

Modeling and Advanced Control for Process Industries

Applications to Paper Making Processes

Other titles published in this Series:

Parallel Processing for Jet Engine Control

Haydn A. Thompson

Iterative Learning Control for Deterministic Systems

Kevin L. Moore

Parallel Processing in Digital Control

D. Fabian Garcia Nocetti and Peter J. Fleming

Intelligent Seam Tracking for Robotic Welding

Nitin Nayak and Asok Ray

*Identification of Multivariable Industrial Processes for Simulation,
Diagnosis and Control*

Yucai Zhu and Ton Backx

Nonlinear Process Control: Applications of Generic Model Control

Edited by Peter L. Lee

*Microcomputer-Based Adaptive Control Applied to Thyristor-Driven
D-C Motors*

Ulrich Keuchel and Richard M. Stephan

Expert Aided Control System Design

Colin Tebbutt

Ming Rao, Qijun Xia and Yiqun Ying

Modeling and Advanced Control for Process Industries

Applications to Paper Making Processes

With 115 Figures



Springer-Verlag

London Berlin Heidelberg New York

Paris Tokyo Hong Kong

Barcelona Budapest

Ming Rao, PhD
Qijun Xia, PhD, MSc, BSc
Yiqun Ying, MSc, BSc
Department of Chemical Engineering
University of Alberta
536 Chemical-Mineral Engineering Building
Edmonton, Canada T6G 2G6

ISBN-13: 978-1-4471-2096-4
DOI: 10.1007/978-1-4471-2094-0

e-ISBN-13: 978-1-4471-2094-0

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

© Springer-Verlag London Limited 1994
Softcover reprint of the hardcover 1st edition 1994

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

69/3830-543210 Printed on acid-free paper

PREFACE

The paper machine is a very important part of pulp and paper manufacturing processes. Process modeling and control play key roles in the paper machine operation. Due to the complexity of the process operation and the requirements of high quality product, low cost production, safety and environment protection, more and more pulp and paper companies are looking for advanced control technology to improve their process operation.

This book reports our research results on the modeling and advanced control for paper machines. Both theoretic fundamentals and industrial applications are presented. This is a book in which all the advanced technologies in modeling and control discussed are focused on applications to paper machines. The book is organized as follows: Chapter 1 gives a brief introduction to paper making process fundamentals and an overview of paper machine control. Various process dynamics analysis and modeling techniques are discussed in detail in Chapter 2. Based on the characteristics of paper machine operation, some typical advanced control strategies, such as robust control (Chapter 3), predictive control (Chapter 4), bilinear control (Chapter 5), fault-tolerant control (Chapter 6) and their design and implementation techniques as well as real industrial applications are presented. Since model-based control systems cannot handle the ill-formulated problems involved in paper machines, fuzzy control (Chapter 7), expert systems (Chapter 8), artificial neural networks (Chapter 9) and intelligent on-line monitoring and control systems (Chapter 10) are then introduced. Their applications to process control, control system design, process modeling and product quality prediction, and on-line monitoring and control for paper and pulp processes are also presented. It should be pointed out that not all the control technologies applied to paper machines have been covered in this book. Some important applications, such as cross-machine direction (CD) control, are not included.

This book is designed as a reference book for engineers and research scientists who work on process control, especially in the pulp and paper industry. It can also be used as a textbook for graduate student courses on process modeling and advanced process control in universities.

We hope that this book will help to narrow the gap between academic research and industry application, and to reduce the barriers that exist in applying advanced control technologies to real industrial processes.

SERIES EDITOR'S FOREWORD

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology impacts all areas of the control discipline. New theory, controllers, actuators, sensors, new industrial processes, computing methods, applications, 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.

It is always valuable to welcome to the Series a text which deals with the control problems of one individual sector. Dr Rao and his colleagues have developed an Intelligent Online Monitoring and Control System (IOMCS) for pulp and paper making process control applications. In this volume, the background research and the development path for the IOMCS is presented. It is a route which takes in process model developments, advanced control methods and methods like fuzzy control before arriving at the integrated construction of the IOMCS. The whole development is underpinned by the technological framework of a plant-wide distributed control system. For this reason, the concept of an IOMCS has a wider applicability to general process control engineering. We hope the volume will be read with interest by this broader audience of control, manufacturing, process and even production engineers.

M. J. Grimble and M. A. Johnson
*Industrial Control Centre,
University of Strathclyde,
Scotland, U.K.*

Professor M.J. Grimbale and Dr M.A. Johnson, editors of the *Advances in Industrial Control Series*, provided us with very important suggestions and assistance in preparing this book.

Professor Y. Sun and Professor C. Zhou of Zhejiang University gave us the valuable suggestions, allowed us to use the research results from their Institute. We gratefully acknowledge Dr P. Li and Dr Q.G. Wang for their important contributions to Chapter 3 and Chapter 7. Professor H. Qiu, Professor L. Peng and Dr X. Shen helped us by reviewing the manuscript, and providing many useful comments for improvement of the book. Graduate students, H. Fazadeh, J. Sun and J. Zurcher and Dr Q. Wang provided technical support to the content of this book. We would like to express our appreciation for their help and contributions.

We also gratefully acknowledge the financial and technical support of the Natural Sciences and Engineering Research Council of Canada, Canadian Pulp and Paper Association, Weyerhaeuser Canada Grande Prairie Operations, Slave Lake Pulp Corporation, DMI Peace River Pulp Division, MoDo Chemetics, Perde Enterprise, and Canada Alberta Partnership on Forestry.

Ming Rao
Qijun Xia
Yiqun Ying
Edmonton, Canada
October 31, 1993

TABLE OF CONTENTS

1 Background	1
1.1 Paper Making: Process Fundamentals	1
1.2 Paper Machine Control Problems	5
1.3 References	14
2 Process Dynamics and Modeling	17
2.1 Introduction	17
2.2 Pressurized Headboxes	19
2.3 Open Headbox	30
2.4 Wire and Press	35
2.5 Drying Section	39
2.6 Model Accuracy Test and Conclusions	49
2.7 References	51
3 Robust Control	53
3.1 Introduction	53
3.2 Multi-model Robust Control	54
3.3 Conclusions	68
3.4 References	69
4 Predictive Control	71
4.1 Adaptive Fading Kalman Filter	71
4.2 Adaptive Predictive Control	88
4.3 Model Algorithmic Control	102
4.4 Conclusions	118
4.5 References	119
5 Bilinear Control	123
5.1 Introduction	123
5.2 Bilinear Decoupling Control	125
5.3 Bilinear State Observers	136
5.4 Bilinear Suboptimal Control	146
5.5 Conclusions	153
5.6 References	154

6 Fault-Tolerant Control	157
6.1 Introduction	157
6.2 Fault-tolerant Control of Headboxes	159
6.3 Fault-tolerant Control of Drying Section	174
6.4 Conclusions	188
6.5 References	189
7 Fuzzy Control	193
7.1 Fuzzy Optimal Control	193
7.2 Fuzzy-Precise Combined Control	201
7.3 Conclusions	211
7.4 References	213
8 Expert Systems	215
8.1 Introduction to Expert Systems	216
8.2 IDIS for Process Control System Design	221
8.3 Application to Headbox Control System Design	233
8.4 Conclusions	242
8.5 References	243
9 Modeling via Artificial Neural Network	245
9.1 Introduction	245
9.2 Fundamentals of Artificial Neural Network	248
9.3 Backpropagation Learning Paradigm	251
9.4 Application to Paper Machine	254
9.5 Conclusions	262
9.6 References	262
10 IOMCS for Pulp and Paper Processes	265
10.1 Introduction	266
10.2 System design and implementation	267
10.3 Conclusions	288
10.4 References	290
Index	293

EDITORIAL BOARD

Professor Dr -Ing J. Ackermann
DLR Institut für Robotik und
Systemdynamik
Postfach 1116
D-82230 Weßling
Germany

Professor I. D. Landau
Le Directeur
Laboratoire d'Automatique de
Grenoble
ENSIEG, BP 46
38402 Saint Martin d'Heres
France

Dr D. C. McFarlane
BHP Research
Melbourne Research Laboratories
245-273 Wellington Road
Mulgrave
Victoria 3170
Australia

Professor B. Wittenmark
Department of Automatic Control
Lund Institute of Technology
PO Box 118
S-221 00 Lund
Sweden

Dr D. W. Clarke, MA., D.Phil,
CEng, FIEE
Reader in Information
Engineering
Department of Engineering
Science
University of Oxford
Parks Road
Oxford, OX1 3PJ
U.K.

Professor H. Kimura
Professor of Control Engineering
Department of Mechanical
Engineering for Computer
Controlled Machinery
Faculty of Engineering
Osaka University
2-1 Yamadaoka
Suita
Osaka 565
Japan

Professor A. J. Laub
Professor and Chairman
Department of Electrical and
Computer Engineering
University of California
Santa Barbara
California 93106
U.S.A.

Professor J. B. Moore
Department of Systems
Engineering
The Australian National
University
Research School of Physical
Sciences
GPO Box 4
Canberra
ACT 2601
Australia

Professor Dr -Ing M. Thoma
Institut Für Regelungstechnik
Universität Hannover
Appelstrasse 11
D-30167 Hanover 1
Germany