Active Control of Structures

André Preumont
Université Libre de Bruxelles, Brussels

Kazuto Seto
Nihon University, Japan

A John Wiley & Sons, Ltd, Publication

Contents

About the Authors xi

Preface xiii

Acknowledgements xv

1 Active Damping 1
1.1 Introduction 1
1.1.1 Why Suppress Vibrations? 1
1.1.2 How can Vibrations be Reduced? 2
1.2 Structural Control 2
1.3 Plant Description 3
1.3.1 Error Budget 4
1.4 Equations of Structural Dynamics 6
1.4.1 Equation of Motion Including Seismic Excitation 6
1.4.2 Modal Coordinates 8
1.4.3 Support Reaction, Dynamic Mass 10
1.4.4 Dynamic Flexibility Matrix 12
1.5 Collocated Control System 15
1.5.1 Transmission Zeros and Constrained System 18
1.5.2 Nearly Collocated Control System 20
1.5.3 Non-Collocated Control Systems 21
1.6 Active Damping with Collocated System 24
1.6.1 Lead Control 25
1.6.2 Direct Velocity Feedback 29
1.6.3 Positive Position Feedback 31
1.6.4 Integral Force Feedback 35
1.6.5 Duality between The Lead and IFF Controllers 44
1.7 Decentralized Control with Collocated Pairs 46
1.7.1 Cross-Talk 46
1.7.2 Transmission Zeros (Case 1) 47
1.7.3 Transmission Zeros (Case 2) 52
References 55

2 Active Isolation 57
2.1 Introduction 57
2.2 Relaxation Isolator 60
2.2.1 Electromagnetic Realization 62
2.3 Sky-hook Damper 64
2.4 Force Feedback 66
2.5 Six-Axis Isolator 69
2.5.1 Decentralized Control 73
2.5.2 Leg Design 76
2.5.3 Model of the Isolator 80
2.5.4 Six-Axis Transmissibility 82
2.6 Vehicle Active Suspension 89
2.6.1 Quarter-Car Model 91
2.7 Semi-Active Suspension 106
2.7.1 Semi-Active Devices 106
2.7.2 Narrow-Band Disturbance 107
2.7.3 Quarter-Car Semi-Active Suspension 108
References 113

3 A Comparison of Passive, Active and Hybrid Control 117
3.1 Introduction 117
3.2 System Description 119
3.3 The Dynamic Vibration Absorber 120
3.3.1 Single-d.o.f. Oscillator 120
3.3.2 Multiple-d.o.f. System 123
3.3.3 Shear Frame Example 124
3.4 Active Mass Damper 126
3.5 Hybrid Control 131
3.6 Shear Control 133
3.7 Force Actuator, Displacement Sensor 135
3.7.1 Direct Velocity Feedback 136
3.7.2 First-Order Positive Position Feedback 137
3.7.3 Comparison of the DVF and the PPF 138
3.8 Displacement Actuator, Force Sensor 140
3.8.1 Comparison of the IFF and the DVF 142
References 144

4 Vibration Control Methods and Devices 147
4.1 Introduction 147
4.2 Classification of Vibration Control Methods 148

4.3 Construction of Active Dynamic Absorber 151
4.4 Control Devices for Wind Excitation Control in Civil Structures 154
4.5 Real Towers Using the Connected Control Method 156
4.6 Application of Active Dynamic Absorber for Controlling Vibration of Single-d.o.f. Systems 158
4.6.1 Equations of Motion and State Equation 159
4.6.2 Representation of a Non-Dimensional State Equation 160
4.6.3 Control System Design 162
4.6.4 Similarity Law between Dimensional and Non-dimensional System 163
4.6.5 Analysis of Vibration Control Effect 165
4.6.6 Experiment 173
4.7 Remarks 175
References 176

5 Reduced-Order Model for Structural Control 179
5.1 Introduction 179
5.2 Modeling of Distributed Structures 180
5.2.1 Equation of Motion for Distributed Structures 180
5.2.2 Conventional Modeling of Structures 181
5.3 Spillover 183
5.4 The Lumped Modeling Method 185
5.4.1 A Key Idea for Deriving a Reduced-Order Model 185
5.4.2 Relationship Between Physical and Modal Coordinate Systems 187
5.4.3 Modification of Normalized Modal Matrix 188
5.5 Method of Equivalent Mass Estimation 190
5.5.1 Meaning of Equivalent Mass 190
5.5.2 Eigenvector Method 191
5.5.3 Mass Response Method 193
5.6 Modeling of Tower-like Structure 197
5.6.1 Two-d.o.f. Model 197
5.6.2 Dimension and Dynamic Characteristics of the Tower-Like Structure 198
5.6.3 Calculation of Parameters of Two-d.o.f. Model 201
5.6.4 Comparison between the Distributed Parameter and Two-d.o.f. Systems 203

5.7 Modeling of Plate Structures 203
5.7.1 *Dimensions of a Plate Structure* 203
5.7.2 *Three-d.o.f. Model* 206
5.7.3 *Calculation of Parameters of the Three-d.o.f. Model* 207
5.7.4 *Comparison between Real System and Three-d.o.f. Systems* 208
5.8 Modeling of a Bridge Tower 209
5.8.1 *Dimensions of a Scaled Bridge Tower* 209
5.8.2 *Construction of a Four-d.o.f. Model* 210
5.8.3 *Calculation of Parameters of the Four-d.o.f. Model* 212
5.8.4 *Comparison between Real System and Four-d.o.f. Systems* 213
5.9 Robust Vibration Control for Neglected Higher Modes 217
5.10 Conclusions 217
References 219

6 Active Control of Civil Structures 221
6.1 Introduction 221
6.2 Classification of Structural Control for Buildings 222
6.3 Modeling and Vibration Control for Tower Structures 222
6.3.1 *One-d.o.f. Model* 222
6.3.2 *Two-d.o.f. Model for Tower-Like Structures and Its LQ Control* 225
6.3.3 *Three-d.o.f. Model for Broad Structures and Its H_∞ Robust Control* 228
6.3.4 *Four-d.o.f. Model for Bridge Tower and Spillover Suppression Using Filtered LQ Control* 239
6.4 Active Vibration Control of Multiple Buildings Connected with Active Control Bridges in Response to Large Earthquakes 249
6.4.1 *Construction of Four Model Buildings* 249
6.4.2 *Characteristics of the Tower Structures* 251
6.4.3 *Reduced-order Model of the Four Tower Structures Connected by Four Actuators* 252
6.4.4 *Control System Design* 254
6.4.5 *Simulated Results of Seismic Response Control* 257
6.4.6 *Experiment* 259
6.5 Vibration Control for Real Triple Towers Using CCM 264
6.5.1 *Outline of the Triple Towers* 264
6.5.2 *Modeling of Towers* 265

6.5.3 *Control System Design* 266
6.5.4 *Simulation of the Triple Towers Using CCM* 269
6.5.5 *Realization of the CCM* 270
6.6 Vibration Control of Bridge Towers Using a Lumped Modeling Approach 274
6.6.1 *Vibration Problem of Bridge Towers Under Construction* 274
6.6.2 *Controlled Object and Its Dynamic Characteristics* 277
6.6.3 *Five-d.o.f. Modeling of a Scaled Bridge Tower Structure with a Crane Tower* 278
6.6.4 *LQ Control System Design* 278
6.6.5 *Simulations* 283
6.6.6 *Experiments* 283
6.6.7 *H_∞ Robust Control* 286
6.7 Conclusion 290
References 291

Index **293**