

# CONTENTS

<i>Preface</i>	<i>vii</i>
<i>Acknowledgements</i>	<i>ix</i>
<i>Foreword</i>	<i>xi</i>
<i>Units and their Values</i>	<i>xxxiii</i>
<i>Abbreviations, Notations and Symbols</i>	<i>xxxv</i>
<b>1. Simple Mechanisms</b>	<b>1</b>
1.1 Introduction	3
1.2 Kinematic Link or Element	3
1.3 Kinematic Pair	5
1.3.1 Nature of Relative Motion between the Elements	5
1.3.2 Nature of Contact between the Elements	5
1.3.3 Nature of the Mechanical Arrangement for Complete or Successful Constraint between the Elements	6
1.4 Kinematic Chain	7
1.4.1 First Equation Using Pairs	8
1.4.2 Second Equation Using Joints	9
1.4.3 According to the Type of Closure between Elements	10
1.4.4 Degrees of Freedom	11
1.5 Mechanism	11
1.6 Inversion	12
1.6.1 Single Slider Crank Chain	12
1.6.2 Double Slider Crank Chain	15
1.6.3 Four-Bar Mechanisms	17
1.7 Exercise	20
1.7.1 Short Answer Questions	20
1.7.2 Problems	22
1.7.3 Multiple Choice Questions	22

<b>2. Mechanisms with Lower Pairs</b>	<b>25</b>
2.1 Introduction	27
2.2 Pantograph	27
2.3 Mechanisms for Straight Line Motions	28
2.3.1 Peaucellier Mechanism	29
2.3.2 Hart Mechanism	29
2.3.3 Scott-Russell Mechanism	30
2.4 Approximate Straight Line Mechanism	31
2.4.1 Watt Mechanism	31
2.4.2 Grasshopper Mechanism	32
2.4.3 Tchebicheff Straight Line Motion	32
2.4.4 Roberts Mechanism	33
2.5 Steering Gear Mechanism	33
2.5.1 Davis Steering Gear (Exact)	34
2.5.2 Ackermann Steering Gear (Approximate)	35
2.6 Hooke's Joint (or) Universal Joint	36
2.7 Double Hooke's Joint	41
2.8 Exercise	43
2.8.1 Short Answer Questions	43
2.8.2 Problems	45
2.8.3 Multiple Choice Questions	46
 <b>3. Velocities and Accelerations in Mechanisms</b>	 <b>49</b>
3.1 Introduction	51
3.2 Motion	51
3.2.1 Translatory Motion	51
3.2.2 Rotary Motion	51
3.2.3 Speed	51
3.2.4 Angular Displacement ( $\theta$ )	52
3.2.5 Radian	52
3.2.6 Angular Velocity ( $\omega$ )	52
3.2.7 Relation between Linear Velocity and Angular Velocity	53
3.3 Instantaneous Centre Method	53
3.3.1 Properties of Instantaneous Centres	54
3.3.2 Number of Instantaneous Centres in a Mechanism	55
3.3.3 Types of Instantaneous Centres	55

3.3.4	Location of Instantaneous Centres	55
3.3.5	Kennedy's Theorem or Three-centres-in-line Theorem	56
3.3.6	Application of Instantaneous Centre to Any Mechanism	57
3.3.7	Steps in Determining the Unknown Instantaneous Centres	57
3.4	Relative Velocity Method	64
3.5	Acceleration in Mechanisms	70
3.5.1	Introduction	70
3.5.2	Angular Acceleration	70
3.5.3	Vector form between Linear and Angular Acceleration	70
3.5.4	Various Steps to be Followed in the Acceleration Analysis	71
3.6	Coriolis Component of Acceleration	78
3.7	Exercise	83
3.7.1	Short Answer Questions	83
3.7.2	Problems	83
3.7.3	Multiple Choice Questions	88

#### **4. Inertia Forces in Reciprocating Parts** 91

4.1	Introduction	93
4.1.1	Terms Used in Static	93
4.1.2	D'Alembert's Principle	94
4.2	Analytical Method for Reciprocating Mechanism	95
4.2.1	Displacement of Piston ( $X_p$ )	96
4.2.2	Velocity of Piston ( $v_p$ )	97
4.2.3	Acceleration of Piston ( $a_p$ )	97
4.2.4	Angular Velocity of Connecting Rod ( $\omega_c$ )	98
4.2.5	Angular Acceleration ( $\alpha_c$ )	98
4.3	Klien's Construction for Reciprocating Mechanisms	100
4.3.1	Klien's Velocity Diagram	100
4.3.2	Klien's Acceleration Diagram	101
4.4	Forces on the Reciprocating parts of an Engine	104
4.4.1	Neglecting the Weight of the Connecting Rod	104
4.4.2	Considering the Weight of the Connecting Rod	109
4.5	Equivalent Dynamical System	110
4.5.1	Dynamically Equivalent System	110
4.5.2	Determination of Dynamically Equivalent System of Two Masses Placed Arbitrarily (Analytically)	111

4.5.3	Determination of Dynamically Equivalent System of Two Masses Placed Arbitrarily (Graphically)	112
4.6	Inertia Forces in a Reciprocating Engine	113
4.6.1	Graphical Method	113
4.6.2	Analytical Method	114
4.7	Exercise	120
4.7.1	Short Answer Questions	120
4.7.2	Problems	120
4.7.3	Multiple Choice Questions	122
<b>5.</b>	<b>Turning Moment Diagrams and Design of Flywheel</b>	<b>125</b>
5.1	Introduction	127
5.2	Single-Cylinder Double-Acting Steam Engine	127
5.3	Four-Stroke Cycle Internal Combustion Engine	128
5.3.1	Fluctuation of Energy	129
5.4	Flywheel	130
5.4.1	Coefficient of Fluctuation of Speed	131
5.4.2	Energy Stored in the Flywheel ( $E$ )	131
5.4.3	Design of Flywheel	132
5.5	Typical Worked Examples	133
5.6	Flywheel in Punching Press	141
5.7	Exercise	144
5.7.1	Short Answer Questions	144
5.7.2	Problems	144
5.7.3	Multiple Choice Questions	145
<b>6.</b>	<b>Friction</b>	<b>147</b>
6.1	Introduction	149
6.2	Laws of Friction	150
6.2.1	Friction between Dry Surfaces	151
6.2.2	Friction between Rough Surfaces	151
6.2.3	Friction is Self Adjusting	151
6.2.4	Angle of Friction ( $\phi$ )	151
6.2.5	Rolling Friction	152
6.3	Equilibrium of Body on a Rough Inclined Plane	153
6.3.1	Motion Up the Plane	154

6.3.2	Motion Down the Plane	154
6.3.3	Maximum Efficiency	155
6.4	Screw Friction	156
6.4.1	Square Thread	156
6.4.2	Relation Between Effort and Weight Lifted by a Screw Jack	157
6.4.3	V-Thread	158
6.4.4	Mechanical Advantage	158
6.5	Pivot and Collar Friction	159
6.5.1	Uniform Intensity of Pressure	161
6.5.2	Uniform Rate of Wear	162
6.6	Clutches	164
6.6.1	Single-plate Clutch	165
6.6.2	Multi-plate Clutch	165
6.6.3	Cone Clutch	166
6.7	Brakes and Dynamometers	168
6.7.1	Introduction	168
6.7.2	Types of Brakes	168
6.7.3	Dynamometers	176
6.7.4	Types of Frictions	178
6.8	Exercise	181
6.8.1	Short Answer Questions	181
6.8.2	Problems	182
6.8.3	Multiple Choice Questions	185
<b>7.</b>	<b>Governors</b>	<b>187</b>
7.1	Introduction	189
7.2	Centrifugal Governors	189
7.3	Various Parts and Terms Used in Governors	191
7.3.1	Height of the Governor ( $h$ )	191
7.3.2	Equilibrium Speed	191
7.3.3	Sleeve Lift	191
7.4	Simple Watt Governor	191
7.4.1	Analytical Method	192
7.4.2	Graphical Method	193
7.5	Porter Governor	194
7.5.1	Analytical Method	195
7.5.2	Graphical Method	197

7.6	Proell Governor	197
7.6.1	Analytical Method	198
7.6.2	Graphical Method	199
7.6.3	Comparison between Flywheel and Governor	209
7.7	Hartnell Governor	209
7.8	Hartung Governor	213
7.9	Definitions	218
7.9.1	Sensitiveness	218
7.9.2	Stable and Unstable	218
7.9.3	Isochronous/Isochronism	218
7.9.4	Hunting	218
7.9.5	Effort	218
7.9.6	Power	218
7.9.7	Controlling Force	218
7.9.8	Coefficient of Insensitiveness	219
7.10	Wilson-Hartnell Governor	219
7.11	Exercise	221
7.11.1	Short Answer Questions	221
7.11.2	Problems	221
7.11.3	Multiple Choice Questions	223
<b>8.</b>	<b>Belt, Rope and Chain Drives</b>	<b>225</b>
8.1	Introduction	227
8.2	Types of Belts	227
8.2.1	Flat Belt	228
8.2.2	V-belt	228
8.2.3	Circular Belt or Rope	229
8.3	Types of Belt Drives	230
8.3.1	Compound Belt Drives	231
8.3.2	Stepped or Cone Pulley	232
8.4	Speed Ratio or Velocity Ratio of a Belt Drive	232
8.4.1	Velocity Ratio of a Compound Belt Drive	233
8.4.2	Slip of the Belt	234
8.4.3	Effect of Creep on Velocity Ratio	235
8.5	Length of an Open Belt	235
8.6	Length of a Crossed Belt	237
8.7	Ratio of Tensions	239

8.7.1	Power Transmitted by a Belt	241
8.7.2	Effect of Centrifugal Tension $T_C$ on Power Transmitted	241
8.7.3	Condition for Maximum Power	242
8.7.4	Effect of Initial Tension ( $T_0$ )	243
8.8	Rope Drive	243
8.8.1	Ratio of Tensions	243
8.9	Chain Drives	245
8.9.1	Types of Chains	246
8.10	Exercise	248
8.10.1	Short Answer Questions	248
8.10.2	Problems	249
8.10.3	Multiple Choice Questions	251
<b>9.</b>	<b>Gyroscope</b>	<b>255</b>
9.1	Introduction	257
9.2	Gyroscopic Couple and its Effect	258
9.3	Effect of Gyroscopic Couple on an Aeroplane	259
9.4	Special Terms Used in Ships	263
9.4.1	Effect of Gyroscopic Couple on the Ship During Steering	264
9.4.2	Effect of Gyroscopic Couple on the Ship During Pitching	265
9.4.3	Effect of Gyroscopic Couple on the Ship During Rolling	266
9.5	Stability of Four-Wheeler	268
9.5.1	Effect of the Gyroscopic Couple	269
9.5.2	Effects of the Centrifugal Couple	270
9.6	Stability of a Two-wheeler	273
9.6.1	Effect of the Gyroscopic Couple	274
9.6.2	Effects of the Centrifugal Couple	275
9.7	Exercise	278
9.7.1	Short Answer Questions	278
9.7.2	Problems	279
9.7.3	Multiple Choice Questions	280
<b>10.</b>	<b>Cams</b>	<b>283</b>
10.1	Introduction	285
10.2	Classification of Followers	286
10.2.1	Based on the Surface in Contact	287

10.2.2	Based on the Type of Movement of the Follower	287
10.2.3	Based on the Line of Motion of Follower	287
10.2.4	Based on the Desired Mathematical Motions	288
10.3	Types of Cams	288
10.3.1	Based on Follower Motion	288
10.3.2	Based on the Shape of the Cam	288
10.4	Terminology	289
10.4.1	Cam Profile	289
10.4.2	Base Circle	289
10.4.3	Trace Point	289
10.4.4	Pitch Curve	290
10.4.5	Prime Circle	290
10.4.6	Pressure Angle	290
10.4.7	Cam Angle	290
10.4.8	Pitch Point	290
10.4.9	Lift or Stroke(s)	290
10.4.10	Pitch Circle	291
10.5	Analysis of Motion of the Follower	291
10.5.1	Uniform Velocity	292
10.5.2	Simple Harmonic Motion (SHM)	294
10.5.3	Uniform Acceleration and Retardation	296
10.5.4	Cycloidal Motion	297
10.6	Construction of Displacement Diagrams	299
10.6.1	Displacement Diagram for Uniform Velocity	300
10.6.2	Displacement Diagram for Simple Harmonic Motion (SHM)	300
10.6.3	Displacement diagram for Uniform Acceleration and Retardation (UAR)	301
10.6.4	Displacement Diagram for Cycloidal Motion	302
10.7	Construction of Cam Profiles	303
10.7.1	Cam Profile with Radial Knife Edge Follower Having Outward Cycloidal Motion and Return Uniform Velocity Motion	303
10.7.2	Cam Profile with a Radial Knife Edge Follower Having Outward SHM and Return Uniform Acceleration and Retardation (UAR)	305
10.7.3	Cam Profile with an Offset Knife Edge Follower Having Outward SHM and Return UAR	305
10.7.4	Cam Profile with the Radial Roller Follower with Outward Cycloidal Motion and Return Uniform Velocity	306
10.7.5	Cam Profile with an Offset Roller Follower with Outward Cycloidal Motion and Return with Uniform Velocity	308



10.7.6	Cam Profile for Radial Flat Faced Radial Follower with Outward Cycloidal Motion and Return Uniform Velocity	309
10.8	Cams with Specified Contours	312
10.8.1	Circular Arc Cam with Flat-faced Reciprocating Follower	312
10.8.2	Tangent Cam with Reciprocating Roller Follower	315
10.9	Exercise	318
10.9.1	Short Answer Questions	318
10.9.2	Problems	319
10.9.3	Multiple Choice Questions	320
<b>11.</b>	<b>Toothed Gearing</b>	<b>323</b>
11.1	Introduction	325
11.2	Classification of Toothed Gearing	325
11.2.1	According to Axes	325
11.2.2	According to the Range of Peripheral Velocity	326
11.2.3	According to Position of Teeth on the Gear Surface	326
11.2.4	According to Type of Gearing	327
11.2.5	According to Materials Used for Gears	328
11.3	Terminology Used in Gears	328
11.3.1	Pitch Circle	328
11.3.2	Addendum ( $a$ )	329
11.3.3	Addendum Circle	329
11.3.4	Dedendum ( $d$ )	330
11.3.5	Dedendum Circle	330
11.3.6	Clearance	330
11.3.7	Face	330
11.3.8	Flank	330
11.3.9	Face Width	331
11.3.10	Top Land	331
11.3.11	Tooth Profile	331
11.3.12	Circular Pitch ( $P_c$ )	331
11.3.13	Pitch Point ( $P$ )	331
11.3.14	Diametral Pitch ( $P_d$ )	331
11.3.15	Module ( $m$ )	331
11.3.16	Pressure Angle or Obliquity ( $\psi$ )	332
11.3.17	Path of Contact	332
11.3.18	Length of Path of Contact	332

11.3.19 Arc of Contact	332
11.4 Condition for Constant Velocity Ratio or Law of Gearing	332
11.5 Length of the Arc of Contact	335
11.6 Minimum Number of Teeth on the Pinion to Avoid Interference	340
11.7 Interference in Involute Gears	344
11.8 Methods of Avoiding Interference	344
11.9 Forms of Teeth	344
11.9.1 Cycloidal Teeth	345
11.9.2 Involute Tooth	346
11.10 Helical Gears	346
11.11 Bevel Gears	347
11.12 Spiral Gears	348
11.13 Exercise	348
11.13.1 Short Answer Questions	348
11.13.2 Problems	349
11.13.3 Multiple Choice Questions	351
 <b>12. Gear Trains</b>	 <b>353</b>
12.1 Introduction	355
12.2 Simple Gear Train or Simple Gear Drive	355
12.2.1 Speed Value or Speed Ratio or Velocity Ratio (VR)	356
12.2.2 Train Value	356
12.2.3 Power Transmitted by a Simple Gear Train	357
12.3 Compound Gear Train	358
12.4 Reverted Gear Train	359
12.5 Epicyclic Gear Train	362
12.6 Torque in Epicyclic Gear Trains	369
12.7 Compound Epicyclic Gear Train	371
12.8 Epicyclic Gear Trains with Bevel Gears	375
12.9 Exercise	380
12.9.1 Short Answer Questions	380
12.9.2 Problems	382
12.9.3 Multiple Choice Questions	386

<b>13. Balancing of Rotating Masses</b>	<b>389</b>
13.1 Introduction	391
13.2 Checking of a Rotating Element	391
13.3 Types of Balancing of Rotating Elements	392
13.3.1 Balancing of a Single Unbalanced Rotating Mass	392
13.3.2 Balancing of Several Unbalanced Rotating Masses	392
13.4 Balancing of a Single Unbalanced Rotating Mass	393
13.4.1 By a Single Balancing Mass Rotating in the Same Plane	393
13.4.2 By Two Balancing Masses in Two Different Planes	394
13.5 Balancing of Several Unbalanced Masses Rotating in the Same Plane	399
13.5.1 Analytical Method	400
13.5.2 Graphical Method	400
13.6 Balancing of Several Unbalanced Masses Rotating in Several Planes	402
13.7 Exercise	410
13.7.1 Short Answer Questions	410
13.7.2 Problems	410
13.7.3 Multiple Choice Questions	412
 <b>14. Balancing of Reciprocating Masses</b>	 <b>413</b>
14.1 Introduction	415
14.2 Partial Balancing	416
14.3 Effect of Partial Balancing in Two-Cylinder Locomotives	417
14.3.1 Tractive Force ( $F_T$ )	418
14.3.2 Swaying Couple	419
14.3.3 Hammer Blow	419
14.3.4 Types of Locomotives	420
14.4 Multi-cylinder In-line Engines	428
14.5 Radial Engines	434
14.5.1 Direct and Reverse Crank Method	435
14.5.2 Analytical Method	436
14.6 V-Engines	439
14.6.1 Analytical Method	440
14.6.2 Direct and Reverse Crank Method	441
14.7 Exercise	443
14.7.1 Short Answer Questions	443
14.7.2 Problems	443
14.7.3 Multiple Choice Questions	445

<b>15. Longitudinal and Transverse Vibrations</b>	<b>447</b>
15.1 Introduction	449
15.2 Basic Elements of Any Vibratory System	449
15.2.1 Inertial Element or Mass	449
15.2.2 Restoring Element or Spring	449
15.2.3 Damping Elements or Damper	450
15.3 Various Terms Used in Vibration and their Meanings	450
15.3.1 Period	450
15.3.2 Cycle	450
15.3.3 Frequency	450
15.3.4 Resonance	450
15.4 Types of Vibrations	450
15.4.1 Free or Natural Vibrations	450
15.4.2 Forced Vibrations	450
15.4.3 Damped Vibrations	450
15.5 Types of Vibrations Based on the Deflection	451
15.5.1 Longitudinal Vibrations	451
15.5.2 Transverse Vibrations	451
15.5.3 Torsional Vibrations	451
15.6 Natural Frequency of Free Longitudinal Vibrations	451
15.6.1 Equilibrium Method	452
15.6.2 Energy Method	453
15.6.3 Rayleigh's Method	454
15.7 Natural Frequency of Free Transverse Vibrations	459
15.7.1 Energy (Rayleigh's) Method of a Shaft Subjected to Number of Point Loads	464
15.7.2 Dunkerley's Method for a Shaft Subjected to a Number of Point Loads	464
15.8 Critical Speed or Whirling Speed of a Shaft	468
15.9 Frequency of Free Damped Vibrations (Viscous Damping)	471
15.9.1 When the Roots are Real (Overdamping or Large Damping)	473
15.9.2 When the Roots are Equal (Critical Damping)	473
15.9.3 When the Roots are Complex Conjugate (Underdamping or Small Damping)	473
15.9.4 Logarithmic Decrement	474
15.10 Frequency of Forced Damped Vibration	476
15.10.1 Magnification Factor or Dynamic Magnifier ( $D$ )	478
15.11 Exercise	480
15.11.1 Short Answer Questions	480
15.11.2 Problems	481
15.11.3 Multiple Choice Questions	483

<b>16. Torsional Vibrations</b>	<b>485</b>
16.1 Introduction	487
16.2 Natural Frequency of Free Torsional Vibrations	487
16.3 Torsional Vibrations of a Shaft with Number of Rotors	488
16.3.1 Free Torsional Vibrations of a Single Rotor System	488
16.3.2 Free Torsional Vibrations of a Two-Rotor System	490
16.3.3 Free Torsional Vibrations of a Three Rotor System	493
16.4 Torsionally Equivalent Shaft	499
16.5 Free Torsional Vibrations of a Geared System	505
16.6 Exercise	509
16.6.1 Short Answer Questions	509
16.6.2 Problems	509
16.6.3 Multiple Choice Questions	510
 <i>Bibliography</i>	 513
<i>Index</i>	515