

CONTENTS

PREFACE	iii
PREREQUISITE KNOWLEDGE	xi
SUGGESTED TEACHING SCHEDULE	xiii
SYMBOLS	xiv

1	CURRENT TRENDS FOR ACTUATORS AND MICROMECHANICS	
1.1	The Need for New Actuators	1
1.2	Conventional Methods for Micropositioning	3
1.3	An Overview of Solid-State Actuators	7
1.4	Critical Design Concepts and the Structure of the Text	32
2	A THEORETICAL DESCRIPTION OF FIELD-INDUCED STRAINS	
2.1	Ferroelectricity	37
2.2	Microscopic Origins of Electric Field Induced Strains	48
2.3	Tensor/Matrix Description of Piezoelectricity	50
2.4	Theoretical Description of Ferroelectric and Antiferroelectric Phenomena	62
2.5	Phenomenology of Magnetostriction	80
2.6	Ferroelectric Domain Reorientation	82
2.7	Grain Size and Electric Field-Induced Strain in Ferroelectrics	92
3	ACTUATOR MATERIALS	
3.1	Practical Actuator Materials	103
3.2	Figures of Merit for Piezoelectric Transducers	129
3.3	The Temperature Dependence of the Electrostrictive Strain	138
3.4	Response Speed	143
3.5	Mechanical Properties of Actuators	145
4	CERAMIC ACTUATOR STRUCTURES AND FABRICATION METHODS	
4.1	Fabrication of Ceramics and Single Crystals	169
4.2	Device Design	176
4.3	Electrode Materials	208
4.4	Commercially Available Piezoelectric and Electrostrictive Actuators	213
5	DRIVE / CONTROL TECHNIQUES FOR PIEZOELECTRIC ACTUATORS	
5.1	Classification of Piezoelectric Actuators	219
5.2	Feedback Control	221

5.3	Pulse Drive	241
5.4	Resonance Drive	256
5.5	Sensors and Specialized Components for Micromechatronic Systems	265
6	LOSS MECHANISMS AND HEAT GENERATION	
6.1	Hysteresis and Loss in Piezoelectrics	285
6.2	Heat Generation in Piezoelectrics	310
6.3	Hard and Soft Piezoelectrics	319
7	INTRODUCTION TO THE FINITE ELEMENT METHOD FOR PIEZOELECTRIC STRUCTURES	
7.1	Background Information	329
7.2	Defining the Equations for the Problem	330
7.3	Application of the Finite Element Method	334
8	SERVO DISPLACEMENT TRANSDUCER APPLICATIONS	
8.1	Deformable Mirrors	347
8.2	Microscope Stages	353
8.3	High Precision Linear Displacement Devices	356
8.4	Servo Systems	360
8.5	VCR Head Tracking Actuators	368
8.6	Vibration Suppression and Noise Elimination Systems	371
9	PULSE DRIVE MOTOR APPLICATIONS	
9.1	Imaging System Applications	375
9.2	Inchworm Devices	379
9.3	Dot Matrix Printer Heads	384
9.4	Inkjet Printers	390
9.5	Piezoelectric Relays	396
9.6	Adaptive Suspension Systems	399
10	ULTRASONIC MOTOR APPLICATIONS	
10.1	General Description and Classification of Ultrasonic Motors	403
10.2	Standing Wave Motors	410
10.3	Mixed-Mode Motors	414
10.4	Traveling Wave Motors	417
10.5	Mode Rotation Motors	430
10.6	Performance Comparison Among Various Ultrasonic Motors	433
10.7	Microscale Walking Machines	434
10.8	Calculations for the Speed and Thrust of Ultrasonic Motors	436
10.9	Elements of Designing an Ultrasonic Motor	442
10.10	Other Ultrasonic Motor Applications	449
10.11	Magnetic Motors	453

Contents

ix

10.12 Reliability of Ultrasonic Motors 454

**11 THE FUTURE OF CERAMIC ACTUATORS IN
MICROMECHATRONIC SYSTEMS**

11.1 Development Trends as Viewed from Patent Statistics 463

11.2 The Piezoelectric Actuator/Ultrasonic Motor Market 465

11.3 Future Trends in Actuator Design 468

INDEX

483