Contents

1 Introduction 1

2 Mechanical Vibratory Systems with Hierarchical Structure. Simulation and Calculation Methods 7

2.1 Introduction 7

2.2 Models of Mechanical Systems with Lumped Parameters 8

2.2.1 Coefficients of Static Stiffness and Compliance 9

2.2.2 Static Stiffness Coefficients for a Beam 11

2.3 Reduction of Models with Lumped Parameters 13

2.4 Coefficients of Dynamic Stiffness and Compliance 15

2.4.1 Coefficients of Dynamic Stiffness 16

2.4.2 Coefficients of Dynamic Compliance 17

2.5 Dimension Reduction of Dynamic Compliance Matrix 21

2.6 Determining Dynamic Compliance Using Experimental Methods 22

2.7 Fundamentals of Finite-Element Method. Analytical Approaches 25

2.7.1 Stiffness Matrix for Beam Finite Element 26

2.7.2 Stiffness Matrix for Assembled System 28

2.7.3 Boundary Conditions and Various Ways of Subsystems Connecting 29

2.8 Decomposition Methods Taking into Account Weak Interactions Between Subsystems 30

2.8.1 Coefficients of Dynamic Interactions 31

2.8.2 Decomposition by Partition into Independent Substructures 34

2.8.3 Other Decomposition Methods 36

2.8.4 Coefficients of Weak Interaction and Criteria for Ill – Conditions of Matrices 37

Part I Systems with Lumped Parameters

3 Vibrations of Regular Systems with Periodic Structure 41

3.1 Introduction: Some Specific Features of Mechanical Systems . . 41

3.2 Wave Approach at Vibrations of Mechanical Systems with Periodic Structure 42

Bibliografische Informationen
http://d-nb.info/1000031551

digitalisiert durch DEUTSCHE NATIONAL BIBLIOTHEK

3.3 Vibrations of Frames with Periodic Structure 47
3.3.1 Combining Finite Elements Method and Dispersion Equation 47
3.3.2 Vibrations of Grate Frames 50
3.4 Dynamic Properties of Laminar Systems with Sparsely Positioned Laminar Ribbing 52
3.4.1 Dispersion Equation for Ribbed Laminar Systems: Conditions for Possibility of Continualization 53
3.4.2 Vibrations of a Single-Section Lamina with Laminar Ribbing: Comparison of Discrete and Continuous Models 58
3.5 Finite-Element Models for Beam Systems: Comparison with Distributed Parameters Models 61
3.5.1 Dispersion Equation for FE-Model of Beam 61
3.5.2 Comparing Models with Distributed Parameters and Finite Elements Models at Different FE-Mesh . . . 64
3.5.3 Beam Systems 68
3.6 Hierarchy of Mathematical Models: Superposition of Wave Motions 70
3.7 Vibrations of Self-Similar Structures in Mechanics 73
3.7.1 Self-Similar Structures: Basic Concepts 73
3.7.2 Vibrations in Self-Similar Mechanical Structures: Dispersion Equation 74

4 Vibrations of Systems with Geometric Symmetry. Quasi-symmetrical Systems 79
4.1 Introduction 79
4.2 Basic Information about Theory of Groups Representation . . . 80
4.2.1 Basic Concepts and Definitions 80
4.2.2 Examples of Applying Groups Representation Theory . 83
4.3 Applying Theory of Group Representation to Mechanical Systems: Generalized Projective Operators of Symmetry 86
4.3.1 Features of Mechanical Systems with Symmetric Structure 86
4.3.2 Generalized Projective Operators and Generalized Modes 87
4.4 Vibrations of Frames with Cyclic Symmetry 89
4.4.1 Stiffness and Inertia Matrices 89
4.4.2 Projective Operators for Frame: Generalized Modes . . 91
4.4.3 Analysis of Forced Vibrations 95
4.5 Effect of FE-Mesh on Matrix Structure 95
4.5.1 The Square Frame: Generalized Modes 96
4.6 Vibroisolation of Body on Symmetrical Frame: Vibrations Interaction 98

4.7 Quasi-symmetrical Systems 100
4.7.1 Vibrations Interaction at Slight Asymmetry 100
4.7.2 Quasi-symmetrical Systems: Free Vibrations 102
4.7.3 Quasi-symmetrical Systems: Forced Vibrations 104
4.8 Hierarchy of Symmetries: Multiplication of Symmetries 105
4.9 Periodic Systems Consisting from Symmetrical Elements 107
4.10 Generalized Modes in Planetary Reduction Gear due to Its Symmetry 108
4.10.1 Dynamic Model of Planetary Reduction Gear 108
4.10.2 Generalized Normal Modes in Planetary Reduction Gear: Decomposition of Stiffness Matrix . . 109
4.10.3 Free Vibrations 111
4.10.4 Forced Vibrations due to Slight Error in Engagement . 112
4.10.5 Vibrations Interaction at Violation of Symmetry 113

Part II Systems with Distributed Parameters

5 Basic Equations and Numerical Methods 117
5.1 Elementary Cells: Connectedness 117
5.2 Fundamental Matrices for Systems with Regular Structure . . . 118
5.2.1 Matrices of Dynamic Compliance and Dynamic Stiffness 118
5.2.2 Mixed Dynamic Matrix 119
5.2.3 Transition Matrix 121
5.3 Finite Difference Equations 122
5.4 Mixed Dynamic Matrix as Finite Difference Equation 124
5.5 Transmission Matrix 125

6 Systems with Periodic Structure 127
6.1 Introduction 127
6.2 Dynamic Compliances and Stiffness for Systems with Periodic Structure 129
6.3 Dynamic Compliances of Single-Connectedness System 131
6.4 Transition Matrix 135
6.5 Forced Vibrations 136
6.6 Vibrations of Blades Package 137
6.7 Collective Vibrations of Blades 139

7 Systems with Cyclic Symmetry 141
7.1 Natural Frequencies and Normal Modes for Systems with Cyclic Symmetry 141
7.1.1 Natural Frequencies 141
7.1.2 Normal Modes 144
7.2 Vibrations of Blades System 144
7.2.1 Different Designs of Blades Connecting 144
7.2.2 Natural Frequencies for Blades System 145
7.2.3 Normal Modes for Blades System 146

7.3 Numerical and Experimental Results for Blades with Shroud . . 147
7.3.1 Free Ring Connection 147
7.3.2 Blades with Paired-Ring Shroud 149
7.3.3 Blades Shrouded by Shelves 151

8 Systems with Reflection Symmetry Elements 155
8.1 Reflection Symmetry Element and Its Dynamic Characteristics . 155
8.1.1 Dynamic Stiffness and Compliance Matrices for Reflection Symmetry Element 157
8.1.2 Mixed Matrix for Reflection Symmetry Element 158
8.2 Finite Differences Equations 161
8.3 Special Types of Boundary Conditions 164
8.3.1 Nonclosed Systems 164
8.3.2 Closed Systems 167
8.4 Filtering Properties of System with Reflection Symmetry Elements 169
8.5 Numerical Examples 170
8.5.1 Single-Connectedness Systems 170
8.5.2 Two-Connectedness Systems 176
8.5.3 Three-Connectedness System 179
8.6 Systems Consisting of Skew-Symmetric (Antisymmetric) Elements 182

9 Self-Similar Structures 187
9.1 Introductory Part: Examples of Self-Similar Mechanical Structures 187
9.2 Dynamic Compliances of Self-Similar Systems 188
9.3 Vibrations of Self-Similar Systems: Numerical Examples 190
9.4 Transition Matrix 191
9.5 Self-Similar Systems with Similar Matrix of Dynamic Compliance 193
9.6 Vibrations of Self-Similar Shaft with Disks 194
9.7 Vibrations of Self-Similar Drum-Type Rotor 196

10 Vibrations of Rotor Systems with Periodic Structure 201
10.1 Rotor Systems with Periodic Structure with Disks 201
10.2 Rotor with Arbitrary Boundary Conditions: Natural Frequencies and Normal Modes 205

11 Vibrations of Regular Ribbed Cylindrical Shells 209
11.1 General Theory of Shells 209
11.2 Dynamic Stiffness and Transition Matrix for Closed Cylindrical Shells 211
11.3 Dynamic Stiffness and Transition Matrix for Cylindrical Panel . 214
11.4 Dynamic Stiffness and Transition Matrices for Circular Ring with Symmetric Profile 215
11.5 Vibrations of Cylindrical Shell with Ring Ribbing under Arbitrary Boundary Conditions 217
11.6 Vibrations of Cylindrical Shell with Longitudinal Ribbing of Nonsymmetric Profile 221

11.6.1 Dynamic Stiffness and Transition Matrices for Longitudinal Stiffening Ribs 222
11.6.2 Numerical Calculation of Shell with Longitudinal Ribbing 223

Appendix A
Stiffness and Inertia Matrices for a Ramified System Consisting of Rigid Bodies Connected by Beam Elements 225

Appendix B
Stiffness Matrix for Spatial Finite Element 231

Appendix C
Stiffness Matrix Formation Algorithm for a Beam System in Analytical Form 233

Appendix D
Stiffness Matrices for a Planetary Reduction Gear Subsystems . . 235

References 237

Index 243