Fluid Power with Applications

Fifth Edition

Anthony Esposito

Professor Emeritus
Department of Manufacturing Engineering
Miami University
Oxford, Ohio

PRENTICE HALL
Upper Saddle River, New Jersey   Columbus, Ohio

Fluid Power with Applications

Fifth Edition

Anthony Esposito

Professor Emeritus
Department of Manufacturing Engineering
Miami University
Oxford, Ohio

PRENTICE HALL
Upper Saddle River, New Jersey   Columbus, Ohio

Library of Congress Cataloging-in-Publication Data
Esposito, Anthony
Fluid power with applications/Anthony Esposito.—5th ed.
p. cm.
ISBN 0-13-010225-3
1. Fluid power technology. I. Title.
TJ843.E86 2000
620. 1′06—dc21 99-26191
CIP

Cover illustration reprinted with permission of Festo Corporation.
Editor: Stephen Helba
Production Editor: Louise N. Sette
Production Supervision: York Production Services
Design Coordinator: Karrie M. Converse-Jones
Cover Designer: Dan Eckel
Production Manager: Deidra M. Schwartz
Marketing Manager: Chris Bracken

This book was set in Times Roman by York Graphic Services, Inc. and was printed and bound by R.R. Donnelley & Sons Company. The cover was printed by Phoenix Color Corp.

© 2000, 1997, 1994, 1988, 1980 by Prentice-Hall, Inc.
Pearson Education
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN: 0-13-010225-3

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall of Canada, Inc., *Toronto*
Prentice-Hall Hispanoamericana, S. A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Prentice-Hall (Singapore) Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

To my wife, Mary,
and to my grandchildren:
Carly, Chelsea, Kevin, Bryan, and Drew

Preface

INTRODUCTION

The primary purpose of the fifth edition of *Fluid Power with Applications* remains the same as that of the previous editions: to provide the student with an in-depth background in the vast field of fluid power. As such, this book covers the subjects essential to understanding the design, analysis, operation, maintenance, and application of fluid power systems. It is written for associate-degree technology students at community and technical colleges as well as baccalaureate-degree technology students at four-year colleges and universities.

As in the previous editions, although theory is presented where desirable, the emphasis is placed on understanding how fluid power systems operate and on practical applications as well. In this way, the student learns not only the "why" but also the "how" of fluid power system operation.

MAJOR CHANGES IN FIFTH EDITION

Based on input from users of the fourth edition and from my colleagues, the following major changes have been incorporated in this book:

1. The material on the maintenance of hydraulic systems (formerly Chapter 14) has been revised and moved forward to become new Chapter 10. In this way, information on hydraulic system maintenance immediately follows the coverage of hydraulics (Chapters 2 through 9). This provides better subject continuity because hydraulics is presented in its entirety before pneumatics is introduced.
2. Many of the example problems and end-of-chapter exercises have been changed to better reflect current industrial applications. The example problems and exercises encompass a wide range of subject matter and difficulty to allow the student to progress in an orderly manner.

此为试读，需要完整PDF请访问：www.ertongbook.com

3. Information on the maintenance-related properties of hydraulic fluids has been revised and moved from Chapter 2 "Physical Properties of Hydraulic Fluids," to Chapter 10, "Maintenance of Hydraulic Systems." This allows the student to develop an in-depth understanding of the operation of hydraulic systems before delving into maintenance-related subjects.
4. A number of photographs and illustrations have been updated to reflect current fluid power technology. These include the areas of programmable logic controllers, microprocessors, and electrohydraulic servo systems.
5. Section 5.13 has been revised to include the use of Mathcad computer software to analyze hydraulic systems. It is frequently desirable to optimize the operation of hydraulic systems based on a performance versus cost analysis. To perform the huge number of calculations to optimize complete hydraulic systems in a reasonable period of time, it is necessary to utilize computers. By using Mathcad computer software, the value of any system parameter can be changed, and the effect on system performance can be quickly determined and compared to the cost of changing the corresponding component in the actual system.
6. Section 8.4 has been expanded and Section 9.14 has been added to provide an analytical method for controlling the speed of hydraulic cylinders and motors using flow control valves. This allows the student to properly select flow control valves for a wide variety of actuator speed control applications.
7. A list of key equations has been added to the end of each chapter. This allows the student to more easily access equations when needed in later chapters. These equations show the units to be used for each parameter where appropriate, to expedite problem solving.
8. The material on the efficiencies of pumps and hydraulic motors has been rewritten for better comprehension. For example, the distinction between brake power and hydraulic power is emphasized when dealing with the performance of pumps and hydraulic motors.
9. The material on the two subjects of viscosity and viscosity index has been rewritten for better clarity and placed into separate sections. This allows viscosity in CGS metric units, SI metric units and English units, to be more readily applied as a parameter in the solution of fluid power problems.
10. Tables of English to English and metric to metric unit conversion factors have been added to the existing table of English to metric unit conversion factors in Appendix E. This allows for more expedient solution of many fluid power problems since unit conversion (such as $1\frac{ft^3}{s} = 448$ gpm and $1\frac{m^3}{s} = 60{,}000$ Lpm) do not have to be derived when needed.

Acknowledgments

As in the case of the previous editions, I am indebted to the numerous fluid power equipment manufacturing companies for permitting the inclusion of their photographs and other illustrations in this textbook.

I thank Robert B. Lantz, Cleveland State Community College; Pascal Zanzano, Niagara County Community College; and Tim Brown, Tri-County Technical College for reviewing the manuscript and providing many helpful suggestions and comments for improving this fifth edition. Thanks to Kirsten Kauffman at York Production Services and Louise Sette at Prentice Hall for handling the production of this edition.

I also wish to thank the users of the previous editions for their many constructive suggestions, which have also been incorporated.

Anthony Esposito

Fluid Power with Applications

Contents

Preface **xv**

1 INTRODUCTION TO FLUID POWER **1**

Learning Objectives 1
1.1 What Is Fluid Power? 2
1.2 History of Fluid Power 3
1.3 Advantages of Fluid Power 6
1.4 Applications of Fluid Power 11
1.5 Components of a Fluid Power System 18
1.6 Closed-Loop versus Open-Loop Systems 20
1.7 Types of Fluid Power Control Systems 21
1.8 The Fluid Power Industry 28
1.9 Environmental Issues 30
Exercises 31

2 PHYSICAL PROPERTIES OF HYDRAULIC FLUIDS **33**

Learning Objectives 33
2.1 Introduction 33
2.2 Fluids: Liquids and Gases 35
2.3 Weight, Density, and Specific Gravity 37
2.4 Force, Pressure, and Head 42
2.5 The SI Metric System 48
2.6 Pascal's Law 53

2.7 Bulk Modulus 57
2.8 Viscosity 58
2.9 Viscosity Index 65
2.10 Illustrative Examples Using the SI Metric System 66
2.11 Key Equations 69
Exercises 70

3 ENERGY AND POWER IN HYDRAULIC SYSTEMS 76

Learning Objectives 76
3.1 Introduction 77
3.2 Review of Mechanics 77
3.3 Applications of Pascal's Law 84
3.4 Conservation of Energy 91
3.5 The Continuity Equation 92
3.6 Hydraulic Horsepower 94
3.7 Bernoulli's Equation 98
3.8 Torricelli's Theorem 105
3.9 The Siphon 107
3.10 Energy, Power, and Flow Rate in the SI Metric System 109
3.11 Illustrative Examples Using the SI Metric System 112
3.12 Key Equations 115
Exercises 116

4 HYDRAULIC CONDUCTORS AND FITTINGS 124

Learning Objectives 124
4.1 Introduction 124
4.2 Conductor Sizing for Flow-Rate Requirements 125
4.3 Pressure Rating of Conductors 127
4.4 Steel Pipes 131
4.5 Steel Tubing 133
4.6 Plastic Tubing 140
4.7 Flexible Hoses 140
4.8 Quick Disconnect Couplings 144
4.9 Metric Steel Tubing 147
4.10 Key Equations 149
Exercises 149

5 BASICS OF HYDRAULIC FLOW IN PIPELINES 152

Learning Objectives 152
5.1 Introduction 153
5.2 Laminar and Turbulent Flow 153
5.3 Reynolds Number 155
5.4 Darcy's Equation 157
5.5 Frictional Losses in Laminar Flow 158
5.6 Frictional Losses in Turbulent Flow 159
5.7 Losses in Valves and Fittings 163
5.8 Equivalent-Length Technique 167
5.9 Hydraulic Circuit Analysis 169
5.10 Flow Measurement 171
5.11 Pressure Measurement 175
5.12 Hydraulic Circuit Analysis Using the SI Metric System 178
5.13 Computer Analysis of Hydraulic Systems 181
5.14 Key Equations 188
Exercises 189

6 THE SOURCE OF HYDRAULIC POWER: PUMPS 196

Learning Objectives 196
6.1 Introduction 197
6.2 Pumping Theory 198
6.3 Pump Classification 199
6.4 Gear Pumps 202
6.5 Vane Pumps 210
6.6 Piston Pumps 216
6.7 Pump Performance 225
6.8 Pump Noise 232
6.9 Pump Selection 238
6.10 Pressure Intensifiers 239
6.11 Pump Performance Ratings in Metric Units 241
6.12 Key Equations 244
Exercises 246

7 HYDRAULIC ACTUATORS AND MOTORS 252

Learning Objectives 252
7.1 Introduction 253
7.2 Linear Hydraulic Actuators (Hydraulic Cylinders) 253

此为试读，需要完整PDF请访问：www.ertongbook.com

7.3 Mechanics of Hydraulic Cylinder Loadings 264
7.4 Limited Rotation Hydraulic Actuator 268
7.5 Gear Motors 272
7.6 Vane Motors 274
7.7 Piston Motors 277
7.8 Hydraulic Motor Theoretical Torque, Power, and Flow Rate 281
7.9 Hydraulic Motor Performance 283
7.10 Hydrostatic Transmissions 286
7.11 Hydraulic Motor Performance in Metric Units 290
7.12 Key Equations 293
Exercises 296

8 VALVES AND OTHER CONTROL COMPONENTS IN HYDRAULIC SYSTEMS 303

Learning Objectives 303
8.1 Introduction 304
8.2 Directional Control Valves 305
8.3 Pressure Control Valves 317
8.4 Flow Control Valves 326
8.5 Servo Valves 332
8.6 Cartridge Valves 335
8.7 Hydraulic Fuses 340
8.8 Pressure and Temperature Switches 341
8.9 Shock Absorbers 344
8.10 Key Equations 348
Exercises 348

9 HYDRAULIC CIRCUIT DESIGN AND ANALYSIS 351

Learning Objectives 351
9.1 Introduction 351
9.2 Control of a Single-Acting Hydraulic Cylinder 352
9.3 Control of a Double-Acting Hydraulic Cylinder 352
9.4 Regenerative Circuit 356
9.5 Pump-Unloading Circuit 360
9.6 Double-Pump Hydraulic System 360
9.7 Pressure Intensifier Circuit 361

9.8 Counterbalance Valve Application 363
9.9 Hydraulic Cylinder Sequencing Circuits 363
9.10 Automatic Cylinder Reciprocating System 364
9.11 Locked Cylinder Using Pilot Check Valves 364
9.12 Cylinder Synchronizing Circuits 366
9.13 Fail-Safe Circuits 367
9.14 Speed Control of a Hydraulic Cylinder 369
9.15 Speed Control of a Hydraulic Motor 374
9.16 Hydraulic Motor Braking System 374
9.17 Hydrostatic Transmission System 375
9.18 Air-over-Oil Circuit 377
9.19 Air-over-Oil Intensifier System 378
9.20 Analysis of Hydraulic System with Frictional Losses Considered 379
9.21 Accumulators and Accumulator Circuits 383
9.22 Mechanical-Hydraulic Servo System 396
9.23 Key Equations 396
Exercises 397

10 MAINTENANCE OF HYDRAULIC SYSTEMS 405

Learning Objectives 405
10.1 Introduction 406
10.2 Oxidation and Corrosion of Hydraulic Fluids 408
10.3 Fire-Resistant Fluids 409
10.4 Foam-Resistant Fluids 411
10.5 Fluid Lubricating Ability 411
10.6 Fluid Neutralization Number 412
10.7 General Types of Fluids 413
10.8 Maintaining and Disposing of Fluids 413
10.9 Sealing Devices 415
10.10 The Reservoir System 424
10.11 Filters and Strainers 427
10.12 Beta Ratio of Filters 433
10.13 Wear of Moving Parts Due to Solid-Particle Contamination of the Fluid 434
10.14 Problems Caused by Gases in Hydraulic Fluids 435
10.15 Temperature Control 438
10.16 Troubleshooting Hydraulic Systems 442

10.17 Safety Considerations 446
10.18 Key Equations 447
Exercises 448

11 PNEUMATICS: AIR PREPARATION AND COMPONENTS 451

Learning Objectives 451
11.1 Introduction 451
11.2 Properties of Air 453
11.3 The Perfect Gas Laws 455
11.4 Compressors 461
11.5 Fluid Conditioners 469
11.6 Control with Orifices 477
11.7 Air Control Valves 479
11.8 Pneumatic Actuators 487
11.9 Key Equations 492
Exercises 494

12 PNEUMATICS: CIRCUITS AND APPLICATIONS 498

Learning Objectives 498
12.1 Introduction 498
12.2 Pneumatic Circuit Design Considerations 500
12.3 Air Pressure Losses in Pipelines 501
12.4 Economic Cost of Energy Losses in Pneumatic Systems 503
12.5 Basic Pneumatic Circuits 505
12.6 Pneumatic Vacuum Systems 511
12.7 Accumulator Systems Analysis 515
12.8 Pneumatic Circuit Analysis Using Metric Units 518
12.9 Key Equations 521
Exercises 521

13 FLUID LOGIC CONTROL SYSTEMS 528

Learning Objectives 528
13.1 Introduction 528
13.2 Moving-Part Logic (MPL) Control Systems 534
13.3 MPL Control of Fluid Power Circuits 539
13.4 Principles of Fluidic Logic Control 542

13.5 Basic Fluidic Devices 544
13.6 Fluid Sensors 550
13.7 Fluidic Control of Fluid Power Systems 553
13.8 Introduction to Boolean Algebra 558
13.9 Illustrative Examples Using Boolean Algebra 564
13.10 Key Equations 569
Exercises 569

14 ELECTRICAL CONTROLS FOR FLUID POWER CIRCUITS 575

Learning Objectives 575
14.1 Introduction 575
14.2 Electrical Components 580
14.3 Control of a Cylinder Using a Single Limit Switch 583
14.4 Reciprocation of a Cylinder Using Pressure or Limit Switches 584
14.5 Dual-Cylinder Sequence Circuits 585
14.6 Box-Sorting System 587
14.7 Electrical Control of Regenerative Circuit 587
14.8 Counting, Timing, and Reciprocation of Hydraulic Cylinder 590
14.9 Electrohydraulic Servo System 592
14.10 Analysis of Electrohydraulic Servo Systems 595
14.11 Programmable Logic Controllers (PLCs) 603
14.12 Key Equations 612
Exercises 612

APPENDIXES 618

A Sizes of Steel Pipe (English Units) 619
B Sizes of Steel Pipe (Metric Units) 621
C Sizes of Steel Tubing (English Units) 623
D Sizes of Steel Tubing (Metric Units) 625
E Unit Conversion Factors 626
F Nomenclature 628
G Fluid Power Symbols 631
H Answers to Selected Odd-Numbered Exercises 634

INDEX 641

1 Introduction to Fluid Power

Learning Objectives

Upon completing this chapter, you should be able to:

1. Explain what fluid power is.
2. Differentiate between the terms *hydraulics* and *pneumatics.*
3. Understand the difference between fluid power systems and fluid transport systems.
4. Appreciate the history of the fluid power industry.
5. Discuss the advantages and disadvantages of fluid power.
6. Describe key applications of fluid power.
7. Specify the basic components of fluid power systems.
8. Distinguish between open-loop and closed-loop fluid power systems.
9. Recognize the various types of fluid power control systems.
10. Appreciate the size and scope of the fluid power industry.
11. Identify the categories of personnel who are employed in the fluid power industry.
12. Describe the environmental issues dealing with developing biodegradable fluids, reducing oil leakage, maintaining and disposing of hydraulic fluids, and reducing noise levels.

1.1 WHAT IS FLUID POWER?

Fluid power is the technology that deals with the generation, control, and transmission of power-using pressurized fluids. It can be said that fluid power is the muscle that moves industry. This is because fluid power is used to push, pull, regulate, or drive virtually all the machines of modern industry. For example, fluid power steers and brakes automobiles, launches spacecraft, moves earth, harvests crops, mines coal, drives machine tools, controls airplanes, processes food, and even drills teeth. In fact, it is almost impossible to find a manufactured product that hasn't been "fluid-powered" in some way at some stage of its production or distribution.

Since a fluid can be either a liquid or a gas, fluid power is actually the general term used for hydraulics and pneumatics. Hydraulic systems use liquids such as petroleum oils, water, synthetic oils, and even molten metals. The first hydraulic fluid to be used was water because it is readily available. However, water has many deficiencies. It freezes readily, is a relatively poor lubricant, and tends to rust metal components. Hydraulic oils are far superior and hence are widely used in lieu of water. Pneumatic systems use air as the gas medium because air is very abundant and can be readily exhausted into the atmosphere after completing its assigned task.

It should be realized that there are actually two different types of fluid systems: fluid transport and fluid power.

Fluid transport systems have as their sole objective the delivery of a fluid from one location to another to accomplish some useful purpose. Examples include pumping stations for pumping water to homes, cross-country gas lines, and systems where chemical processing takes place as various fluids are brought together.

Fluid power systems are designed specifically to perform work. The work is accomplished by a pressurized fluid bearing directly on an operating fluid cylinder or fluid motor. A fluid cylinder produces a force, whereas a fluid motor produces a torque. Fluid cylinders and motors thus provide the muscle to do the desired work. Of course, control components are also needed to ensure that the work is done smoothly, accurately, efficiently, and safely.

Liquids provide a very rigid medium for transmitting power and thus can provide huge forces to move loads with utmost accuracy and precision. On the other hand, pneumatic systems exhibit spongy characteristics due to the compressibility of air. However, pneumatic systems are less expensive to build and operate. In addition, provisions can be made to control the operation of the pneumatic actuators that drive the loads.

Fluid power equipment ranges in size from huge hydraulic presses to miniature fluid logic components used to build reliable control systems.

How versatile is fluid power? In terms of brute power, a feather touch by an operator can control hundreds of horsepower and transmit it to any location where a hose or pipe can go. In terms of precision such as applications in the machine tool industry, tolerances of one ten-thousandth of an inch can be achieved and repeated over and over again. Fluid power is not merely a powerful muscle; it is a controlled, flexible muscle that provides power smoothly, efficiently, safely, and precisely to accomplish useful work.

此为试读，需要完整PDF请访问：www.ertongbook.com