Advances in Industrial Control

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Smart Helicopter Rotors

Optimization and Piezoelectric Vibration Control

Springer

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ISSN 1430-9491 ISSN 2193-1577 (electronic)
Advances in Industrial Control
ISBN 978-3-319-24766-3 ISBN 978-3-319-24768-7 (eBook)
DOI 10.1007/978-3-319-24768-7

Library of Congress Control Number: 2015951797

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Series Editors' Foreword

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. New theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies…, new challenges. Much of this development work resides in industrial reports, feasibility study papers, and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

Occasionally, the *Advances in Industrial Control* monograph series has the opportunity to publish a highly focused technical monograph on an emerging technology for a specialist domain of application. This is the case with this monograph *Smart Helicopter Rotors: Optimization and Piezoelectric Vibration Control* by R. Ganguli, D. Thakkar, and S.R. Viswamurthy. One of the many fascinations of such a monograph is to see how researchers develop and evolve a new applications paradigm. A considerable strength of this particular monograph is that the chapters have a strong narrative thread. The chapters begin from basic configurations and as the chapters proceed, build more and more realistic constructional and operational features and constraints. Essentially the chapters are studies of the rotor vibration reduction potential for different rotor and actuator configurations. The results use application and laboratory test data in determining parameters to ensure the reasonable applications validity of the results presented. These are the initial studies of possible new routes to control the vibrations that occur in helicopter rotors with the objectives of increased safety, stability, and ride comfort. The technology uses smart piezoelectric materials to give control of "better" rotor shape.

The book has a classical monograph format, with Chap. 1 presenting a detailed technical literature review of the nine topics that comprise the constituent subjects for the subsequent chapters of the monograph. This introductory chapter concludes with a short section describing the monograph's organization. Chapter 2 is about modeling that describes the context and definitions of many of the terms used in this helicopter application. The remaining chapters of the monograph is then divided into two sets. Chapters 3–6 treat rotor vibration control using active flap actuators and Chaps. 7–11 treat rotor vibration control using rotor twisting delivered by piezoelectric actuation. References are collected together in one section at the end of the monograph along with four technical appendices. The chapters of the monograph are very strongly focused on these two particular helicopter rotor developments and the chapter sequence follows an agenda of increasing applications realism. This has pedagogical value for understanding how to research and develop novel and new ideas for specific control applications. Helicopter rotors may seem to be a narrow domain but it is an important one, and the research reported here may have implications for other rotor applications, for example, the blades of wind turbine rotors.

The use of smart materials and piezoelectric materials in control applications has received some exposure in the *Advances in Industrial Control* monograph series and readers might find the following two monographs to provide insight into related fields:

- *Design, Modelling and Control of Nanopositioning Systems* by Andrew J. Fleming and Kam K. Leang (ISBN 978-3-319-06616-5, 2014); and
- *Advanced Control of Piezoelectric Micro-/Nano-Positioning Systems* by Qingsong Xu and Kok Kiong Tan (ISBN 978-3-319-21622-5, 2016).

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Preface

Helicopters are susceptible to high vibration levels. The development of smart-material based piezoelectric actuators has made it possible to address this high vibration problem directly by developing a smart helicopter rotor. The basic idea of the smart rotor concept is to generate new unsteady aerodynamic forces and moments on the rotor blade which cancel the existing forces and moments which are the key sources of helicopter vibration. By appropriately actuating the piezoelectric materials using an electric field, the motion of the rotor blade can be actively controlled. The smart rotor development is multidisciplinary and requires knowledge of structural dynamics, aeroelasticity, helicopter dynamics, control theory, and piezoelectric materials. In this book, the concepts of active trailing edge flap and active twist rotor blade are investigated for the helicopter vibration reduction problem. These are the two most promising concepts for the development of smart rotor. The active trailing edge flaps are placed near the tip of the rotor blades and actuated at higher harmonics of the main rotor speed. In the active twist concept, the full blade is twisted at higher harmonics of the main rotor speed.

Fundamental issues in the trailing edge flap problem include (*a*) the optimal number of flaps, (*b*) placement of the flaps along the rotor blade, and (*c*) optimal controller design for helicopter vibration and flap deflection objective. Typically, the active flap rotor is actuated by a piezostack actuator. Such an actuator can lead to hysteresis which can cause poor performance of the controller. In this book, we present a novel hysteresis compensation algorithm to alleviate this problem. Another problem in the trailing edge flap concept is the ability to use multiple trailing edge flaps effectively. This book presents a controller algorithm to maximize the potential of multiple trailing edge flaps and a response surface-based optimization method to place such trailing edge flaps for best vibration reduction performance at least flap power. An optimization study, which shows that dual trailing edge flaps are best for vibration reduction, is also discussed. Multi-objective optimization is used and the pareto front for the flap design problem is studied.

The book also showcases the concept of using piezoceramic-induced shear actuation for the active twist rotor concept. Active twist is investigated for a rotating beam, a box-beam blade and an airfoil cross-section blade. Single-crystal piezoceramics are considered. It is also shown that nonlinearity of piezoceramic shear coefficient with respect to the applied electric field can be used to extract more actuation out of the material. A velocity feedback controller is implemented and found to be suitable for vibration control using active twist. Finally, it is shown that dynamic stall-induced vibration can be actively controlled using active twist rotor. As smart material concepts develop, the active twist concept becomes useful for reducing helicopter vibration and suppressing dynamic stall.

This book will help researchers who are engaged in the development of active vibration control methods for helicopter rotors. It is also useful for researchers and engineers in the fields of smart structures, aerospace and mechanical engineering, control theory, applied mathematics, material science, and optimization. Most of the concepts are useful in all applications of rotating systems such as wind turbines, turbomachinery, and propellers. The authors are grateful to the Rotary Wing Research and Development Centre, Hindustan Aeronautics Limited, for supporting much of this work through a sponsored research project.

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The authors are an experienced and authoritative team in this field.

Professor Ranjan Ganguli is with the Department of Aerospace Engineering at the Indian Institute of Science, Bangalore, India. He was made Professor in his Department in 2009 and has had a long involvement with helicopter research since at least 1991.

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