

# CONTENTS

	<b>PREFACE</b>	<b>xi</b>
	<b>THE SI SYSTEM OF UNITS</b>	<b>1</b>
<b>CHAPTER 1</b>	<b>OSCILLATORY MOTION</b>	<b>5</b>
1.1	Harmonic Motion	6
1.2	Periodic Motion	9
1.3	Vibration Terminology	11
<b>CHAPTER 2</b>	<b>FREE VIBRATION</b>	<b>16</b>
2.1	Vibration Model	16
2.2	Equation of Motion: Natural Frequency	16
2.3	Energy Method	20
2.4	Rayleigh Method: Effective Mass	23
2.5	Principle of Virtual Work	25
2.6	Viscously Damped Free Vibration	27
2.7	Logarithmic Decrement	31
2.8	Coulomb Damping	35
<b>CHAPTER 3</b>	<b>HARMONICALLY EXCITED VIBRATION</b>	<b>49</b>
3.1	Forced Harmonic Vibration	49
3.2	Rotating Unbalance	53

3.3	Rotor Unbalance	56
3.4	Whirling of Rotating Shafts	59
3.5	Support Motion	63
3.6	Vibration Isolation	65
3.7	Energy Dissipated by Damping	67
3.8	Equivalent Viscous Damping	70
3.9	Structural Damping	72
3.10	Sharpness of Resonance	74
3.11	Vibration-Measuring Instruments	75
<b>CHAPTER 4</b>	<b>TRANSIENT VIBRATION</b>	<b>89</b>
4.1	Impulse Excitation	89
4.2	Arbitrary Excitation	91
4.3	Laplace Transform Formulation	94
4.4	Pulse Excitation and Rise Time	97
4.5	Shock Response Spectrum	100
4.6	Shock Isolation	104
4.7	Finite Difference Numerical Computation	105
4.8	Runge-Kutta Method	112
<b>CHAPTER 5</b>	<b>SYSTEMS WITH TWO OR MORE DEGREES OF FREEDOM</b>	<b>126</b>
5.1	The Normal Mode Analysis	127
5.2	Initial Conditions	131
5.3	Coordinate Coupling	134

5.4	Forced Harmonic Vibration	139
5.5	Finite Difference Method for Systems of Equations	141
5.6	Vibration Absorber	144
5.7	Centrifugal Pendulum Vibration Absorber	145
5.8	Vibration Damper	147
<b>CHAPTER 6</b>	<b>PROPERTIES OF VIBRATING SYSTEMS</b>	<b>163</b>
6.1	Flexibility Influence Coefficients	164
6.2	Reciprocity Theorem	167
6.3	Stiffness Influence Coefficients	172
6.4	Stiffness Matrix of Beam Elements	176
6.5	Static Condensation for Pinned Joints	176
6.6	Orthogonality of Eigenvectors	177
6.7	Modal Matrix	179
6.8	Decoupling Forced Vibration Equations	181
6.9	Modal Damping in Forced Vibration	182
6.10	Normal Mode Summation	183
6.11	Equal Roots	187
6.12	Unrestrained (Degenerate) Systems	189
<b>CHAPTER 7</b>	<b>LAGRANGE'S EQUATION</b>	<b>199</b>
7.1	Generalized Coordinates	199
7.2	Virtual Work	204
7.3	Lagrange's Equation	207

7.4	Kinetic Energy, Potential Energy, and Generalized Force in Terms of Generalized Coordinates $q$	214
7.5	Assumed Mode Summation	216
<b>CHAPTER 8</b>	<b>COMPUTATIONAL METHODS</b>	<b>227</b>
8.1	Root Solving	227
8.2	Eigenvectors by Gauss Elimination	229
8.3	Matrix Iteration	230
8.4	Convergence of the Iteration Procedure	233
8.5	The Dynamic Matrix	233
8.6	Transformation Coordinates (Standard Computer Form)	234
8.7	Systems with Discrete Mass Matrix	235
8.8	Cholesky Decomposition	237
8.9	Jacobi Diagonalization	242
8.10	QR Method for Eigenvalue and Eigenvector Calculation	247
<b>CHAPTER 9</b>	<b>VIBRATION OF CONTINUOUS SYSTEMS</b>	<b>268</b>
9.1	Vibrating String	268
9.2	Longitudinal Vibration of Rods	271
9.3	Torsional Vibration of Rods	273
9.4	Vibration of Suspension Bridges	276
9.5	Euler Equation for Beams	281
9.6	System with Repeated Identical Sections	289

<b>CHAPTER 10</b>	<b>INTRODUCTION TO THE FINITE ELEMENT METHOD</b>	<b>287</b>
10.1	Element Stiffness and Mass	287
10.2	Stiffness and Mass for the Beam Element	292
10.3	Transformation of Coordinates (Global Coordinates)	295
10.4	Element Stiffness and Element Mass in Global Coordinates	297
10.5	Vibrations Involving Beam Elements	302
10.6	Spring Constraints on Structure	309
10.7	Generalized Force for Distributed Load	311
10.8	Generalized Force Proportional to Displacement	313
<b>CHAPTER 11</b>	<b>MODE-SUMMATION PROCEDURES FOR CONTINUOUS SYSTEMS</b>	<b>329</b>
11.1	Mode-Summation Method	329
11.2	Normal Modes of Constrained Structures	335
11.3	Mode-Acceleration Method	339
11.4	Component-Mode Synthesis	341
<b>CHAPTER 12</b>	<b>CLASSICAL METHODS</b>	<b>351</b>
12.1	Rayleigh Method	351
12.2	Dunkerley's Equation	358
12.3	Rayleigh-Ritz Method	363
12.4	Holzer Method	366
12.5	Digital Computer Program for the Torsional System	369

12.6	Myklestad's Method for Beams	371
12.7	Coupled Flexure-Torsion Vibration	375
12.8	Transfer Matrices	376
12.9	Systems with Damping	378
12.10	Geared System	380
12.11	Branched Systems	381
12.12	Transfer Matrices for Beams	383
<b>CHAPTER 13</b>	<b>RANDOM VIBRATIONS</b>	<b>395</b>
13.1	Random Phenomena	395
13.2	Time Averaging and Expected Value	396
13.3	Frequency Response Function	398
13.4	Probability Distribution	401
13.5	Correlation	407
13.6	Power Spectrum and Power Spectral Density	411
13.7	Fourier Transforms	417
13.8	FTs and Response	424
<b>CHAPTER 14</b>	<b>NONLINEAR VIBRATIONS</b>	<b>436</b>
14.1	Phase Plane	436
14.2	Conservative Systems	438
14.3	Stability of Equilibrium	441
14.4	Method of Isoclines	443
14.5	Perturbation Method	445
14.6	Method of Iteration	448

14.7	Self-Excited Oscillations	451
14.8	Runge-Kutta Method	453
<b>APPENDICES</b>		
<b>A</b>	Specifications of Vibration Bounds	462
<b>B</b>	Introduction to Laplace Transformation	464
<b>C</b>	Determinants and Matrices	469
<b>D</b>	Normal Modes of Uniform Beams	479
<b>E</b>	Introduction to MATLAB®	487
<b>F</b>	Computer Programs	492
<b>G</b>	Convergence to Higher Modes	501
<b>ANSWERS TO SELECTED PROBLEMS</b>		<b>506</b>
<b>INDEX</b>		<b>519</b>