Smart Structures

Smart structures and smart structural components have unusual abilities: they can sense a change in temperature, pressure, or strain; diagnose a problem; and initiate an appropriate action to preserve structural integrity while continuing to perform their intended functions. Smart structures can also store processes in memory and learn to repeat the actions taken. Among the varied applications of smart structures are aircraft sensors that warn of impending cracks and medical devices that monitor blood sugar and deliver insulin.

This text provides the basic information needed to analyze and design smart devices and structures. Among topics covered are piezoelectric crystals, shape memory alloys, electrorheological fluids, vibration absorbers, fiber optics, and mistuning. A final chapter offers an intriguing view of biomimetics and design strategies that can be incorporated at the microstructural level, deriving inspiration from biological structures.

The design of smart structures is on the cutting edge of engineering research and development, and there is a great need for an introductory book on the subject. This book will be welcomed by both students and practicing engineers.

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Smart Structures

ANALYSIS AND DESIGN

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Contents

Preface

1 Introduction

1.1 Introduction

1.2 Piezoelectric Properties

1.2.1 Example: Inchworm Linear Motor

1.3 Actuation of Structural Components by Piezoelectric Crystals

1.3.1 Actuator-Structure Interaction

1.3.2 Axial Motion of Rods

1.3.3 Bending of Beams

1.3.3.1 Example: Harmonic Excitation

1.3.3.2 Example: Impulsive Load from a Triangular Patch

1.4 Summary

BIBLIOGRAPHY

PROBLEMS

2 Piezoelectric Materials and Induced-Strain Actuation

2.1 Introduction

2.2 Piezoelectric Properties

2.2.1 Example: Inchworm Linear Motor

2.3 Actuation of Structural Components by Piezoelectric Crystals

2.3.1 Actuator-Structure Interaction

2.3.2 Axial Motion of Rods

2.3.3 Bending of Beams

2.3.3.1 Example: Harmonic Excitation

2.3.3.2 Example: Impulsive Load from a Triangular Patch

2.4 Summary

BIBLIOGRAPHY

PROBLEMS

3 Shape Memory Alloys

3.1 Introduction

3.2 Experimental Phenomenology

3.3 Influence of Stress on the Characteristic Temperatures

3.4 Constitutive Modeling of the Shape Memory Effect

3.4.1 Design Considerations: A Simple Example

3.5 Vibration Control through Shape Memory Alloys

3.6 Multiplexing Embedded NiTiNOL Actuators

3.6.1 Analytical Basis for the Design of Composite Beams

3.6.2 Control Scheme and Test Specimens: Analysis and Design

BIBLIOGRAPHY

PROBLEMS
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

4 Electrorheological and Magnetorheological Fluids 73
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

5 Vibration Absorbers 97
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 Gyrosopic 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
Contents

6 Mistuning 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

7 Fiber Optics 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

8 Control of Structures 157
8.1 Introduction 157
8.2 Structures as Controlled Plants 158
8.2.1 Modeling Structures for Control 158
9 Biomimetics

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 Ceramics: 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

Appendix A Selected Topics from Structural Dynamics 203

Appendix B Selected Topics from Automatic Control 207

Index 223
Preface

Structural design in the traditional context once simply meant a selection of the dimensions of load-bearing components of a structure. Essentially two disciplines, mathematics and materials science, were integrated to obtain a structural design. Mathematics ensured equilibrium of the structure, and materials science provided material properties such as modulus of elasticity, yield stress and ultimate stress. A suitable material was chosen, and the design was considered complete upon establishing a factor of safety and a further check to ensure structural stability using a criterion such as Euler load to prevent buckling. Such an approach was considered adequate as long as the material selection was limited to wood and metals.

Advanced research in materials science resulted in man-made materials, such as plastics and composites. Selection of unusual shapes in the design of structural components and ideas of embedding sensors to monitor complex strain fields then took hold. Furthermore, materials with unusual properties were discovered: properties by which material behavior can be varied depending upon the phase of the material (e.g., shape memory alloys, such as NiTiNOL, whose phases change at critical temperatures), the poling direction (as in piezoelectric materials such as PZT), and the level of electric field (electrorheological fluids). These discoveries have opened up the design space to such an extent that possibilities of designing structures that can not only monitor themselves but also adapt to the environment are now contemplated by the research community.

This is the background that has ushered in an era of research efforts leading to “smartness” in structural design. As funds have become available to pursue research in this area, terminologies have been introduced to define the field of study. Not unexpectedly, a variety of names, such as smart materials, intelligent materials, and adaptive structures, have been proposed.

A certain amount of exaggeration is to be expected when a new field emerges, but to ascribe cognitive abilities to a structure would be, in our opinion, beyond the capabilities that can be integrated into a structural design. Similarly, we wish to emphasize that materials have properties that may be interesting and unusual, but smartness can be
Preface

defined in the context of structures only when materials properties are exploited to serve a design function better than is possible through a conventional structural design.

It is with this conviction that we introduce the concept of a complete structure that can be the basis, in the new millennium, to design structural components. The viewpoint proposed in this book is that functions of sensing, diagnosing, and assessing the health of structures and actuating structures should all be integrated to form the complete structure, and this philosophy forms the basis for developing smart structures. It is important to note that smartness can be inherent in a structure by virtue of the material microstructure or the design itself. For example, a rope is a smart structure because of the hierarchical design in which individual wires are assembled to form a strand and several strands woven into a wide variety of rope architectures. The concept of hierarchy is incorporated into the design and provides the basis for smartness. Rope structures simulate a similar biological structure, tendon, whose architecture is highly hierarchical, with seven levels varying from atomic to microlevels. Thus, one is tempted to examine structural systems in nature that could provide broad guidelines for the structural engineering design of man-made components. Although it is futile to look for engineering analogs in the biological world, certain strategies developed by biological structures through evolution could be helpful in conceiving, designing, developing, manufacturing and testing smart structures.

This book is developed through courses taught first as a graduate seminar at the University of Connecticut in 1994 and 1995 and later as a regular course open to senior undergraduate and graduate students at Worcester Polytechnic Institute in 1996 and 1997. Also, a special week-long course was conducted in June of 1997 at the University of Kassel in Germany covering piezoelectrics, shape memory alloys, gyroscopic vibration absorbers, mistuning and biomimetics. In addition, the organization of the chapters draws upon the authors’ research efforts in the areas of vibration absorption, multiplexing shape memory wires in composites to enhance frequency bandwidth of plate-like structures, fiber optics, mistuning and biomimetics. The example problems chosen are aimed at driving home the principles discussed in the text and provide an opportunity to the student to apply the same in typical engineering structural design situations.

We believe that the time is ripe for innovation by means of which smartness in structures can come about through development of new materials with required properties and new designs that allow integration of multiple functions of sensing, diagnosing, and actuating the structure, leading to vastly enhanced structural integrity. Innovations are therefore needed in a variety of engineering disciplines that cover the functions described above. Analysis procedures that permit modeling at the microstructural level are needed, as are instruments that sense and actuate at the level. Manufacturing processes that allow tailoring structural components from the micro to macro levels are needed. We hope that the topics presented in this text book serve to provide some inspiration to scientists and engineers in academia, government and industry.

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