
Contents

1	Introduction to Smart Structures	1
1.1	Smart Materials and Structures - Theory and Concepts	1
1.2	Active Vibration Control (AVC)	3
1.3	A Brief Survey on Smart Structures Research	4
1.4	Review of Beam Theories	7
1.4.1	Euler-Bernoulli Beam Theory	7
1.4.2	Timoshenko Beam Theory	8
1.5	Mathematical Models for Smart Structures	9
1.6	Review of Control Techniques	11
1.6.1	Multirate Output Feedback	11
1.6.2	Periodic Output Feedback	12
1.6.3	Fast Output Sampling Feedback	13
1.6.4	Robust Decentralized Multirate Output Feedback	13
1.6.5	Model Order Reduction	14
1.6.6	Sliding Mode Control	14
1.7	Contributions of the Monograph	16
1.7.1	Modeling of Smart Structures	16
1.7.2	Design of POF Controllers	18
1.7.3	Design of FOS Controllers	19
1.7.4	Design of DSM Controllers	20
1.7.5	Implementation of the Designed Controllers	20
1.8	Motivation for Modeling and Control of Smart Structures	21
2	Modeling of Smart Structures	23
2.1	Modeling of Smart Structures Using Euler-Bernoulli Beam Theory	23
2.1.1	Modeling of Smart Beams as SISO Systems for 2 and 3 Vibratory Modes	24
2.1.2	Modeling of Smart Beams as MIMO Systems for 2 and 3 Vibratory Modes	44

2.1.3	Modeling of the Smart Structure as Multimodel System Comprising of Multivariable Plants	48
2.1.4	Modeling of Smart Beams for 6 Vibratory Modes (Higher Order).....	52
2.1.5	Conclusions.....	54
2.2	Modeling of Smart Structures Based on Timoshenko Beam Theory.....	55
2.2.1	Modeling of SISO Structures with Surface Mounted Shear Sensors and Actuators	55
2.2.2	Modeling of Smart Beams with Surface Mounted Sensors-Actuators for a MIMO Case	70
2.2.3	Modeling of Smart Timoshenko Cantilever Beam with Embedded Shear Sensors and Actuators as SISO and MIMO Systems	71
2.2.4	Conclusions.....	85
3	Periodic Output Feedback Controllers for Smart Structures	87
3.1	A Brief Review of the Periodic Output Feedback Control Technique	87
3.2	Controller Design for Smart Structures Modelled Using EB Theory.....	90
3.2.1	Design of SISO Controllers for Smart Beam Divided into 3, 4, 5 Finite Elements	90
3.2.2	Design of MIMO Controller for a Multivariable System ..	98
3.2.3	Design of Robust Decentralized Fault Tolerant Controller for Smart Structures	101
3.2.4	Robust Decentralized Periodic Output Feedback Controller Design via Reduced Order Model for Multimodel System	108
3.3	Controller Design for Smart Structures Modelled Using Timoshenko Theory	118
3.3.1	Design of SISO Controllers for Smart Beams Using Surface Mounted Piezos	118
3.3.2	Design of MIMO Controllers for Smart Beam with Surface Mounted Piezos.....	124
3.3.3	Design of SISO Controllers for Smart Beams Using Embedded Piezos	131
3.3.4	Design of MIMO Controller for Smart Beams Using Embedded Piezos	137
3.4	Conclusions.....	142
4	Fast Output Sampling Feedback Controllers for Smart Structures	145
4.1	A Brief Review of the Fast Output Sampling Feedback Control Technique	145

4.2	Controller Design for Smart Structures Modelled Using EB Theory.....	150
4.2.1	Design of SISO Controllers for Smart Beam Divided into 3, 4, 5 Finite Elements	150
4.2.2	Design of MIMO FOS Controller for a Multivariable System	155
4.2.3	Design of Robust Decentralized Fault Tolerant Controller for Smart Structures	159
4.2.4	Robust Decentralized Fast Output Sampling Feedback Controller Design via Reduced Order Model for Multivariable Systems	170
4.3	Controller Design for Smart Structures Modelled Using Timoshenko Theory	178
4.3.1	Design of SISO Controllers for Smart Beams Using Surface Mounted Piezos	178
4.3.2	Design of MIMO FOS Controller for Smart Beam Using Surface Mounted Piezos	182
4.3.3	Design of SISO Controllers for Smart Beams Using Embedded Piezos	185
4.3.4	Design of MIMO Controller for Smart Beams Using Embedded Piezos	189
4.4	Conclusions	192
5	Discrete Time Sliding Mode Control for Smart Structures ..	195
5.1	Discrete Time Sliding Mode Control with Switching Function ..	195
5.1.1	Controller Design for Euler-Bernoulli Smart Beams as SISO Systems	197
5.1.2	Controller Design for Euler-Bernoulli Smart Beam as MIMO System	202
5.1.3	Controller Design for Timoshenko Smart Beams with Surface Mounted PZT's as SISO Systems	204
5.1.4	Controller Design for Timoshenko Smart Beams with Surface Mounted PZT's as MIMO System	205
5.1.5	Controller Design for Timoshenko Smart Beams with Embedded PZT's for a SISO Case	207
5.1.6	Controller Design for Timoshenko Smart Beam with Embedded PZT's for a MIMO Case.....	208
5.2	Discrete Time Sliding Mode Control Without Switching Function ..	209
5.2.1	Controller Design for Euler-Bernoulli Smart Beams as SISO Systems	212
5.2.2	Controller Design for Euler-Bernoulli Smart Beam as a MIMO System	214
5.2.3	Controller Design for Smart Timoshenko Beam with Surface Mounted PZT's as SISO System	215

5.2.4	Controller Design for Smart Timoshenko Beam with Surface Mounted PZT's for a MIMO Case	215
5.2.5	Controller Design for Smart Timoshenko Beams with Embedded PZT's as SISO Systems	219
5.2.6	Controller Design for the Smart Beam as a Multivariable System with Embedded PZT's	220
5.3	Conclusions	222
6	Implementation of Control Techniques for Smart Structures.	223
6.1	Experimental Set-Up Details	223
6.2	Introduction to the dSPACE 1104 Controller Hardware	226
6.3	System Identification of the Smart Structure	226
6.4	Controller Design and Implementation	230
6.4.1	Controller Design Using Simulations	232
6.4.2	Experimental Evaluation of the Simulated Results	234
6.4.3	Procedural Rules for Observing the OL/CL Responses in the Experiment	236
6.5	Conclusions	238
A	Appendix	241
	References	247
	Index	255