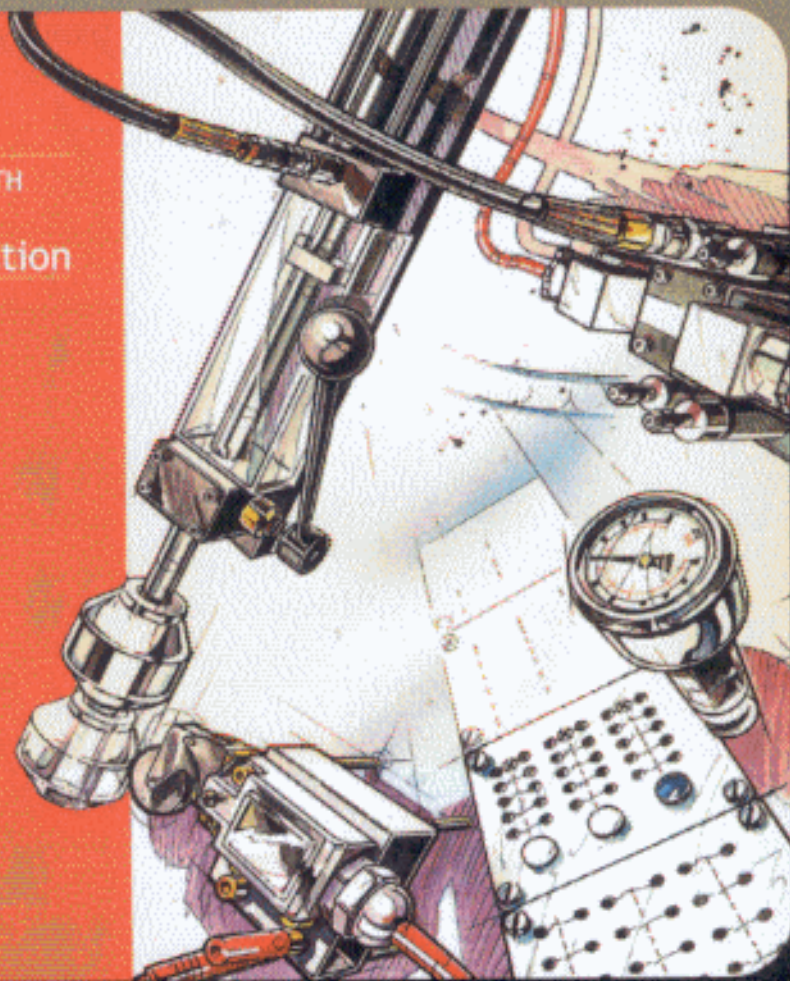


# FLUID POWER

## WITH APPLICATIONS

6<sup>TH</sup>  
Edition



Anthony Esposito

# **1 INTRODUCTION TO FLUID POWER**

**1**

Learning Objectives 1

- 1.1 What Is Fluid Power? 1
  - 1.2 History of Fluid Power 3
  - 1.3 Advantages of Fluid Power 6
  - 1.4 Applications of Fluid Power 10
  - 1.5 Components of a Fluid Power System 14
  - 1.6 The Fluid Power Industry 17
- Exercises 18

# **2 PHYSICAL PROPERTIES OF HYDRAULIC FLUIDS**

**21**

Learning Objectives 21

- 2.1 Introduction 21
  - 2.2 Fluids: Liquids and Gases 23
  - 2.3 Specific Weight, Density, and Specific Gravity 25
  - 2.4 Force, Pressure, and Head 30
  - 2.5 The SI Metric System 37
  - 2.6 Bulk Modulus 40
  - 2.7 Viscosity 41
  - 2.8 Viscosity Index 48
  - 2.9 Illustrative Examples Using the SI Metric System 51
  - 2.10 Key Equations 52
- Exercises 53

### **3 ENERGY AND POWER IN HYDRAULIC SYSTEMS**

**57**

- Learning Objectives 57
- 3.1 Introduction 57
- 3.2 Review of Mechanics 59
- 3.3 Multiplication of Force (Pascal's Law) 65
- 3.4 Applications of Pascal's Law 69
- 3.5 Conservation of Energy 76
- 3.6 The Continuity Equation 77
- 3.7 Hydraulic Power 79
- 3.8 Bernoulli's Equation 84
- 3.9 Torricelli's Theorem 91
- 3.10 The Siphon 93
- 3.11 Energy, Power, and Flow Rate in the SI Metric System 94
- 3.12 Illustrative Examples Using the SI Metric System 96
- 3.13 Key Equations 99
- Exercises 102

### **4 FRICTIONAL LOSSES IN HYDRAULIC PIPELINES**

**111**

- Learning Objectives 111
- 4.1 Introduction 111
- 4.2 Laminar and Turbulent Flow 113
- 4.3 Reynolds Number 114
- 4.4 Darcy's Equation 117
- 4.5 Frictional Losses in Laminar Flow 117
- 4.6 Frictional Losses in Turbulent Flow 118
- 4.7 Losses in Valves and Fittings 122
- 4.8 Equivalent-Length Technique 127
- 4.9 Hydraulic Circuit Analysis 128
- 4.10 Circuit Analysis Using the SI Metric System 131
- 4.11 Key Equations 134
- Exercises 135

### **5 HYDRAULIC PUMPS**

**141**

- Learning Objectives 141
- 5.1 Introduction 142

- 5.2 Pumping Theory 144
- 5.3 Pump Classification 145
- 5.4 Gear Pumps 148
- 5.5 Vane Pumps 156
- 5.6 Piston Pumps 162
- 5.7 Pump Performance 171
- 5.8 Pump Noise 178
- 5.9 Pump Selection 184
- 5.10 Pump Performance Ratings in Metric Units 185
- 5.11 Key Equations 188
  - Exercises 190

## **6 HYDRAULIC CYLINDERS AND CUSHIONING DEVICES**

**195**

- Learning Objectives 195
- 6.1 Introduction 195
- 6.2 Hydraulic Cylinder Operating Features 197
- 6.3 Cylinder Mountings and Mechanical Linkages 199
- 6.4 Cylinder Force, Velocity, and Power 201
- 6.5 Cylinder Loads Due to Moving of Weights 204
- 6.6 Special Cylinder Designs 207
- 6.7 Cylinder Loadings Through Mechanical Linkages 207
- 6.8 Hydraulic Cylinder Cushions 213
- 6.9 Hydraulic Shock Absorbers 216
- 6.10 Key Equations 220
  - Exercises 222

## **7 HYDRAULIC MOTORS**

**227**

- Learning Objectives 227
- 7.1 Introduction 227
- 7.2 Limited Rotation Hydraulic Motors 230
- 7.3 Gear Motors 232
- 7.4 Vane Motors 235
- 7.5 Piston Motors 238
- 7.6 Hydraulic Motor Theoretical Torque, Power, and Flow-Rate 240
- 7.7 Hydraulic Motor Performance 244
- 7.8 Hydrostatic Transmissions 248

- 12.4 Foam-Resistant Fluids 426
- 12.5 Fluid Lubricating Ability 426
- 12.6 Fluid Neutralization Number 427
- 12.7 Petroleum-Base Versus Fire-Resistant Fluids 427
- 12.8 Maintaining and Disposing of Fluids 428
- 12.9 Filters and Strainers 429
- 12.10 Beta Ratio of Filters 434
- 12.11 Fluid Cleanliness Levels 436
- 12.12 Wear of Moving Parts Due to Solid-Particle Contamination of the Fluid 438
- 12.13 Problems Caused by Gases in Hydraulic Fluids 439
- 12.14 Troubleshooting Hydraulic Systems 442
- 12.15 *Safety Considerations* 446
- 12.16 Environmental Issues 446
- 12.17 Key Equations 447
  - Exercises 448

## **13 PNEUMATICS: AIR PREPARATION AND COMPONENTS**

**450**

- Learning Objectives 450
- 13.1 Introduction 451
- 13.2 Properties of Air 452
- 13.3 The Perfect Gas Laws 454
- 13.4 Compressors 460
- 13.5 Fluid Conditioners 469
- 13.6 Analysis of Moisture Removal from Air 477
- 13.7 Air Flow Rate Control with Orifices 480
- 13.8 Air Control Valves 482
- 13.9 Pneumatic Actuators 490
- 13.10 Key Equations 498
  - Exercises 499

## **14 PNEUMATICS: CIRCUITS AND APPLICATIONS**

**504**

- Learning Objectives 504
- 14.1 Introduction 504
- 14.2 Pneumatic Circuit Design Considerations 507
- 14.3 Air Pressure Losses in Pipelines 508
- 14.4 Economic Cost of Energy Losses in Pneumatic Systems 510

- 14.5 Basic Pneumatic Circuits 512
- 14.6 Pneumatic Vacuum Systems 518
- 14.7 Sizing of Gas-Loaded Accumulators 522
- 14.8 Pneumatic Circuit Analysis Using Metric Units 525
- 14.9 Key Equations 528
  - Exercises 528

## **15 BASIC ELECTRICAL CONTROLS FOR FLUID POWER CIRCUITS**

**535**

- Learning Objectives 535
- 15.1 Introduction 535
- 15.2 Electrical Components 539
- 15.3 Control of a Cylinder Using a Single Limit Switch 542
- 15.4 Reciprocation of a Cylinder Using Pressure or Limit Switches 543
- 15.5 Dual-Cylinder Sequence Circuits 544
- 15.6 Box-Sorting System 545
- 15.7 Electrical Control of Regenerative Circuit 548
- 15.8 Counting, Timing, and Reciprocation of Hydraulic Cylinder 549
  - Exercises 551

## **16 FLUID LOGIC CONTROL SYSTEMS**

**555**

- Learning Objectives 555
- 16.1 Introduction 555
- 16.2 Moving-Part Logic (MPL) Control Systems 557
- 16.3 MPL Control of Fluid Power Circuits 561
- 16.4 Introduction to Boolean Algebra 565
- 16.5 Illustrative Examples Using Boolean Algebra 571
- 16.6 Key Equations 576
  - Exercises 576

## **17 ADVANCED ELECTRICAL CONTROLS FOR FLUID POWER SYSTEMS**

**580**

- Learning Objectives 580
- 17.1 Introduction 580
- 17.2 Components of an Electrohydraulic Servo System 585
- 17.3 Analysis of Electrohydraulic Servo Systems 588

- 17.4 Programmable Logic Controllers (PLCs) 596
- 17.5 Key Equations 606
  - Exercises 607

## **APPENDIXES**

- A Sizes of Steel Pipe (English Units) 611
- B Sizes of Steel Pipe (Metric Units) 613
- C Sizes of Steel Tubing (English Units) 615
- D Sizes of Steel Tubing (Metric Units) 617
- E Unit Conversion Factors 618
- F Nomenclature 620
- G Fluid Power Symbols 623
- H Answers to Selected Odd-Numbered Exercises 626
- I Derivation of Key Equations 631
- J Computer Analysis of Fluid Power Systems 636
- K Exercises for Computer Solutions 644