FUNDAMENTALS OF FLUID POWER CONTROL

This exciting new reference text is concerned with fluid power control. It is an ideal reference for the practicing engineer and a textbook for advanced courses in fluid power control. In applications in which large forces and/or torques are required, often with a fast response time, oil-hydraulic control systems are essential. They excel in environmentally difficult applications because the drive part can be designed with no electrical components, and they almost always have a more competitive power–weight ratio than electrically actuated systems. Fluid power systems have the capability to control several parameters, such as pressure, speed, and position, to a high degree of accuracy at high power levels. In practice, there are many exciting challenges facing the fluid power engineer, who now must have a broad skill set.

John Watton entered industry in 1960 working on the design of heat exchangers. He then studied Mechanical Engineering at Cardiff University, obtaining his BSc degree followed by his PhD degree. In 1969, he returned to industry as a Senior Systems Engineer working on the electrohydraulic control of guided pipe-laying machines. Following a period at Huddersfield University, he returned to Cardiff University in 1979 and was appointed Professor of Fluid Power in 1996, receiving his DSc degree in the same year. He was awarded the Institution of Mechanical Engineers Bramah Medal in 1999 and a special award from the Japan Fluid Power Society in 2005, both for outstanding research contributions to fluid power.

Professor Watton has been continually active as a researcher and consultant with industry in the past 40 years. He has worked on components and systems design, manufacturing plant monitoring, and the design of new mobile machines, and he has acted as an Expert Witness on a variety of fluid power issues. He is a Chartered Engineer, a Fellow of the Institution of Mechanical Engineers, and was elected a Fellow of the Royal Academy of Engineering in 2007.

Fundamentals of Fluid Power Control

John Watton, DSc FREng
Cardiff University, School of Engineering

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo

Cambridge University Press
32 Avenue of the Americas, New York, NY 10013-2473, USA

www.cambridge.org
Information on this title: www.cambridge.org/9780521762502

First published 2009

Printed in the United States of America

A catalog record for this publication is available from the British Library.

Library of Congress Cataloging in Publication data

Watton, J., 1944–
Fundamentals of fluid power control / John Watton.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-521-76250-2 (hardback)
1. Fluid power technology. 2. Hydraulic control. 3. Component analysis. I. Title.
TJ843.W383 2009
629.8′042 – dc22 2008054781

ISBN 978-0-521-76250-2 Hardback

Contents

Cambridge University Press
978-0-521-76250-2 - Fundamentals of Fluid Power Control
John Watton
Frontmatter
More information

Preface

This book is aimed at undergraduate students as a second-year and beyond entry stage to fluid power. There is much material that will also appeal to technicians regarding the background to fluid power and the operation of components and systems. Fluid power is often considered a specialist subject but should not be so given that the same would not be said for electrical power. In fact, there are many applications for which fluid power control is the only possibility because of force/torque/power/environmental demands. In the past 20 years, a number of groups around the world have made significant steps forward in both the understanding and the application of theory and control, complementing the R&D activity undertaken within the manufacturing industry. Details of just one organization involving many participating fluid power centers around the world are available at www.fluid.power.net. I embarked on this book ostensibly as a replacement for my first book, *Fluid Power Systems – Modelling, Simulation, Analog and Microcomputer Control*, published by Prentice-Hall in 1989 and now out of print. However, the result is a much different book and perhaps not surprising, given the developments in fluid power in the past 20 years. Following many constructive comments by undergraduate students, friends in industry, and academic friends who still use my first book for teaching, it was clear that a new book was needed. It was felt that a new book should integrate far more fundamental background theory with its application to real components and systems, but without the book becoming research orientated; this is the intention. Validation of theory has been significantly aided by advances in computer modeling of fluid mechanics and system dynamic issues, together with advances in sensors and instrumentation for experimental validation of component and systems performance. These aspects are introduced where appropriate.

Chapter 1 introduces fluid power, indicating its need, circuit symbols, various standard circuits, and associated components. Practical examples of fluid power control are given with the intention of conveying the power-level breadth and application breadth of the subject, varying from precision micrometer position control to primary processing of materials and products. Some common circuit components are presented with their operating concepts, and a further reading list includes textbooks and related industrial literature.

Chapter 2 introduces fluid physical properties for different applications that now must seriously begin to consider the use of less mineral-oil content as both supply and environmental issues begin to dominate many new applications. Fluid bulk modulus issues are presented in some detail, particularly for flexible-hose applications for which its reduction can be dramatic. Fluid cleanliness is also introduced, as is the importance of understanding the effects of cavitation conditions on material erosion. Electrorheological and magnetorheological fluids are now emerging in fluid power applications following many years of awareness, and this is presented for a student racing car suspension real-time control application. A further reading list is included.

Chapter 3 is the first substantial chapter; it discusses the steady-state characteristics of circuit components. It begins with essentials of fluid flow theory and moves on to applications involving restrictors, control gaps, and leakage gaps used in components. Unique solutions are presented where appropriate, with practical data and supporting computation fluid dynamics simulations introduced for the first time. A section on flow-reaction forces is essential and considered in some detail. Developments in servovalves are also briefly discussed and their characteristics analyzed. Positive-displacement pumps and motors are discussed with respect to generic losses and supported by measurements, particularly with respect to efficiency. A section on servovalve behavior is included, together with other control valves and accumulators commonly used in circuits. Finally, the concept of design of experiments is introduced to aid experimental testing to determine performance characteristics. Many worked examples are also included, together with a further reading list.

Chapter 4 is concerned with the steady-state performance of drive systems; it discusses the interconnection of valves, servovalves, pumps, and motors in a variety of configurations. The relatively unknown theory of power transfer units for aircraft applications is discussed and compared with practice in a qualitative sense. This chapter covers graphical and explicit design approaches to understanding steady-state behavior. Several worked examples are also included as well as a further reading list.

Chapter 5, the second substantial chapter, is concerned with system dynamics – that is, time-varying behavior. The philosophy of this chapter is to derive the basic mass flow and force–torque continuity equations, integrate them into typical components and circuits, and then consider solutions to determine the dynamic response of common components and circuits. Linear differential equations are considered, together with frequency response and transfer function concepts. The concept of linearizing equations is introduced to aid analysis when components have nonlinear pressure–flow characteristics such as servovalves. Transmission-line effects are covered in some detail with practical validation. State-space analysis is introduced as a basis for control-theory developments in the next chapter. Finally, an overview of data-based modeling is considered as a means of growing importance when considering the determination of a dynamic model with some knowledge of its probable form. Various methods are introduced, such as the group method of data handling, artificial neural networks, and time-series modeling, with practical validation. Many additional worked examples are also included, together with a further reading list.

Chapter 6 is concerned with controlling fluid power systems and therefore calls on the work of previous chapters. The third substantial chapter, it brings together basic background theory for closed-loop stability, digital control, closed-loop response improvement, and feedback control implementation. The concepts are applied to typical circuits, including the effect of long lines. State feedback is developed for both analog and digital feedback control and extended to include state estimation for state control and linear quadratic control. Again, many examples and additional worked examples are included. On–off switching of valves is then considered as an alternative to conventional control techniques because this is gaining popularity, particularly for high-water-content fluid applications. This part of the chapter is dominated by the practical aspect, but real application results are shown. Finally, an introduction to fuzzy-logic and neural network control is added to whet the appetite for these relatively new approaches for hydraulic systems control. Developing these aspects further is beyond the scope of this book, although some practical results are shown to allow the reader to obtain a feel for the approaches used. Again, a further reading list is included.

Chapter 7 is the final substantial chapter; it consists of just five of the many advanced studies undertaken by me, colleagues, and undergraduate students who have worked with me on a range of applications. The idea here is to develop existing concepts presented in the previous chapters, not to present a collection of research papers but to show a continuing thread of what usually happens in practice. Hence, many aspects of each study are not included but may be taken further from the references given. The first study is concerned with extending hydrostatic pump slipper theory to the case in which the slipper has a groove, rotation, and tilt, the last giving rise to hydrodynamic effects. The second study is concerned with modeling and real control of a forging press cylinder, including both proportional and switched valve systems. The third study is concerned with the modeling and control of a real vehicle wheel active suspension and includes model identification, control by computer simulation, and practical computer control. The fourth study is concerned with the performance of a commercially used car power-steering unit and, in particular, the crucial performance of the power-steering valve. The fifth study is concerned with progress toward intelligent monitoring of pump cylinder pressures using onboard electronics. These five studies embrace theory and practice with practical data to show the effectiveness and limitations of the approaches taken.

John Watton
jwatton@fluidpowerconsultants.com
Llandaff, Cardiff, July 2008