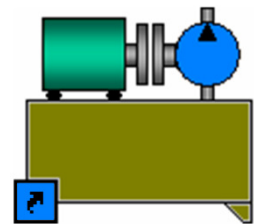


Hydraulic Systems Volume 2

Electro-Hydraulic Components and Systems

*Dr. Medhat Kamel Bahr Khalil, Ph.D, CFPHS, CFPAL.
Director of Professional Education and Research Development,
Applied Technology Center, Milwaukee School of Engineering,
Milwaukee, WI, USA.*



CompuDraulic LLC
www.CompuDraulic.com

Hydraulic System Volume 2

Electro-Hydraulic Components and Systems

ISBN: 978-0-9977634-2-3

Printed in the United States of America

First Published by 2017

Revised by October 2019

All rights reserved for CompuDraulic LLC.
3850 Scenic Way, Franksville, WI, 53126 USA.
www.compudraulic.com

No part of this book may be reproduced or utilized in any form or by any means, electronic or physical, including photocopying and microfilming, without written permission from CompuDraulic LLC at the address above.

Disclaimer

It is always advisable to review the relevant standards and the recommendations from the system manufacturer. However, the content of this book provides guidelines based on the author's experience.

Any portion of information presented in this book might not be suitable for some applications due to various reasons. Since errors can occur in circuits, tables, and text, the author/publisher assumes no liability for the safe and/or satisfactory operation of any system designed based on the information in this book.

The author/publisher does not endorse or recommend any brand name product by including such brand name products in this book. Conversely the author/publisher does not disapprove any brand name product not included in this book. The publisher obtained data from catalogs, literatures, and material from hydraulic components and systems manufacturers based on their permissions. The author/publisher welcomes additional data from other sources for future editions. This disclaimer is applicable for the workbook (if available) for this textbook.

Hydraulic Systems Volume 2 **Electro-Hydraulic Components and Systems**

PREFACE, 10

ACKNOWLEDGEMENT, 11

ABOUT THE BOOK, 12

ABOUT THE AUTHOR, 15

Chapter 1: Hydraulic versus Electrical Systems, 16

1.1- Structural Analogy between Hydraulic and Electrical Systems, 17

1.1.1- Power Generation (Conversion), 18

1.1.1.1- Electrical Power Generators, 18

1.1.1.2- Hydraulic Power Generators, 19

1.1.2- Power Control, 20

1.1.2.1- Power Quantification, 20

1.1.2.2- Effort Variable Controllers (Overload Protection), 21

1.1.2.3- Flow Variable Controllers (Resistive Elements), 22

1.1.2.4- Directional Controllers, 28

1.1.2.5- Energy Storage Elements (Capacitive Elements), 29

1.1.2.6- Non-Return Elements, 30

1.1.2.7- Electrical versus Hydraulic Power Control Elements, 30

1.1.3- Power Consumption (Actuation), 31

1.1.3.1- Rotational Actuators, 31

1.1.3.2- Linear Actuators, 33

1.2- Operational Analogy between Hydraulic and Electrical Systems, 34

1.2.1- Energy Transmission in a Circuit, 34

1.2.2- Energy Transmission Efficiency, 35

1.2.3- Energy Transmission Cost Factor, 36

1.2.4- Energy Transmission Distance, 37

1.2.5- Readiness of Operation, 38

1.2.6- Cleanliness of Operation, 39

1.2.7- Maintenance of Operation, 40

1.2.8- Safety of Operation under High Temperature, 41

1.2.9- Noise of Operation, 42

Chapter 2: Hydro-Mechanical versus Electro-Hydraulic Solutions, 43

2.1- Features and Challenges of Electro-Hydraulic Systems, 44

2.2- Pressure Control Solutions, 46

- 2.2.1- Pressure Control using Hydro-Mechanical Pressure Relief Valve, 46
- 2.2.2- Pressure Control using Hydro-Mechanical Pressure Compensated Pump, 47
- 2.2.3- Multiple Pressure Settings using Electro-Hydraulic Switching Valves, 48
- 2.2.4- Pressure Control using an Electro-Hydraulic Continuous Valve, 50
- 2.2.5- Pressure Control using an Electro-Hydraulic Pressure Compensated Pump, 52

2.3- Flow Control Solutions, 54

- 2.3.1- Flow Control using Hydro-Mechanical Flow Control Valve, 54
- 2.3.2- Flow Control using Hydro-Mechanical Displacement Controlled Pump, 55
- 2.3.3- Multiple Flow Settings using Electro-Hydraulic Switching Valves, 56
- 2.3.4- Flow Control using an Electro-Hydraulic Continuous Valve, 58
- 2.3.5- Flow Control using an Electro-Hydraulic Displacement Controlled Pump, 60
- 2.3.6- Flow Control using a Fixed Pump Driven by Variable Speed Motor, 62

2.4- Power Control Solutions, 64

- 2.4.1- Hydro-Mechanical Power Controlled Pumps, 65
- 2.4.2- Electro-Hydraulic Power Controlled Pumps, 67

2.5- Sequence Control Solutions, 70

- 2.5.1- Hydro-Mechanical Sequence Control, 70
- 2.5.2- Electro-Hydraulic Sequence Control, 71

2.6- Hydraulic Deceleration System, 73

- 2.6.1- Hydro-Mechanical Deceleration System, 73
- 2.6.2- Electro-Hydraulic Deceleration System, 74

2.7- Cylinder Speed Synchronization, 75

- 2.7.1- Hydro-Mechanical Cylinder Speed Synchronization, 75
- 2.7.2- Electro-Hydraulic Cylinder Speed Synchronization, 76

2.8- Accumulator Charging, 77

- 2.8.1- Hydro-Mechanical Accumulator Charging, 77
- 2.8.2- Electro-Hydraulic Accumulator Charging, 78

2.9- Control of Overrunning Loads, 80

- 2.9.1- Hydro-Mechanical Overrunning Load Control, 80
- 2.9.2- Electro-Hydraulic Overrunning Load Control, 81

2.10- Control Block Actuation in Mobile Applications, 82

- 2.10.1- Hydro-Mechanical Control Block Actuation, 82
- 2.10.2- Electro-Hydraulic Control Block Actuation, 83

Chapter 3: Switching Valves Construction and Operation, 84**3.1- Basic Electro-Magnetic Concepts, 85**

- 3.1.1- Magnetic Field around a Conducting Wire, 85
- 3.1.2- Magnetic Field Measuring Units, 85
- 3.1.3- Magnetic Field Intensity, 86
- 3.1.4- Magnetic Field around a Coil, 87
- 3.1.5- Electro-Magnetic Force, 88

3.2- Switching Solenoids, 89

- 3.2.1- Switching Solenoid Basic Structure, Operation, and Functions, 89
- 3.2.2- Wiring Methods of a Coil, 92
- 3.2.3- Switching Solenoids Force-Stroke Relationship, 95
- 3.2.4- Switching Solenoid Performance Terminologies, 97

3.3- Switching Solenoids for Electro-Hydraulic Valves, 99

- 3.3.1- Dry (Air) Type Switching Solenoids for EH Valves, 99
- 3.3.2- Wet (Oil) Type Switching Solenoids for EH Valves, 101
- 3.3.3- Dry versus Wet Type Switching Solenoids for EH Valves, 102
- 3.3.4- DC Switching Solenoids for EH Valves, 103
 - 3.3.4.1- Construction and Operation of DC Switching Solenoids for EH Valves, 103
 - 3.3.4.2- Performance of DC Switching Solenoids for EH Valves, 104
 - 3.3.4.3- Applications of DC Switching solenoids for EH Valves, 105
- 3.3.5- AC Switching Solenoids for EH Valves, 106
 - 3.3.5.1- Construction and Operation of AC Switching Solenoids for EH Valves, 106
 - 3.3.5.2- AC Hum, 107
 - 3.3.5.3- Eddy Current, 109
 - 3.3.5.4- Inrush Current, 110
 - 3.3.5.5- Performance of AC Switching Solenoids for EH Valves, 113
 - 3.3.5.6- Applications of AC switching Solenoids for EH Valves, 114
- 3.3.6- DC versus AC Switching Solenoid, 114
- 3.3.7- Electrical Ratings for Switching Solenoids, 115
- 3.3.8- Manual Override, 116
- 3.3.9- Switching Solenoids for Cartridge Valves, 117
- 3.3.10- Standard Electrical Terminations for Switching Solenoids, 118

3.4- Electro-Hydraulic Switching Directional Control Valves, 120**3.5- Electro-Hydraulic Switching Pressure Control Valves, 131**

3.6- Electro-Hydraulic Switching Flow Control Valves, 133**Chapter 4: Electrical Circuits for Switching Valves, 134****4.1- Best Practices for Safe Operation of Electro-Hydraulic Systems, 135****4.2- Basic Electrical Symbols, 140****4.3- Basic Electrical Devices, 142**

- 4.3.1- Measuring Instruments, 142
- 4.3.2- Electrical Pushbuttons and Switches, 144
- 4.3.3- Limit Switches, 145
- 4.3.4- Proximity Switches, 146
- 4.3.5- Pressure Switches, 147
- 4.3.6- Fluid Flow Switches, 148
- 4.3.7- Fluid Level Switches, 148
- 4.3.8- Temperature Switches, 149
- 4.3.9- Control Relays, 149
- 4.3.10 - Programmable Logic Controllers (PLCs), 151

4.4- Electrical Schematic Diagrams, 153

- 4.4.1- JIC Schematic Diagrams, 153
- 4.4.2- Wiring Diagrams, 156
- 4.4.3- Sequence Diagrams, 157

4.5- Electrical Circuits for Applications of Switching Valves, 158

- 4.5.1- Identity (YES Function) by Direct Activation, 158
- 4.5.2- Negation (NOT Function) by Direct Activation, 159,
- 4.5.3- Identity (YES Function) by Indirect Activation, 160
- 4.5.4- Negation (NOT Function) by Indirect Activation, 161
- 4.5.5- Signal Storage by Electrical Latching, 162
- 4.5.6- Electromechanical Protection of a Valve with Two Solenoids, 163
- 4.5.7- Electrical Protection of a Valve with Two Solenoids, 164
- 4.5.8- Position-Dependent Cylinder Deceleration, 167
- 4.5.9- One-Cycle Hydraulic Cylinder Reciprocation, 171
- 4.5.10- Continuous Cylinder Reciprocation, 173
- 4.5.11- Panic Circuit, 176
- 4.5.12- Conjunction Functions, 177
- 4.5.13- Disjunction Functions, 181
- 4.5.14- Timer Circuits, 183
- 4.5.15- Sequence Control, 185

Chapter 5: Proportional Valves, 191

5.1- Introduction to Proportional Valves, 192

5.2- Proportional Solenoids, 196

5.2.1- Force-Controlled Proportional Solenoid, 196

5.2.2- Stroke-Controlled Proportional Solenoid, 200

5.3- Proportional Directional Control Valves, 204

5.3.1- Interpretation of Symbols for Proportional Directional Valves, 204

5.3.2- Hydraulic Static Characteristics of Proportional Directional Valves, 205

5.3.3- Direct-Operated Force-Controlled Proportional Directional Valve, 207

5.3.4- Direct-Operated Stroke-Controlled Proportional Directional Valve, 210

5.3.5- High Performance Proportional Directional Valve, 213

5.3.6- Pilot-Operated Force-Controlled Proportional Directional Valve, 218

5.3.7- Pilot-Operated Stroke-Controlled Proportional Directional Valve, 225

5.3.8- Proportional Directional Valves with Variable Load Compensator, 232

5.4- Proportional Pressure Control Valves, 236

5.4.2- Hydraulic Static Characteristics of Proportional Pressure Relief Valves, 237

5.4.3- Direct-Operated Force-Controlled Proportional Pressure Relief Valves, 238

5.4.4- Direct-Operated Stroke-Controlled Proportional Pressure Relief Valves, 242

5.4.5- Pilot-Operated Force-Controlled Proportional Pressure Relief Valves, 244

5.4.6- Pilot-Operated Stroke-Controlled Proportional Pressure Relief Valves, 251

5.4.7- Proportional Pressure Reducing Valves, 252

5.5- Proportional Flow Control Valves, 254

5.6- Proportional Valves for Mobile Applications, 259

Chapter 6: Servo Valves, 260

6.1- Introduction to Servo Hydraulics, 261

6.1.1- Historical Background, 261

6.1.2- Servo Valve Applications, 261

6.2- Torque Motors, 264

6.2.1- Torque Motor Construction and Operation, 264

6.2.2- Torque Motor Wiring, 266

6.2.2.1- Parallel Wiring, 266

6.2.2.2- Series Wiring, 267

6.2.2.3- Single Wiring, 268

6.3- Servo Valve Configurations, 269

- 6.3.1- Power Assistance using Mechanical Servo Valve, 269
- 6.3.2- Single-Stage Servo Valve, 271
- 6.3.3- Two-Stage Servo Valve with Tracking Sleeve, 273
- 6.3.4- Flapper–Nozzle Concept of Operation, 275
 - 6.3.4.1- Half-Bridge Flapper-Nozzle Concept, 275
 - 6.3.4.2- Full-Bridge Flapper-Nozzle Concept, 277
 - 6.3.4.3- Power Gain of Servo Valve, 279
- 6.3.5- Two-Stage Flapper–Nozzle Servo Valve with Barometric Feedback, 280
- 6.3.6- Two-Stage Flapper–Nozzle Servo Valve with Mechanical Feedback, 282
- 6.3.7- Two-Stage Flapper–Nozzle Servo Valve with Electrical Feedback, 292
- 6.3.8- Two-Stage Flapper–Nozzle Servo Valve with Mechanical and Electrical Feedback, 294
- 6.3.9- Three-Stage Flapper–Nozzle Servo Valve, 295
- 6.3.10- Jet Pipe Concept of Operation, 299
- 6.3.11- Two-Stage Jet Pipe Servo Valve with Mechanical Feedback, 300
- 6.3.12- Two-Stage Jet-Pipe Servo Valve with Electrical Feedback, 304
- 6.3.13- Jet Pipe versus Flapper-Nozzle Pilot Stage, 206
- 6.3.14- Two-Stage Jet-Deflector Servo Valve with Mechanical Feedback, 307

Chapter 7: Electro-Hydraulic Valve Selection Criteria, 309

7.1- Importance of Proper Selection of an EH Valve, 310

7.2- Electro-Hydraulic Valve Selection Criteria, 311

7.3- Valve Type, 312

7.4- Valve Spool Design, 316

- 7.4.1- Spool Null Conditions, 316
 - 7.4.1.1- Overlapped (Closed-Center) Null Conditions, 317
 - 7.4.1.2- Zero-Lapped (Critical-Center) Null Conditions, 319
 - 7.4.1.3- Underlapped (Open-Center) Null Conditions, 320
- 7.4.2- Spool Transitional Conditions, 323
- 7.4.3- Spool Fail-Safe Position, 324
- 7.4.4- Spool Control Edges, 325
 - 7.4.4.1- Holes versus Control Edges, 325
 - 7.4.4.2- Custom Control Edges, 326
 - 7.4.4.3- Standard Control Edges, 326
 - 7.4.4.4- Distribution of Control Edges, 332

7.5- Valve Static Characteristics, 334

- 7.5.1- Valve Flow Gain, 335
- 7.5.2- Valve Flow-Pressure Coefficient, 345
- 7.5.3- Power Limits, 350
- 7.5.4- Pressure Gain, 353

7.5.5-Valve Sizing, 355

7.5.6-Valve Hysteresis, 367

7.6-Valve Dynamic Characteristics, 370

7.6.1-Step Response, 370

7.6.2-Frequency Response, 376

7.7-Valve Operating Conditions, 383

7.8-Examples of Published Data, 383

Chapter 8: Open-Loop versus Closed-Loop EH Applications, 392

8.1- Electro-Hydraulic Open-Loop Control Systems, 393

8.1.1- Structure of Electro-Hydraulic Open-Loop Control Systems, 393

8.1.2- Features of Electro-Hydraulic Open-Loop Control Systems, 394

8.1.3- Electro-Hydraulic Open-Loop Speed Control Systems, 395

8.1.4- Electro-Hydraulic Open-Loop Load Control Systems, 397

8.2- Electro-Hydraulic Closed-Loop Control Systems, 400

8.2.1- Structure of Electro-Hydraulic Closed-Loop Control Systems, 400

8.2.2- Features of Electro-Hydraulic Closed-Loop Control Systems, 401

8.2.3- Electro-Hydraulic Closed-Loop Speed Control Systems, 403

8.2.3.1- Electro-Hydraulic Closed-Loop Flow Control System, 403

8.2.3.2- Electro-Hydraulic Closed-Loop Motor Speed Control System, 406

8.2.4- Electro-Hydraulic Closed-Loop Load Control Systems, 408

8.2.4.1- EH Closed-Loop Single-Acting Cylinder Pressure Control System, 408

8.2.4.2- Electro-Hydraulic Closed-Loop Single-Acting Cylinder Force Control System, 411

8.2.4.3- EH Closed-Loop Double-Acting Cylinder Pressure Control System, 412

8.2.4.4- EH Closed-Loop Double-Acting Cylinder Force Control System, 415

8.2.5- Electro-Hydraulic Closed-Loop Position Control Systems, 416

8.3- Closed-Loop Performance Analysis, 420

8.4- Electro-Hydraulic Control Systems Applications Examples, 422

8.4.1- Industrial Applications, 422

8.4.2- Mobile Applications, 430

Chapter 9: Control Electronics for Electro-Hydraulic Valves, 437

9.1- Control Electronics Basic Functions, 438

9.2- DC Power Supply, 441

9.3- Signal Amplifier, 442**9.4- Dither Signal, 443****9.5- Pulse Width Modulation, 443****9.6- Input Signal Generator, 447**

9.6.1- Format of Input Signal, 447

9.6.2- Source and Mode of Input Signal, 448

9.7- Feedback Sensors, 450**9.8- PID Controller, 450****9.9- Gain Adjustor, 453****9.10- Ramp Adjustor, 456****9.11- Null Adjustor (I_{Bias}), 459****9.12- Dead Band Eliminator (I_{min}), 462****9.13- Saturation Adjustor (I_{max}), 465****9.14- Control Electronics Basic Configurations, 467****9.15- Hardware Configuration, 468****9.16- Typical Electronic Schematics for Continuous Valves, 469****Chapter 10: Electro-Hydraulic Valves Commissioning and Maintenance, 504****10.1- Installation and Commissioning Instructions, 505**

10.1.1- Cleanliness, 505

10.1.2- Installation Position (review phrasing on the slide), 506

10.1.3- Mounting Screws, 506

10.1.4- Seals (rephrase on the slide), 506

10.1.5- Electrical Connections, 506

10.1.6- Storage Locations, 506

10.2- Filtration Requirements, 507

10.2.1-Reservoir Breather Filter, 507

10.2.2-Filtration, 507

10.2.3- System Flushing, 511

10.3- Electro-Hydraulic Valve Tests and Maintenance, 512

APPENDIXES, 513

APPENDIX A: LIST OF FIGURES, 513

APPENDIX B: LIST OF TABLES, 531

APPENDIX C: LIST OF ANIMATED CIRCUITS (AUTOMATION STUDIO), 531

APPENDIX E: LIST OF REFERENCES, 533

INDEX, 542

PREFACE

Questions being asked that are: “should a machine built based on electrical or hydraulic power transmission and control system?” and “what are the benefits of converting a legacy hydro-mechanical system into an electro-hydraulic system?”

This book is intended for industry professionals who would like to achieve a deeper understanding of the principles of electro-hydraulic control, and who would like to improve their practical skills in building an EH-driven machine. Unlike similar books, the contents of this book are presented in a unique way. It fills the gap between the very academic style of fluid power books and the very commercial style of books that are produced by fluid power manufacturers basically to promote their products.

The book contains *Animated Circuits Files* to download. The files are produced by Automation Studio to presents examples of electrical circuits that drive switching valves. Other circuits are to present examples of open-loop and closed-loop electro-hydraulic control systems.

Hydraulic system builders and users will find this book beneficial in understanding the construction and the operating principles of the electro-hydraulic systems. The book is written to cover the knowledge of electro-hydraulic components including solenoid operated valves, proportional valves, servo valves and amplifiers. The book also covers the technicalities of in-field tuning of open-loop and closed-loop electro-hydraulic systems. The book also presents guideline to select a valve for an application and how to read data sheet of a valve. The book covers the basic functions contained in the electronic control units that drive EH valves such as gain adjustor, maximum current limiter, ramp generator, pulse width modulation, dead band eliminator, null adjustment, and much more.

With more than twenty-five years of experience in teaching fluid power for industry professionals, the author had effectively applied his solid understanding to the subject and his post-doctoral level of academic education in the preparation of this book. The book features in brief are easy language, brand non-biased, practical oriented, associated with a workbook, colored, and demonstrative.

The author wants to continue on his goal of supporting fluid power and motion control professional education by developing the following series of volumes:

- Hydraulic Systems Volume 1: Introduction to Hydraulics for Industry Professionals.
- Hydraulic Systems Volume 2: Electro-Hydraulic Components and Systems.
- Hydraulic Systems Volume 3: Hydraulic Fluids and Contamination Control.
- Hydraulic Systems Volume 4: Hydraulic Fluids Conditioning.
- Hydraulic Systems Volume 5: Best Practices for Safety and Maintenance.
- Hydraulic Systems Volume 6: Troubleshooting and Failure Analysis.
- Hydraulic Systems Volume 7: Hydraulic Systems Modeling and Simulation for Application Engineers.
- Hydraulic Systems Volume 8: Design Strategies of Hydraulic Systems.
- Hydraulic Systems Volume 9: Design Strategies of Electro-Hydraulic Systems.
- Hydraulic Systems Volume 10: Hydraulic Components Modeling and Simulation.

ACKNOWLEDGEMENT

All praise is to Allah who granted me the knowledge, resources and health to finish this work.

To the soul of my parents who taught me the values of ISLAM

To my family: wife, sons, daughters in law, and grandson “Adam”

To my best teachers and supervisors

To friends who were always supportive

The author wishes to thank these companies: (Bosch Rexroth, Assofluid, Atos, Wandfluh, Hydraforce, Moog, Parker, and others) who permit us to use some of their copyrighted material to make this book more demonstrative.

Lastly, the author particularly wishes to thank the following gentlemen for their effective reviews of the book language:

- *Tom Wanke, Director of Fluid Power Institute at Milwaukee School of Engineering.*
- *Kamara Sheku, Dean of Applied Researches at Milwaukee School of Engineering.*

ABOUT THE BOOK

Book Description:

The book is a learning package for students and professionals who are looking to advance their fluid power careers. The package includes colored *textbook*, electronic files *for the animated hydraulic circuits*, and a *colored workbook* (separate price) that contains printed power point slides, chapter reviews and assignments. The book is the second in a series that the author plans to publish to offer complete and comprehensive teaching and design tools for the fluid power industry. This book is an attempt to fill the gap between the very academic style of fluid power books and the very commercial style of books that are produced by fluid power manufacturers basically to promote their products.

The book presents constructional and operational qualitative analogies between electrical, hydraulic and electro-hydraulic systems. The book considers presenting real-life examples for various types of electro-hydraulic valves. The book also covers the technicalities of in-field tuning of open-loop and closed-loop electro-hydraulic systems. The book also presents guideline to select a valve for an application and how to read data sheet of a valve. The book covers the basic functions contained in the electronic control units that drive EH valves such as gain adjustor, maximum current limiter, ramp generator, pulse width modulation, dead band eliminator, null adjustment current, and much more.

The textbook is produced in letter size (8.5 x 11) inches, and weighs 3.5 lb. The textbook contains a total of ten chapters distributed on 498 pages. The workbook is produced in the same size and weighs 2 lb. The associated software is online downloadable.

Book Objectives:

Chapter 1: Hydraulic versus Electrical Systems

This chapter presents structural and operational comparisons between hydraulic and electrical power transmission and control systems. Similarities and differences between the inductive, capacitive, and resistive elements are discussed.

Chapter 2: Hydro-Mechanical versus Electro-Hydraulic Solutions

This chapter explores the features and challenges of electro-hydraulic systems. Additionally, the chapter introduces the benefits of converting the classical hydro-mechanical systems into electro-hydraulic ones. Pressure control, flow control, power control, and sequence control are among the systems discussed.

Chapter 3: Switching Valves Construction and Operation

This chapter covers the principle of operation and the construction of various types of switching (ON/OFF) solenoids that are used to actuate hydraulic valves. The chapter discusses, qualitatively, the pros and cons of wet type versus dry type switching solenoids and DC type versus AC type switching solenoids. The chapter also discusses the undesirable effects of using AC switching solenoids such as AC hum, eddy current, and inrush current, and constructional considerations to minimize their effects. The chapter concludes by presenting examples of using switching solenoids in directional, pressure, and control functions.

Chapter 4: Electrical Circuits for Switching Valves

This chapter covers the basic safety precautions that must be considered when building an electrohydraulic circuit that drives a switching valve. The chapter also presents the electrical devices and their symbols that are most commonly used with switching valves including: switches, buttons, relays, and PLCs. The chapter also covers the rules to read and write various forms of electrical circuit diagrams including: Joint Industrial Council (JIC) schematic diagrams, wiring diagram, and sequence diagram. The chapter concludes with various electrohydraulic circuits that simulate typical applications.

Chapter 5: Proportional Valves

This chapter introduces the technology of proportional valves and discusses the construction differences as compared to conventional switching valves. The chapter also introduces the conceptual construction of force-controlled versus stroke-controlled types of proportional valves. Additionally, the chapter presents the control schemes when a proportional valve is used in open-loop and closed-loop control system. More important, the chapter concludes by exploring examples of actual proportional directional, pressure, and flow control valves from various suppliers.

Chapter 6: Servo Valves

This chapter covers the construction and wiring methods of the main electric components in servo valves including torque motors. The chapter also covers the conceptual construction and the operation of flapper-nozzle and jet-pipe servo valves. The chapter introduces examples of typical valves with mechanical or electrical feedback.

Chapter 7: Electro-Hydraulic Valve Selection Criteria

This chapter presents the various criteria to select a specific valve for an application. These criteria include, valve type, spool design, operating conditions, static and dynamic characteristics. The chapter also provides examples of the current valves that are produced by existing manufacturers.

Chapter 8: Open-Loop versus Closed-Loop EH Applications

This chapter explores the differences between electro-hydraulic open-loop and closed-loop systems. Several examples have been presented to discuss various ways to control load, speed and position of a hydraulic actuator. The chapter concludes by introducing examples from industrial and mobile applications.

Chapter 9: Control Electronics for Electro-Hydraulic Valves

This chapter explores the differences between electro-hydraulic open-loop and closed-loop systems. Several examples have been presented to discuss various ways to control load, speed and position of a hydraulic actuator. The chapter concludes by introducing examples from industrial and mobile applications.

Chapter 10: Electro-Hydraulic Valves Commissioning and Maintenance

This chapter introduces guidelines for commissioning and maintenance of EH valves.

Book Statistics:

The table shown below contains interesting statistical data about the textbook:

<i>Chapter #</i>	<i>Pages</i>	<i>Figures</i>	<i>Animated Circuits</i>	<i>Equations</i>	<i>Tables</i>	<i>Lines</i>	<i>Words</i>	<i>Characters</i>
<i>Chapter 1</i>	27	26	1	11	0	522	3086	21373
<i>Chapter 2</i>	40	31	16	0	0	1310	6046	38834
<i>Chapter 3</i>	50	75	0	6	3	1086	7477	46084
<i>Chapter 4</i>	57	48	17	0	1	1361	6746	39681
<i>Chapter 5</i>	69	76	0	0	0	1106	7022	38398
<i>Chapter 6</i>	49	41	0	5	1	917	5484	34027
<i>Chapter 7</i>	83	83	0	5	3	1459	7349	46195
<i>Chapter 8</i>	45	45	0	1	0	908	6104	38171
<i>Chapter 9</i>	77	58	0	1	1	891	4249	22092
<i>Chapter 10</i>	9	7	0	1	0	209	1157	6316
<i>Other</i>	45	-	-	-	-	-	-	-
<i>Total</i>	550	490	34	30	9	9769	54720	331171

ABOUT THE AUTHOR



Medhat Khalil, Ph.D., Director of Professional Education & Research Development at the Applied Technology Center, Milwaukee School of Engineering, Milwaukee, WI, USA. Medhat got his bachelor's degree in mechanical engineering from Military Technical College (MTC), Cairo, Egypt. He got his master's degree in Mechanical Engineering from Cairo University, Cairo, Egypt. Medhat has been granted his Ph.D. in Mechanical Engineering and Post-Doctoral Industrial Research Fellowship from Concordia University in Montreal, Quebec, Canada. Medhat, published several fluid power textbooks. He participated in many technical conferences, published several reviewed technical papers, and is in the process of registering a number of patents.

Medhat has been certified by the International Fluid Power Society (IFPS) as: Certified Fluid Power Hydraulic Specialist (CFPHS) and Certified Fluid Power Accredited Instructor (CFPAI). Medhat is a member of many grand institutions such as Center for Compact and Efficient Fluid Power Engineering Research Center (CCEFP), listed Fluid Power Consultant by the National Fluid Power Association (NFPA) and listed professional instructor by the American Society of Mechanical Engineers (ASME) and National American Die Casting Association (NADCA). Medhat has been assigned as the chair of the education committee for the International Fluid Power Exposition (IFPE 2017 and 2020). Medhat developed and taught various courses for industry professionals. He has a balanced academic and industrial experience. Medhat has a deep working experience in the field of Mechanical Engineering; more specifically in fluid power and motion control. Medhat had worked for several world-wide recognized industrial organizations such as Rexroth in Germany and CAE in Canada. Medhat has designed several

hydraulic systems and developed analytical and educational software. Medhat also has vast experience in modeling and simulation of dynamic systems using Matlab-Simulink. Medhat was the designer and founder of the Universal Fluid Power Trainers. Medhat was the recipient of the "Otto Maha Pioneers in Fluid Power" award in 2012.

