

Vibration Control of Active Structures
2nd Edition

SOLID MECHANICS AND ITS APPLICATIONS

Volume 96

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Vibration Control of Active Structures

An Introduction

2nd Edition

by

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*” . . . le travail éloigne de nous
trois grands maux:
l’ennui, le vice et le besoin. ”*

Voltaire, *Candide* (XXX)

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Preface to the second edition

My objective in writing this book was to cross the bridge between the structural dynamics and control communities, while providing an overview of the potential of *SMART* materials for sensing and actuating purposes in active vibration control. I wanted to keep it relatively simple and focused on systems which worked. This resulted in the following: (i) I restricted the text to fundamental concepts and left aside most advanced ones (i.e. robust control) whose usefulness had not yet clearly been established for the application at hand. (ii) I promoted the use of collocated actuator/sensor pairs whose potential, I thought, was strongly underestimated by the control community. (iii) I emphasized control laws with guaranteed stability for active damping (the wide-ranging applications of the *IFF* are particularly impressive). (iv) I tried to explain why an accurate prediction of the transmission zeros (usually called anti-resonances by the structural dynamicists) is so important in evaluating the performance of a control system. (v) I emphasized the fact that the open-loop zeros are more difficult to predict than the poles, and that they could be strongly influenced by the model truncation (high frequency dynamics) or by local effects (such as membrane strains in piezoelectric shells), especially for nearly collocated distributed actuator/sensor pairs; this effect alone explains many disappointments in active control systems. The success of the first edition confirmed that this approach was useful and it is with pleasure that I accepted to prepare this second edition in the same spirit as the first one.

The present edition contains three additional chapters: chapter 6 on active isolation where the celebrated “sky-hook” damper is revisited, chapter 12 on semi-active control, including some material on magneto-rheological fluids whose potential seems enormous, and chapter 14 on the control of cable-structures. It is somewhat surprising that this last subject is finding applications for vibration amplitudes which are nine orders of magnitude apart (respectively meters for large cable-stayed bridges and nanometers for precision space structures). Some material has also been added on the modelling of piezoelectric structures (chapter 3) and on the application of distributed sensors in vibroacoustics (chapter 13).

I am deeply indebted to my coworkers, particularly Younes Achkire and Frédéric Bossens for the cable-structures, Vincent Piefort for the modelling of piezoelectric structures, Pierre De Man and Arnaud François in vibroacoustics, Ahmed Abu Hanieh and Mihăiță Horodincă in active isolation and, last but not least, Nicolas Loix and Jean-Philippe Verschueren who run with enthusiasm and competence our spin-off company, *Micromega Dynamics*. I greatly

enjoyed working with them, exploring not only the concepts and the modelling techniques, but also the technology to make these control systems work. I also express my thanks to David de Salle who did all the editing, and to the Series Editor, Prof. Graham Gladwell who, once again, improved my English.

André Preumont
Brussels, November 2001.

Preface to the first edition

I was introduced to structural control by Raphaël Haftka and Bill Hallauer during a one year stay at the Aerospace and Ocean Engineering department of Virginia Tech., during the academic year 1985-1986. At that time, there was a tremendous interest in large space structures in the USA, mainly because of the Strategic Defense Initiative and the space station program. Most of the work was theoretical or numerical, but Bill Hallauer was one of the few experimentalists trying to implement control systems which worked on actual structures. When I returned to Belgium, I was appointed at the chair of Mechanical Engineering and Robotics at *ULB*, and I decided to start some basic vibration control experiments on my own. A little later, *SMART* materials became widely available and offered completely new possibilities, particularly for precision structures, but also brought new difficulties due to the strong coupling in their constitutive equations, which requires a complete reformulation of the classical modelling techniques such as finite elements. We started in this new field with the support of the national and regional governments, the European Space Agency, and some bilateral collaborations with European aerospace companies. Our *Active Structures Laboratory* was inaugurated in October 1995.

In recent years, with the downsizing of the space programs, active structures seem to have lost some momentum for space applications, but they gave birth to interesting spin-offs in various fields of engineering, including the car industry, machine tools, consumer products, and even civil engineering. I believe that the field of *SMART* materials is still in its infancy; significant improvements can be expected in the next few years, that will dramatically improve their recoverable strain and their load carrying capability.

This book is the outgrowth of research work carried out at *ULB* and lecture notes for courses given at the Universities of Brussels and Liège. I take this opportunity to thank all my coworkers who took part in this research, particularly Jean-Paul Dufour, Christian Malekian, Nicolas Loix, Younes Achkire, Paul Alexandre and Pierre De Man; I greatly enjoyed working with them along the years, and their enthusiasm and creativity have been a constant stimulus in my work. I particularly thank Pierre who made almost all the figures.

Finally, I want to thank the Series Editor, Prof. Graham Gladwell who, as he did for my previous book, read the manuscript and corrected many mistakes in my English. His comments have helped to improve the text.

André Preumont
Bruxelles, July 1996.