

# Contents

<i>Preface</i>	<i>page ix</i>
<b>1 Introduction</b>	1
BIBLIOGRAPHY	6
<b>2 Piezoelectric Materials and Induced-Strain Actuation</b>	7
2.1 Introduction	7
2.2 Piezoelectric Properties	7
2.2.1 Example: Inchworm Linear Motor	9
2.3 Actuation of Structural Components by Piezoelectric Crystals	10
2.3.1 Actuator-Structure Interaction	11
2.3.2 Axial Motion of Rods	13
2.3.3 Bending of Beams	15
2.3.3.1 Example: Harmonic Excitation	20
2.3.3.2 Example: Impulsive Load from a Triangular Patch	21
2.4 Summary	23
BIBLIOGRAPHY	23
PROBLEMS	23
<b>3 Shape Memory Alloys</b>	26
3.1 Introduction	26
3.2 Experimental Phenomenology	28
3.3 Influence of Stress on the Characteristic Temperatures	34
3.4 Constitutive Modeling of the Shape Memory Effect	38
3.4.1 Design Considerations: A Simple Example	41
3.5 Vibration Control through Shape Memory Alloys	44
3.6 Multiplexing Embedded NiTiNOL Actuators	48
3.6.1 Analytical Basis for the Design of Composite Beams	50
3.6.2 Control Scheme and Test Specimens: Analysis and Design	51

3.6.2.1	Electrical Control System	51
3.6.2.2	Preliminary Tests: Steel Beam with External Actuation	52
3.6.2.3	Composite Beam with Embedded Fiber Actuation	53
3.6.2.4	Steel Beam with External Actuation	55
3.6.2.5	Composite Beam with Embedded NiTiNOL Fibers	58
3.7	Applications of Shape Memory Alloys	65
3.8	Summary	69
	BIBLIOGRAPHY	69
	PROBLEMS	70
<b>4</b>	<b>Electrorheological and Magnetorheological Fluids</b>	<b>73</b>
4.1	Introduction	73
4.2	Mechanisms and Properties	73
4.2.1	Fluid Composition and Behavior	73
4.2.2	Discovery and Early Developments	75
4.2.2.1	The Bingham Plastic and Related Models	76
4.2.2.2	Pre-Yield Response	78
4.2.2.3	Post-Yield Flow and Device Geometry	79
4.2.2.4	Other Effects	83
4.2.3	Summary of Material Properties	84
4.3	Applications of ER and MR Fluids	85
4.3.1	Clutches	87
4.3.2	Dampers	88
4.3.3	Other Applications	91
4.4	Summary	93
	BIBLIOGRAPHY	93
	PROBLEMS	95
<b>5</b>	<b>Vibration Absorbers</b>	<b>97</b>
5.1	Introduction	97
5.2	Parallel Damped Vibration Absorber	100
5.2.1	Analysis	100
5.2.2	A Special Case	102
5.2.2.1	The Optimum Case	104
5.3	Numerical Results	105
5.4	Gyroscopic Vibration Absorbers	107
5.4.1	Analysis: Perissogyro Vibration Absorber	110
5.4.2	Experimental Setup and Observations	116
5.5	Numerical Results	118
5.6	Active Vibration Absorbers	120
5.7	Summary	120
	BIBLIOGRAPHY	121
	PROBLEMS	121

<b>6</b>	<b>Mistuning</b>	123
	6.1 Introduction	123
	6.2 Vibration Characteristics of Mistuned Systems	124
	6.2.1 Nearly Periodic Simply Supported Beams	124
	6.2.2 Circularly Symmetric Structures	128
	6.2.3 Jet Engine Blades	131
	6.3 Analytical Approach	133
	6.4 Summary	138
	BIBLIOGRAPHY	138
	PROBLEMS	138
<b>7</b>	<b>Fiber Optics</b>	140
	7.1 Introduction	140
	7.2 The Physical Phenomena	140
	7.2.1 Total Internal Reflection	140
	7.2.2 Numerical Aperture	142
	7.3 Fiber Characteristics	142
	7.4 Fiber-Optic Strain Sensors	144
	7.4.1 Strain Measurement	144
	7.4.2 Microbent and Graded-Index Fibers	145
	7.4.3 Extrinsic Fabry-Perot Sensors	146
	7.4.4 Mach-Zehnder Interferometers	148
	7.4.5 Other Fiber-Optic Strain Measurement Techniques	149
	7.4.5.1 Bragg Grating Sensor	149
	7.4.5.2 White Light Interferometry	149
	7.5 Twisted and Braided Fiber-Optic Sensors	149
	7.5.1 Preliminary Experiments	150
	7.5.2 Coupon Tests	150
	7.6 Optical Fibers as Load Bearing Elements	152
	7.7 Additional Applications	153
	7.7.1 Crack Detection	153
	7.7.2 Integration of Fiber-Optic Sensors and Shape Memory Elements	153
	7.7.3 Chemical Sensing	154
	7.8 Summary	155
	BIBLIOGRAPHY	155
	PROBLEMS	156
<b>8</b>	<b>Control of Structures</b>	157
	8.1 Introduction	157
	8.2 Structures as Controlled Plants	158
	8.2.1 Modeling Structures for Control	158

8.2.2 Control Strategies and Limitations	160
8.3 Active Structures in Practice	161
8.3.1 Systems Using SMA Actuators	161
8.3.2 Systems Using PZT Sensors and Actuators	167
8.4 Summary	169
BIBLIOGRAPHY	170
PROBLEMS	172
<b>9 Biomimetics</b>	174
9.1 Introduction	174
9.2 Characteristics of Natural Structures	175
9.3 Biomimetic Structural Design	180
9.3.1 Fiber-Reinforced Organic-Matrix Natural Composites	180
9.3.1.1 Wood: A Plant Analog	180
9.3.1.2 Insect Cuticle: An Animal Analog	184
9.3.2 Fiber-Reinforced Natural Ceramers: Bone and Antler	185
9.3.3 Fiber-Reinforced Organic-Matrix and Ceramic-Matrix Composites: Mollusks	188
9.4 Biomimetic Sensing	192
9.4.1 Cochlea	193
9.4.2 Bats	193
9.4.3 Arachnids	194
9.5 Challenges and Opportunities	194
9.6 Summary	199
BIBLIOGRAPHY	199
PROBLEMS	201
<b>Appendix A Selected Topics from Structural Dynamics</b>	203
<b>Appendix B Selected Topics from Automatic Control</b>	207
<i>Index</i>	223