Mechanical Engineering Series

Frederick F. Ling
Editor-in-Chief

Mechanical Engineering Series

R. Firoozian, **Servo Motors and Industrial Control Theory**
G. Genta, **Vibration Dynamics and Control**
G. Genta and L. Morello, **The Automotive Chassis, Volumes 1 & 2**
F. A. Leckie and D. J. Dal Bello, **Strength and Stiffness of Engineering Systems**
Wodek Gawronski, **Modeling and Control of Antennas and Telescopes**
Makoto Ohsaki and KiyohiroIkeda, **Stability and Optimization of Structures: Generalized Sensitivity Analysis**
A.C. Fischer-Cripps, **Introduction to Contact Mechanics, 2nd ed.**
W. Cheng and I. Finnie, **Residual Stress Measurement and the Slitting Method**
J. Angeles, **Fundamentals of Robotic Mechanical Systems: Theory, Methods and Algorithms, 3rd ed.**
J. Angeles, **Fundamentals of Robotic Mechanical Systems: Theory, Methods, and Algorithms, 2nd ed.**
P. Basu, C. Kefa, and L. Jestin, **Boilers and Burners: Design and Theory**
J.M. Berthelot, **Composite Materials: Mechanical Behavior and Structural Analysis**
I.J. Busch-Vishniac, **Electromechanical Sensors and Actuators**
J. Chakrabarty, **Applied Plasticity**
K.K. Choi and N.H. Kim, **Structural Sensitivity Analysis and Optimization 1: Linear Systems**
K.K. Choi and N.H. Kim, **Structural Sensitivity Analysis and Optimization 2: Nonlinear Systems and Applications**
G. Chryssolouris, **Laser Machining: Theory and Practice**
V.N. Constantinescu, **Laminar Viscous Flow**
G.A. Costello, **Theory of Wire Rope, 2nd ed.**
K. Czolczynski, **Rotordynamics of Gas-Lubricated Journal Bearing Systems**
M.S. Darlow, **Balancing of High-Speed Machinery**
W. R. DeVries, **Analysis of Material Removal Processes**
J.F. Doyle, **Nonlinear Analysis of Thin-Walled Structures: Statics, Dynamics, and Stability**
J.F. Doyle, **Wave Propagation in Structures: Spectral Analysis Using Fast Discrete Fourier Transforms, 2nd Edition**
P.A. Engel, **Structural Analysis of Printed Circuit Board Systems**
A.C. Fischer-Cripps, **Introduction to Contact Mechanics**
A.C. Fischer-Cripps, **Nanoindentation, 2nd ed.**
J. García de Jalón and E. Bayo, **Kinematic and Dynamic Simulation of Multibody Systems: The Real-Time Challenge**
W.K. Gawronski, **Advanced Structural Dynamics and Active Control of Structures**
W.K. Gawronski, **Dynamics and Control of Structures: A Modal Approach**
G. Genta, **Dynamics of Rotating Systems**

(*continued after index*)

Riazollah Firoozian

Servo Motors and Industrial Control Theory

Springer

Riazollah Firoozian
Firoozian Electronics
and Electro-Technique Co
Tehran, Iran
riazollah@yahoo.com

ISSN 0941-5122
ISBN 978-0-387-85458-8 e-ISBN 978-0-387-85460-1
DOI 10.1007/978-0-387-85460-1

Library of Congress Control Number: 2008933316

Printed on acid-free paper

springer.com

Mechanical Engineering Series

Frederick F. Ling
Editor-in-Chief

The Mechanical Engineering Series features graduate texts and research monographs to address the need for information in contemporary mechanical engineering, including areas of concentration of applied mechanics, biomechanics, computational mechanics, dynamical systems and control, energetics, mechanics of materials, processing, production systems, thermal science, and tribology.

Series Preface

Mechanical engineering, and engineering discipline born of the needs of the industrial revolution, is once again asked to do its substantial share in the call for industrial renewal. The general call is urgent as we face profound issues of productivity and competitiveness that require engineering solutions, among others. The Mechanical Engineering Series is a series featuring graduate texts and research monographs intended to address the need for information in contemporary areas of mechanical engineering.

The series is conceived as a comprehensive one that covers a broad range of concentrations important to mechanical engineering graduate education and research. We are fortunate to have a distinguished roster of series editors, each an expert in one of the areas of concentration. The names of the series editors are listed on page v of this volume. The areas of concentration are applied mechanics, biomechanics, computational mechanics, dynamic systems and control, energetics, mechanics of materials, processing, thermal science, and tribology.

Preface

In recent years, there has been an increased activity in the field of automation, as manufacturers demand increased performance requirements from servo feed drive control systems and acceleration input. The selection of a servo system has become a technology of its own right. This book investigates the performance, characteristics, and design of various types of servo control systems, including electrical, DC, AC, Stepping, and Electrohydraulic servo motors. It is hoped that the topics discussed in this book will help designers achieve optimum performance for the required applications.

When designing servo control systems, several key parameters must be considered, including the effect of input signal (such as steady state error), the following error, and the effect of disturbance (such as external load). Several parameters will be introduced for each servo control system discussed in the book, so that the designer can easily compare several servo control systems.

A chapter is dedicated to Electro-rheological fluid-based servo control systems. These fluids have become commercially available and several parameters have been established for designing such systems, which are discussed in this book. Electro-rheological fluids are fluids that become solids when a voltage is placed across two plates with the gap of 0.5 to 1 mm. In this form, they can be used as valves, clutches, and catches. The design parameters for clutches and torque control are discussed.

The types of servo motors available in the market for high performance applications can be classified in two versions: electric and hydraulic. In the hydraulic category, the performance of the axial motor is considered. These motors are controlled with electrohydraulic servo valve. In the electric category, stepping, AC, and DC motors are discussed. For the stepping motors, the hybrid design is most suitable for high performance applications. These motors are controlled by transistor controlled switching devices.

In the DC motors' category, normal design, brushless, and moving coil motors will be discussed, as well as the four versions of controllers: Thyristor controlled with current frequencies of 50, 100, and 150 Hz, and the Pulse Width Modulated drive system, which has superior performance.

There has been an increase in the development of high power transistors and thyristors, thereby offering a method of controlling high current. Electric motors now can compete with electrohydraulic servo motors, which still have a wide range of applications, specifically in mining and heavy equipments, due to their high power to mass ratios. AC motors are still the first choice for constant speeds. DC motors, now at small to medium power requirements, are available for speed and position control. The invention of invertors allow AC motors to compete with DC motors.

As it was discussed earlier, the choice of a servo motor feed-drive for a specific application requires careful investigation at the design stage. This book analyzes the performance of each type of servo motor and establishes models of different complexity. For each type of velocity, feedback, and lead-lag network will be studied with the view of practical difficulties.

The mathematical model for all servo motors is similar and certain parameters will influence the design. This is discussed in detail for each type of servo motor. The mathematical model for a simple system will be considered first, however, as the required performance increases, the complexity of the mathematical model also increases, and computer programs are, therefore, developed for each type of servo system.

The root locus method will be considered for each servo motor with various mathematical complexities. The governing differential equations are then solved for step, velocity, and acceleration input. In this way, the steady state and following error will be calculated. The effect of disturbance such as external torque will also be calculated. In this way, various servo motors can be compared.

The first and second chapters of this book are dedicated to the modern control theory relevant to servo motors, so that prior knowledge of control theory is not required for understanding the book. Only feedback and state variable feedback control theory techniques are discussed. For digital control, the reader is referred to the relevant digital control books. Due to the widespread use of personal computers and software which makes detailed calculations simple, tedious graphical methods have been omitted.

The third chapter is dedicated to multivariable control theory. Servo control systems are inherently two input variable control systems, that is, input signal and external torque/force input. Chapter 4 is dedicated to electrical DC servo motors. The application of state variable feedback control strategy to high performance servo motors are discussed in detail in this chapter.

In Chapter 5, the characteristic behavior of stepping motors are investigated. In Chapter 6, the properties of AC motors controlled by variable frequency converters are discussed. The dynamic and static behavior of electrohydraulic servo motors are discussed in Chapter 7. The applications of Electrorheological fluids to servo motor applications are discussed in Chapter 8, while Chapter 9 gives a comparison of various types of servo motors and a design strategy for selecting a servo motor is discussed.

This book is the result of PhD work undertaken by the author at the University of Aston in Birmingham and several years of research and teaching work at the University of Liverpool and The University of Sheffield, UK, and Sharif University of Technology, Iran. This book is meant to serve as a practical guide for students or engineers, and includes an appendix with appropriate problems.

Tehran Riazollah Firoozian

Contents