

CONTENTS

PREFACE	v
LIST OF SYMBOLS	x
CHAPTER 1. KINEMATICS OF VIBRATION	1
1.1. Definitions	1
1.2. The Vector Method of Representing Vibrations	3
1.3. Beats	5
1.4. A Case of Hydraulic-turbine Penstock Vibration	7
1.5. Representation by Complex Numbers	9
1.6. Work Done on Harmonic Motions	12
1.7. Non-harmonic Periodic Motions	17
CHAPTER 2. THE SINGLE-DEGREE-OF-FREEDOM SYSTEM	23
2.1. Degrees of Freedom	23
2.2. Derivation of the Differential Equation	24
2.3. Other Cases	26
2.4. Free Vibrations without Damping	31
2.5. Examples	34
2.6. Free Vibrations with Viscous Damping	37
2.7. Forced Vibrations without Damping	42
2.8. Forced Vibrations with Viscous Damping	47
2.9. Frequency-measuring Instruments	55
2.10. Seismic Instruments	57
2.11. Electrical Measuring Instruments	62
2.12. Theory of Vibration Isolation	69
2.13. Application to Single-phase Electrical Machinery	72
2.14. Application to Automobiles; Floating Power	76
CHAPTER 3. TWO DEGREES OF FREEDOM	79
3.1. Free Vibrations; Natural Modes	79
3.2. The Undamped Dynamic Vibration Absorber	87
3.3. The Damped Vibration Absorber	93
3.4. Ship Stabilization	106
3.5. Automobile Shock Absorbers	113
3.6. Isolation of Non-rigid Foundations	117
CHAPTER 4. MANY DEGREES OF FREEDOM	122
4.1. Free Vibrations without Damping	122
4.2. Forced Vibrations without Damping	126
4.3. Free and Forced Vibrations with Damping	130

4.4. Strings and Organ Pipes; Longitudinal and Torsional Vibrations of Uniform Bars	135
4.5. Rayleigh's Method	141
4.6. Bending Vibrations of Uniform Beams	148
4.7. Beams of Variable Cross Section	155
4.8. Normal Functions and Their Applications	159
4.9. Stodola's Method for Higher Modes	162
4.10. Rings, Membranes, and Plates	165
CHAPTER 5. MULTICYLINDER ENGINES	170
5.1. Troubles Peculiar to Reciprocating Engines	170
5.2. Dynamics of the Crank Mechanism	174
5.3. Inertia Balance of Multicylinder Engines	180
5.4. Natural Frequencies of Torsional Vibration	184
5.5. Numerical Example	187
5.6. Torque Analysis	197
5.7. Work Done by Torque on Crank-shaft Oscillation	200
5.8. Damping of Torsional Vibration; Propeller Damping	206
5.9. Dampers and Other Means of Mitigating Torsional Vibration	210
CHAPTER 6. ROTATING MACHINERY	225
6.1. Critical Speeds	225
6.2. Holzer's Method for Flexural Critical Speeds	229
6.3. Balancing of Solid Rotors	232
6.4. Simultaneous Balancing in Two Planes	239
6.5. Balancing of Flexible Rotors; Field Balancing	243
6.6. Secondary Critical Speeds	247
6.7. Critical Speeds of Helicopter Rotors	249
6.8. Gyroscopic Effects	253
6.9. Frame Vibration in Electrical Machines	265
6.10. Vibration of Propellers	269
6.11. Vibration of Steam-turbine Wheels and Blades	277
CHAPTER 7. SELF-EXCITED VIBRATIONS	282
7.1. General	282
7.2. Mathematical Criterion of Stability	285
7.3. Instability Caused by Friction	289
7.4. Internal Hysteresis of Shafts and Oil-film Lubrication in Bearings as Causes of Instability	295
7.5. Galloping of Electric Transmission Lines	299

7.7. Hunting of Steam-engine Governors	309
7.8. Diesel-engine Fuel-injection Valves	313
7.9. Vibrations of Turbines Caused by Leakage of Steam or Water	317
7.10. Airplane-wing Flutter	321
7.11. Wheel Shimmy	329
CHAPTER 8. SYSTEMS WITH VARIABLE OR NON-LINEAR CHARACTERISTICS	335
8.1. The Principle of Superposition	335
8.2. Examples of Systems with Variable Elasticity	336
8.3. Solution of the Equation	343

CONTENTS	ix
8.4. Interpretation of the Result	347
8.5. Examples of Non-linear Systems	351
8.6. Free Vibrations with Non-linear Characteristics	353
8.7. Relaxation Oscillations	363
8.8. Forced Vibrations with Non-linear Springs	370
8.9. Forced Vibrations with Non-linear Damping	373
8.10. Subharmonic Resonance.	377
PROBLEMS	380
ANSWERS TO PROBLEMS.	417
APPENDIX: A COLLECTION OF FORMULAS.	429
INDEX.	435