel's Mechanism). 6. Approximate Straight Line Motion Mechanisms. 7. Straight Line Motions for Engine Indicators. 8. Steering Gear Mechanism. 9. Davis Steering Gear. 10. Ackerman Steering Gear. 11. Universal or Hooke's Joint. 12. Ratio of the Shafts Velocities. 13. Maximum and Minimum Speeds of the Driven Shaft. 14. Condition for Equal Speeds of the Driving and Driven Shafts. 15. Angular Acceleration of the Driven Shaft. 16. Maximum Fluctuation of Speed. 17. Double Hooke's Joint.



10. Friction ...258–324

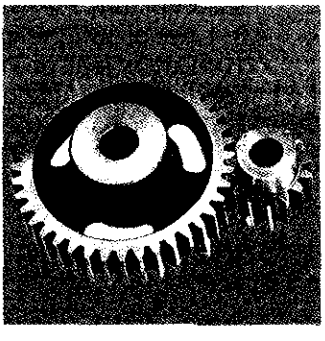
1. Introduction. 2. Types of Friction. 3. Friction Between Unlubricated Surfaces. 4. Friction Between Lubricated Surfaces. 5. Limiting Friction. 6. Laws of Static Friction. 7. Laws of Kinetic or Dynamic Friction. 8. Laws of Solid Friction. 9. Laws of Fluid Friction. 10. Coefficient of Friction. 11. Limiting Angle of Friction. 12. Angle of Repose. 13. Minimum Force Required to Slide a Body on a Rough Horizontal Plane. 14. Friction of a Body Lying on a Rough Inclined Plane. 15. Efficiency of Inclined Plane. 16. Screw Friction. 17. Screw Jack. 18. Torque Required to Lift the Load by a Screw Jack. 19. Torque Required to Lower the Load by a Screw Jack. 20. Efficiency of a Screw Jack. 21. Maximum Efficiency of a Screw Jack. 22. Over Hauling and Self Locking Screws. 23. Efficiency of Self Locking Screws. 24. Friction of a V-thread. 25. Friction in Journal Bearing-Friction Circle. 26. Friction of Pivot and Collar Bearing. 27. Flat Pivot Bearing. 28. Conical Pivot Bearing. 29. Trapezoidal or Truncated Conical Pivot Bearing. 30. Flat Collar Bearing 31. Friction Clutches. 32. Single Disc or Plate Clutch. 33. Multiple Disc Clutch. 34. Cone Clutch. 35. Centrifugal Clutches.

11. Belt, Rope and Chain Drives ...325–381

1. Introduction. 2. Selection of a Belt Drive. 3. Types of Belt Drives. 4. Types of Belts. 5. Material used for Belts. 6. Types of Flat Belt

Drives. 7. Velocity Ratio of Belt Drive. 8. Velocity Ratio of a Compound Belt Drive. 9. Slip of Belt. 10. Creep of Belt. 11. Length of an Open Belt Drive. 12. Length of a Cross Belt Drive. 13. Power Transmitted by a Belt. 14. Ratio of Driving Tensions for Flat Belt Drive. 15. Determination of Angle of Contact. 16. Centrifugal Tension. 17. Maximum Tension in the Belt. 18. Condition for the Transmission of Maximum Power. 19. Initial Tension in the Belt. 20. V-belt Drive. 21. Advantages and Disadvantages of V-belt Drive Over Flat Belt Drive. 22. Ratio of Driving Tensions for V-belt. 23. Rope Drive. 24. Fibre Ropes. 25. Advantages of Fibre Rope Drives. 26. Sheave for Fibre Ropes. 27. Wire Ropes. 28. Ratio of Driving Tensions for Rope Drive. 29. Chain Drives. 30. Advantages and Disadvantages of Chain Drive Over Belt or Rope Drive. 31. Terms Used in Chain Drive. 32. Relation Between Pitch and Pitch Circle Diameter. 33. Relation Between Chain Speed and Angular Velocity of Sprocket. 34. Kinematic of Chain Drive. 35. Classification of Chains. 36. Hoisting and Hauling Chains. 37. Conveyor Chains. 38. Power Transmitting Chains. 39. Length of Chains.

12. Toothed Gearing ...382–427



1. Introduction. 2. Friction Wheels. 3. Advantages and Disadvantages of Gear Drive. 4. Classification of Toothed Wheels. 5. Terms Used in Gears. 6. Gear Materials. 7. Condition for Constant Velocity Ratio of Toothed Wheels-Law of Gearing. 8. Velocity of Sliding of Teeth. 9. Forms of Teeth. 10. Cycloidal Teeth. 11. Involute Teeth. 12. Effect of Altering the Centre Distance on the Velocity Ratio For Involute Teeth Gears. 13. Comparison Between Involute and Cycloidal Gears. 14. Systems of Gear Teeth. 15. Standard Proportions of Gear Systems. 16. Length of Path of Contact. 17. Length of Arc of Contact. 18. Contact Ratio (or Number of Pairs of Teeth in Contact). 19. Interference in Involute Gears. 20. Minimum Number of Teeth on the Pinion in Order to Avoid Interference. 21. Minimum Number of Teeth on the Wheel in Order to Avoid Interference. 22. Minimum Number of Teeth on a Pinion for Involute Rack in Order to Avoid Interference. 23. Helical Gears. 24. Spiral Gears. 25. Centre Distance for a Pair of Spiral Gears. 26. Efficiency of Spiral Gears.

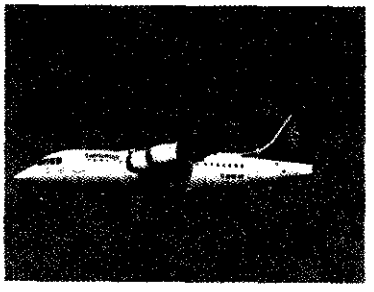
13. Gear Trains ...428–479

1. Introduction. 2. Types of Gear Trains. 3. Simple Gear Train. 4. Compound Gear Train.

5. Design of Spur Gears. 6. Reverted Gear Train. 7. Epicyclic Gear Train. 8. Velocity Ratio of Epicyclic Gear Train. 9. Compound Epicyclic Gear Train (Sun and Planet Wheel). 10. Epicyclic Gear Train With Bevel Gears. 11. Torques in Epicyclic Gear Trains.

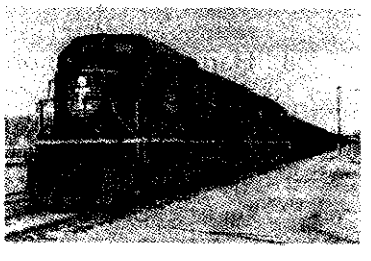
14. Gyroscopic Couple and Precessional Motion ...480–513

1. Introduction. 2. Precessional Angular Motion. 3. Gyroscopic Couple. 4. Effect of Gyroscopic Couple on an Aeroplane. 5. Terms Used in a Naval Ship. 6. Effect of Gyroscopic Couple on a Naval Ship during Steering. 7. Effect of Gyroscopic Couple on a Naval Ship during Pitching. 8. Effect of Gyroscopic Couple on a Navel during Rolling. 9. Stability of a Four Wheel drive Moving in a Curved Path. 10. Stability of a Two Wheel Vehicle Taking a Turn. 11. Effect of Gyroscopic Couple on a Disc Fixed Rigidly at a Certain Angle to a Rotating Shaft.



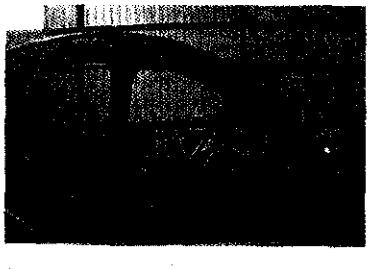
15. Inertia Forces in Reciprocating Parts ...514–564

1. Introduction. 2. Resultant Effect of a System of Forces Acting on a Rigid Body. 3. D-Alembert's Principle. 4. Velocity and Acceleration of the Reciprocating Parts in Engines. 5. Klien's Construction. 6. Ritterhaus's Construction. 7. Bennett's Construction. 8. Approximate Analytical Method for Velocity and Acceleration of the Piston. 9. Angular Velocity and Acceleration of the Connecting Rod. 10. Forces on the Reciprocating Parts of an Engine Neglecting Weight of the Connecting Rod. 11. Equivalent Dynamical System. 12. Determination of Equivalent Dynamical System of Two Masses by Graphical Method. 13. Correction Couple to be Applied to Make the Two Mass Systems Dynamically Equivalent. 14. Inertia Forces in a Reciprocating Engine Considering the Weight of Connecting Rod. 15. Analytical Method for Inertia Torque.



16. Turning Moment Diagrams and Flywheel ... 565–611

1. Introduction. 2. Turning Moment Diagram for a Single Cylinder Double Acting Steam Engine. 3. Turning Moment Diagram for a Four Stroke Cycle Internal Combustion Engine. 4. Turning Moment Diagram for a Multicylinder Engine. 5. Fluctuation of Energy. 6. Determination of Maximum Fluctuation of Energy. 7. Coefficient of Fluctuation of Energy. 8. Flywheel. 9. Coefficient of Fluctuation of Speed. 10. Energy Stored in a Flywheel. 11. Dimensions of the Flywheel Rim. 12. Flywheel in Punching Press.

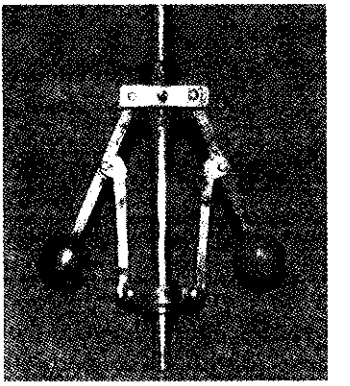


17. Steam Engine Valves and Reversing Gears ...612–652

1. Introduction. 2. D-slide Valve. 3. Piston Slide Valve. 4. Relative Positions of Crank and Eccentric Centre Lines. 5. Crank Positions for Admission, Cut off, Release and Compression. 6. Approximate Analytical Method for Crank Positions at Admission, Cut-off, Release and Compression. 7. Valve Diagram. 8. Zeuner Valve Diagram. 9. Reuleaux Valve Diagram. 10. Bilgram Valve Diagram. 11. Effect of the Early Point of Cut-off with a Simple Slide Valve. 12. Meyer's Expansion Valve. 13. Virtual or Equivalent Eccentric for the Meyer's Expansion Valve. 14. Minimum Width and Best Setting of the Expansion Plate for Meyer's Expansion Valve. 15. Reversing Gears. 16. Principle of Link Motions-Virtual Eccentric for a Valve with an Off-set Line of Stroke. 17. Stephenson Link Motion. 18. Virtual or Equivalent Eccentric for Stephenson Link Motion. 19. Radial Valve Gears. 20. Hackworth Valve Gear. 21. Walschaert Valve Gear.

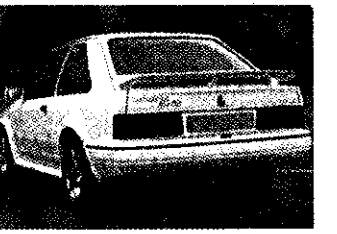
18. Governors ...653–731

1. Introduction. 2. Types of Governors. 3. Centrifugal Governors. 4. Terms Used in Governors. 5. Watt Governor. 6. Porter Governor. 7. Proell Governor. 8. Hartnell Governor. 9. Hartung Governor. 10. Wilson-Hartnell Governor. 11. Pickering Governor. 12. Sensitiveness of Governors. 13. Stability of Governors. 14. Isochronous Governor. 15. Hunting. 16. Effort and Power of a Governor. 17. Effort and Power of a Porter Governor. 18. Controlling Force. 19. Controlling Force Diagram for a Porter Governor. 20. Controlling Force Diagram for a Spring-controlled Governor. 21. Coefficient of Insensitiveness.



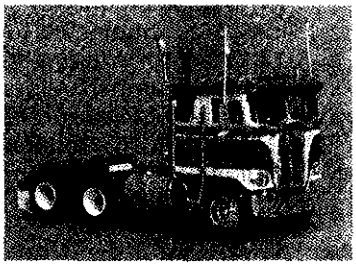
19. Brakes and Dynamometers ...732–773

1. Introduction. 2. Materials for Brake Lining. 3. Types of Brakes. 4. Single Block or Shoe Brake. 5. Pivoted Block or Shoe Brake. 6. Double Block or Shoe Brake. 7. Simple Band Brake. 8. Differential Band Brake. 9. Band and Block Brake. 10. Internal Expanding Brake. 11. Braking of a Vehicle. 12. Dynamometer. 13. Types of Dynamometers. 14. Classification of Absorption Dynamometers. 15. Prony Brake Dynamometer. 16. Rope Brake Dynamometers. 17. Classification of Transmission Dynamometers. 18. Epicyclic-train Dynamometers. 19. Belt Transmission Dynamometer-Froude or Throneycraft Transmission Dynamometer. 20. Torsion Dynamometer. 21. Bevis Gibson Flash Light Torsion Dynamometer.



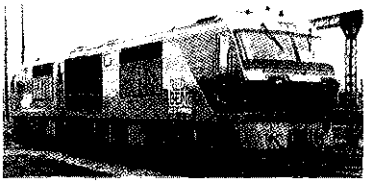
20. Cams ...774–832

1. Introduction. 2. Classification of Followers. 3. Classification of Cams. 4. Terms used in Radial cams. 5. Motion of the Follower. 6. Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Uniform Velocity. 7. Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Simple Harmonic Motion. 8. Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Uniform Acceleration and Retardation. 9. Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Cycloidal Motion. 10 Construction of Cam Profiles. 11. Cams with *Specified Contours*. 12. *Tangent Cam with Reciprocating* Roller Follower. 13. Circular Arc Cam with Flat-faced Follower.



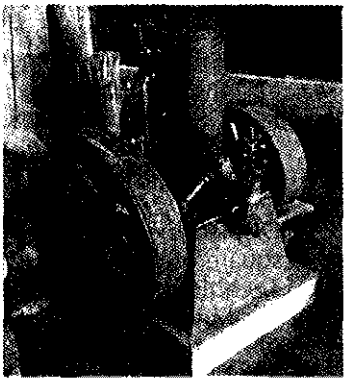
21. Balancing of Rotating Masses ...833–857

1. Introduction. 2. Balancing of Rotating Masses. 3. Balancing of a Single Rotating Mass By a Single Mass Rotating in the Same Plane. 4. Balancing of a Single Rotating Mass By Two Masses Rotating in Different Planes. 5. Balancing of Several Masses Rotating in the Same Plane. 6. Balancing of Several Masses Rotating in Different Planes.



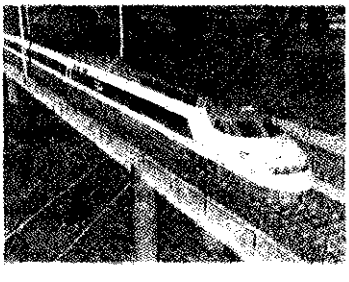
22. Balancing of Reciprocating Masses ...858–908

1. Introduction. 2. Primary and Secondary Unbalanced Forces of Reciprocating Masses. 3. Partial Balancing of Unbalanced Primary Force in a Reciprocating Engine. 4. Partial Balancing of Locomotives. 5. Effect of Partial Balancing of Reciprocating Parts of Two Cylinder Locomotives. 6. Variation of Tractive Force. 7. Swaying Couple. 8. Hammer Blow. 9. Balancing of Coupled Locomotives. 10. Balancing of Primary Forces of Multi-cylinder In-line Engines. 11. Balancing of Secondary Forces of Multi-cylinder In-line Engines. 12. Balancing of Radial Engines (Direct and Reverse Crank Method). 13. Balancing of V-engines.



23. Longitudinal and Transverse Vibrations ...909–971

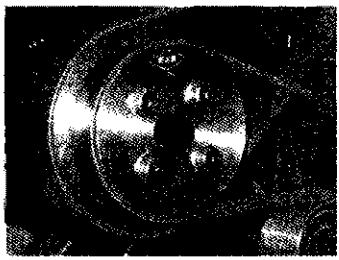
1. Introduction. 2. Terms Used in Vibratory Motion. 3. Types of Vibratory Motion. 4. Types of Free Vibrations. 5. Natural Frequency of Free Longitudinal Vibrations. 6. Natural Frequency of Free Transverse Vibrations. 7. Effect of Inertia of the Constraint in Longitudinal and Transverse Vibrations. 8. Natural Frequency of Free Transverse Vibrations Due to a Point Load Acting Over a Simply Supported Shaft. 9. Natural Frequency of Free Transverse Vibrations *Due to Uniformly Distributed Load Over a Simply*



Supported Shaft. 10. Natural Frequency of Free Transverse Vibrations of a Shaft Fixed at Both Ends and Carrying a Uniformly Distributed Load. 11. Natural Frequency of Free Transverse Vibrations for a Shaft Subjected to a Number of Point Loads. 12. Critical or Whirling Speed of a Shaft. 13. Frequency of Free Damped Vibrations (Viscous Damping). 14. Damping Factor or Damping Ratio. 15. Logarithmic Decrement. 16. Frequency of Underdamped Forced Vibrations. 17. Magnification Factor or Dynamic Magnifier. 18. Vibration Isolation and Transmissibility.

24. Torsional Vibrations ...972–1001

1. Introduction. 2. Natural Frequency of Free Torsional Vibrations. 3.Effect of Inertia of the Constraint on Torsional Vibrations. 4. Free Torsional Vibrations of a Single Rotor System. 5. Free Torsional Vibrations of a Two Rotor System. 6. Free Torsional Vibrations of a Three Rotor System. 7. Torsionally Equivalent Shaft. 8. Free Torsional Vibrations of a Geared System.

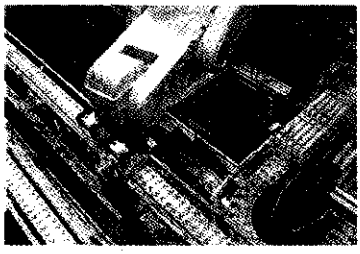


25. Computer Aided Analysis and Synthesis of Mechanisms ...1002–1049

1. Introduction. 2. Computer Aided Analysis for Four Bar Mechanism (Freudenstein's Equation). 3. Programme for Four Bar mechanism. 4. Computer Aided Analysis for Slider Crank Mechanism. 6. Coupler Curves. 7. Synthesis of Mechanisms. 8. Classifications of Synthesis Problem. 9. Precision Points for Function Generation. 10. Angle Relationship for function Generation. 11. Graphical Synthesis of Four Bar Mechanism. 12. Graphical synthesis of Slider Crank Mechanism. 13. Computer Aided (Analytical) synthesis of Four Bar Mechanism. 14. Programme to Co-ordinate the Angular Displacements of the Input and Output Links. 15. Least square Technique. 16. Programme using Least Square Technique. 17. Computer Aided Synthesis of Four Bar Mechanism With Coupler Point. 18. Synthesis of Four Bar Mechanism for Body Guidance. 19. Analytical Synthesis for slider Crank Mechanism.

26. Automatic Control ...1050–1062

1. Introduction. 2. Terms Used in Automatic Control of Systems. 3. Types of Automatic Control System. 4. Block Diagrams. 5. Lag in Response. 6. Transfer Function. 7. Overall Transfer Function. 8 Transfer Function for a system with Viscous Damped Output. 9. Transfer Function of a Hartnell Governor. 10. Open-Loop Transfer Function. 11. Closed-Loop Transfer Function.



Index ...1063–1071