

Table of Contents

Preface	xi
Nomenclature	xv
Chapter 1. Introduction to Damping Models and Analysis Methods	1
1.1. Models of damping	3
1.1.1. Single-degree-of-freedom systems	4
1.1.2. Continuous systems	8
1.1.3. Multiple-degrees-of-freedom systems	10
1.1.4. Other studies	11
1.2. Modal analysis of viscously damped systems	13
1.2.1. The state-space method	14
1.2.2. Methods in the configuration space	15
1.3. Analysis of non-viscously damped systems	21
1.3.1. State-space-based methods	22
1.3.2. Time-domain-based methods	23
1.3.3. Approximate methods in the configuration space	23
1.4. Identification of viscous damping	24
1.4.1. Single-degree-of-freedom systems	24
1.4.2. Multiple-degrees-of-freedom systems	25
1.5. Identification of non-viscous damping	28
1.6. Parametric sensitivity of eigenvalues and eigenvectors	29
1.6.1. Undamped systems	29
1.6.2. Damped systems	30
1.7. Motivation behind this book	32
1.8. Scope of the book	33

Chapter 2. Dynamics of Undamped and Viscously Damped Systems	41
2.1. Single-degree-of-freedom undamped systems	41
2.1.1. Natural frequency	42
2.1.2. Dynamic response	43
2.2. Single-degree-of-freedom viscously damped systems	45
2.2.1. Natural frequency	46
2.2.2. Dynamic response	47
2.3. Multiple-degree-of-freedom undamped systems	52
2.3.1. Modal analysis	53
2.3.2. Dynamic response	55
2.4. Proportionally damped systems	58
2.4.1. Condition for proportional damping	60
2.4.2. Generalized proportional damping	61
2.4.3. Dynamic response	65
2.5. Non-proportionally damped systems	80
2.5.1. Free vibration and complex modes	81
2.5.2. Dynamic response	87
2.6. Rayleigh quotient for damped systems	93
2.6.1. Rayleigh quotients for discrete systems	94
2.6.2. Proportional damping	96
2.6.3. Non-proportional damping	97
2.6.4. Application of Rayleigh quotients	100
2.6.5. Synopses	101
2.7. Summary	101
Chapter 3. Non-Viscously Damped Single-Degree-of-Freedom Systems	103
3.1. The equation of motion	104
3.2. Conditions for oscillatory motion	108
3.3. Critical damping factors	112
3.4. Characteristics of the eigenvalues	113
3.4.1. Characteristics of the natural frequency	114
3.4.2. Characteristics of the decay rate corresponding to the oscillating mode	118
3.4.3. Characteristics of the decay rate corresponding to the non-oscillating mode	122
3.5. The frequency response function	123
3.6. Characteristics of the response amplitude	126
3.6.1. The frequency for the maximum response amplitude	128
3.6.2. The amplitude of the maximum dynamic response	137
3.7. Simplified analysis of the frequency response function	141
3.8. Summary	144

Chapter 4. Non-viscously Damped Multiple-Degree-of-Freedom Systems	147
4.1. Choice of the kernel function	149
4.2. The exponential model for MDOF non-viscously damped systems	151
4.3. The state-space formulation	153
4.3.1. Case A: all coefficient matrices are of full rank	153
4.3.2. Case B: coefficient matrices are rank deficient	158
4.4. The eigenvalue problem	162
4.4.1. Case A: all coefficient matrices are of full rank	162
4.4.2. Case B: coefficient matrices are rank deficient	165
4.5. Forced vibration response	166
4.5.1. Frequency domain analysis	167
4.5.2. Time-domain analysis	168
4.6. Numerical examples	169
4.6.1. Example 1: SDOF system with non-viscous damping	169
4.6.2. Example 2: a rank-deficient system	170
4.7. Direct time-domain approach	174
4.7.1. Integration in the time domain	174
4.7.2. Numerical realization	175
4.7.3. Summary of the method	179
4.7.4. Numerical examples	181
4.8. Summary	184
Chapter 5. Linear Systems with General Non-Viscous Damping	187
5.1. Existence of classical normal modes	188
5.1.1. Generalization of proportional damping	189
5.2. Eigenvalues and eigenvectors	191
5.2.1. Elastic modes	193
5.2.2. Non-viscous modes	197
5.2.3. Approximations for lightly damped systems	198
5.3. Transfer function	199
5.3.1. Eigenvectors of the dynamic stiffness matrix	201
5.3.2. Calculation of the residues	202
5.3.3. Special cases	204
5.4. Dynamic response	205
5.4.1. Summary of the method	207
5.5. Numerical examples	208
5.5.1. The system	208
5.5.2. Example 1: exponential damping	210
5.5.3. Example 2: GHM damping	213
5.6. Eigenrelations of non-viscously damped systems	215
5.6.1. Nature of the eigensolutions	216
5.6.2. Normalization of the eigenvectors	217

5.6.3. Orthogonality of the eigenvectors	219
5.6.4. Relationships between the eigensolutions and damping	223
5.6.5. System matrices in terms of the eigensolutions	225
5.6.6. Eigenrelations for viscously damped systems	226
5.6.7. Numerical examples	227
5.7. Rayleigh quotient for non-viscously damped systems	230
5.8. Summary	234
Chapter 6. Reduced Computational Methods for Damped Systems	237
6.1. General non-proportionally damped systems with viscous damping	238
6.1.1. Iterative approach for the eigensolutions	239
6.1.2. Summary of the algorithm	244
6.1.3. Numerical example	246
6.2. Single-degree-of-freedom non-viscously damped systems	247
6.2.1. Nonlinear eigenvalue problem for non-viscously damped systems	250
6.2.2. Complex conjugate eigenvalues	251
6.2.3. Real eigenvalues	253
6.2.4. Numerical examples	257
6.3. Multiple-degrees-of-freedom non-viscously damped systems	259
6.3.1. Complex conjugate eigenvalues	260
6.3.2. Real eigenvalues	262
6.3.3. Numerical example	263
6.4. Reduced second-order approach for non-viscously damped systems	264
6.4.1. Proportionally damped systems	266
6.4.2. The general case	271
6.4.3. Numerical examples	274
6.5. Summary	277
Appendix	281
Bibliography	299
Author index	329
Index	335