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Design of Shape Memory Alloy (SMA) Actuators

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This book is dedicated to my parents Raghavendra Rao and Jayashree R. Rao, who have raised me, motivated me, and have guided me through all ups and downs of my life.

Ashwin Rao

This book is dedicated to my parents Ramaswamy and Saroja and to my wife Prabha and children Vishnu and Divya, who sacrificed their time so that I could finish this book.

Arun Srinivasa

This book is dedicated to my baava, Tummala Janardhan Reddy, a constant admirer of the highest evidences of the human spirit, for his friendship and for introducing me to "rational thinking."

J.N. Reddy

Preface

Shape memory alloys have been fascinating to designers, architects, and researchers in the past decade. There is something about the uncanny ability of seemingly inanimate wires suddenly reacting to external nonmechanical stimulus that evokes curiosity and childlike fascination in everyone. However, commercial applications (other than in the medical field) has been slow. Part of the reason is the lack of accessible explanations that allow people with only basic exposure to such materials to carry out designs that are viable.

Too often, papers and books written (many by the authors themselves) about arcane aspects of SMA behavior are not meant for designers. This leads to exasperation from a designer who wants us to "tell me how do I design with this?"

This book seeks to provide an accessible account of SMA behavior together with examples of preliminary design methodology to students with a basic undergraduate background. The aim is to provide an "on ramp" to explore the unique properties of these devices, and so the book only deals with the "bare necessities" and ignores many nuances including important issues of functional fatigue. Rather the design recommendations are based on being conservative and making design decisions that will eliminate the need for considering such issues at the expense of not being optimal. Our philosophy in designing with SMA is "robust, repeatable, guaranteed behavior" over "optimal" response.

This monograph is by no means extensive but just an introduction and an invitation to the readers to explore the behavior of these materials. It grew out of a National Science Foundation Grant to develop "strength of materials-like" approaches to shape memory wires and springs. While the current applications at the cutting edge have moved on to tubes, plates, and so on, the commercial availability of wires and springs for common devices has grown quite a bit and this is what we wish to emphasize.

If a reader gains a qualitative understanding of SMA response together with the ability to do a “first-cut” design by reading this book and is able to go on to explore SMA better, then we have succeeded in achieving our purpose of writing this book.

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Contents

Chapter 1
Introduction to Shape Memory Alloys

1.1 Smart Materials–An Overview

Classical materials like metals and alloys have played a significant role as structural materials for many centuries [1]. Engineers have designed components and selected alloys by employing the classical engineering approach of understanding the macroscopic properties of the material and selecting the appropriate one to match the desired functionality based on the application [2]. With advancements in material science and with increasing space and logistical limitations, scientists have been constantly developing high performing materials for various applications [2]. The everlasting goal for engineers in many cases is to improve product efficiency and reduce its weight without comprising on either its cost or performance. To achieve this goal, replacing multi-component and multi-material systems with fewer multi-functional light weight, high performing materials has been an attractive alternative [2, 3]. Such advanced materials have played a leading role in the development of many engineering innovations and achievements like the Airbus A380, Boeing 787 Dreamliner, reliable fuel efficient cars, superior drug delivery devices, and so on, to list a few. The ingenious commercial products across various engineering disciplines are meeting all requirements by encompassing many of the latest technologies and meeting the challenges of tomorrow's needs.

In pursuit of this, material scientists over the last few decades have focused on the possibility of tailoring the microstructure of the material to generate the required functionality for different applications [2, 4]. Such an effort has resulted in an entire new area of **active or multifunctional materials** that posses more than one desirable property [5, 6]. With the introduction of such materials, researchers are now focusing on how the combined microstructural changes of such materials are able to perform multiple functions. The integration of multiple functions like actuation, sensing, and control into a single structure using one or more material constituent is seen as a possibility [2, 3]. Mamoda in her recent review of future materials discusses some application ideas with such materials like: a smart solar panel that can change its orientation automatically during the day depending on sun's position; a smart shock

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