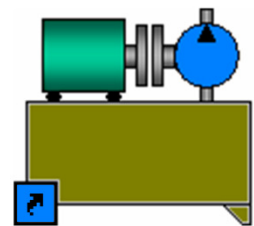


**Hydraulic Systems Volume 8**

# **Advanced Designs for Mobile Applications**

**Dr. Medhat Kamel Bahr Khalil, Ph.D., CFPHS, CFPAL.**  
**Program Manager of Fluid Power Education**  
**Center for Professional Education,**  
**Milwaukee School of Engineering,**  
**Milwaukee, WI, USA.**



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## PREFACE

Hydraulic power has long played a fundamental role in mobile machinery. The high-power density, controllability, durability, and load-handling capabilities of hydraulic actuators make hydraulic systems particularly suitable for machines operating under demanding and highly variable conditions. Consequently, hydraulics continue to provide the primary means of actuation for many functions in construction, agricultural, material-handling, transportation, and other categories of mobile equipment. The mobile machinery industry, however, is undergoing significant technological development. Increasing demands for energy efficiency, reduced emissions, improved productivity, enhanced controllability, and automation are accelerating the integration of hybrid and electrified technologies. Modern mobile machines therefore increasingly combine hydraulic power with electrical and electronic systems, advanced controls, energy-recovery technologies, and alternative power architectures. This book addresses these developments from an application-oriented perspective. It is intended primarily for engineers, technicians, and other industry professionals involved in the operation, maintenance, troubleshooting, and design of mobile machines and their hydraulic systems. The book contains twenty chapters. The first four chapters introduce systems, components, and concepts that are commonly applicable to mobile machinery. The subsequent sixteen chapters examine sixteen categories of mobile equipment. Each category begins with a brief introduction to the machine and its functions and then examines the hydraulically driven functions and representative hydraulic circuits associated with that equipment. Hybrid and electrified configurations are also presented where applicable. The hydraulic systems discussed throughout the book include both generic circuits and examples based on industry applications. Generic circuits are used to explain fundamental principles and system architectures, while industry examples provide a connection between those principles and their practical implementation in mobile machinery. This volume forms part of the author's broader effort to support fluid power education and professional development through the *Hydraulic Systems* series and associated software resources. The series consists of:

- 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. Under Development
- Hydraulic Systems Volume 5: Safety and Maintenance.
- Hydraulic Systems Volume 6: Troubleshooting and Failure Analysis.
- Hydraulic Systems Volume 7: Modeling and Simulation for Application Engineers.
- Hydraulic Systems Volume 8: Advanced Designs for Mobile Applications.
- Hydraulic Systems Volume 9: Advanced Designs for Industrial Applications (Under Development).
- Hydraulic Systems Volume 10: Design Strategies of Hydraulic and EH Systems (Under Development).

**Dr. Medhat Kamel Bahr Khalil**

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Carl was very generous in granting the author permission to use LunchBox Sessions fluid power animations as a foundation for developing and illustrating hydraulic circuit diagrams for mobile machinery throughout this book.

The author greatly appreciates Carl's support and contribution to fluid power education. From a professional and educational perspective, the author also highly recommends LunchBox Sessions to readers who wish to expand their understanding of fluid power systems. Its interactive animations and instructional resources provide valuable visual insights that complement the concepts, circuits, and applications presented in this book.



The author also gratefully acknowledges the following companies and organizations, listed alphabetically, for granting permission to reproduce or adapt portions of their copyrighted materials in this book:

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## ABOUT THE BOOK

### Book Description:

Hydraulic power remains a fundamental technology in mobile machinery because of its high-power density, robustness, and ability to perform demanding functions under widely varying operating conditions. At the same time, increasing requirements for energy efficiency, reduced emissions, improved performance, and advanced control are driving the integration of hybrid and electrified technologies into modern mobile machines. This book provides a practical and application-oriented reference to hydraulic systems and emerging technologies used in mobile equipment. It is intended for engineers, technicians, educators, and other industry professionals involved in the operation, maintenance, troubleshooting, and design of mobile machines. The first four chapters of the book cover conceptually the systems commonly encountered across mobile machines such as hydrostatic transmission, control blocks, steering systems, fan drive systems, hybrid systems, and mobile machine electrification. It then examines sixteen categories of mobile equipment, including construction and road-building machinery, aerial work platforms, material-handling equipment, cranes, mining equipment, trucks, agricultural machinery, tunnel-boring machines, and selected aerospace, marine, military, and railway applications. Each application chapter introduces the equipment and its major hydraulically driven functions, supported by hydraulic circuit diagrams and representative industry examples. Hybrid and electrified configurations are also discussed where applicable, providing readers with insight into both established hydraulic solutions and evolving mobile-machine technologies.

### Book Objectives:

#### Chapter 1: Hydrostatic Transmissions

This chapter, aided by examples from industry, overviews the concepts of travel drive functions in mobile machines. This chapter focuses on the construction and operating principles of HYDROSTATIC TRANSMISSIONS. Among the presented topics are the various configurations of hydrostatic transmissions, the various methods of integrating hydrostatic transmissions in mobile machines, and the various methods of varying the displacement of the main pump.

#### Chapter 2: Control Blocks in Mobile Machines

This chapter, aided by examples from industry, overviews CONTROL BLOCKS construction, central position, architecture that sets the priority of the operations, and methods of actuation. This chapter also briefly presents the difference between using control block versus controlling actuators directly by a pump.

### **Chapter 3: Steering and Fan Drive Systems**

This chapter overviews STEERING and FAN DRIVE systems in mobile machines, with a focus on hydraulic power steering. This chapter presents the construction and operating principle of orbital steering valves including open center, closed center, and load reaction type of steering valves. This chapter also presents the concept of steering in track-drive mobile machines. This chapter also overviews hydrostatic fan drive systems as applied in mobile machines using hydraulic-driven cooling fan systems.

### **Chapter 4: Concepts of Hybrid and Electrified Mobile Machines**

This chapter discusses HYBRID and ELECTRIFIED concepts as applied to mobile machines. This chapter presents various concepts for energy recovery/regeneration and electrification of mobile machines. The presented concepts for energy recovery/regeneration are secondary control, hydraulic fly wheel, and hydraulic-hybrid. This chapter also discusses the feasibility and barriers for mobile machine electrification and emission reduction concepts in semi-electric and full electric mobile machines.

### **Chapter 5: Excavators and Shovels**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in EXCAVATORS & SHOVELS. Among the presented examples are boom functions, arm functions, bucket functions, swing functions, brake functions, travel drive systems, steering systems, cooling systems, and excavator attachments. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 6: Loaders**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in LOADERS. Among the presented concepts are boom functions, passive versus active boom suspension, bucket functions, other auxiliary functions, travel drive systems, steering systems, cooling systems, and attachments. This chapter considers various types of loaders such as wheel loaders, track loaders, swing loaders, backhoes, and skid-steer loaders. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 7: Dozers**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in DOZERS. Among the presented concepts are blade tilt & lift functions, tipping & ripping functions, winch functions, travel drive, steering and cooling systems. It also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

## **Chapter 8: Graders**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in GRADERS. Among the presented concepts are blade tilt & side shift functions, tipping and ripping functions, blade circle drive function, blade articulation function, steering systems, and brake system. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

## **Chapter 9: Road Construction Machines**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in ROAD CONSTRUCTION MACHINES. Among the presented concepts are implement functions, travel drive systems, and steering systems. This chapter considers various types of road construction machines such as trenchers, cold planers, asphalt pavers, and compactors. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

## **Chapter 10: Aerial Work Platforms**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in AERIAL WORK PLATFORMS. Among the presented concepts are implement functions, brake systems, travel drive systems, and steering systems. This chapter considers various types of aerial work platforms machines, such as scissor lifts, boom lifts, manlifts, and aerial ladders. The chapter also presents alternative designs (if applicable) for replacing the conventional functions to run as hybrid or electrified functions for the purpose of reducing the emissions and improving fuel efficiency, and machine performance.

## **Chapter 11: Forklifts and Telehandlers**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in FORKLIFTS AND TELEHANDLERS. Among the presented concepts are implement functions, brake systems, drive systems, steering systems, and attachments. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

## **Chapter 12: Cranes**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in CRANES. Among the presented concepts are implement functions, brake systems, travel drive systems, steering systems, and cooling systems. This chapter considers various types of mobile and

stationary cranes such as truck-mounted cranes, carry-deck cranes, rough terrain cranes, floating cranes, telescopic trains, crawler cranes, tower cranes, gantry cranes, harbor and offshore cranes, and stacker cranes. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 13: Mining Equipment**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic system layout, and the related hydraulic circuit diagrams in material extraction MINING EQUIPMENT. Among the presented concepts are implement functions in open and closed-circuit architectures, cutting head drive function, slewing function, travel drive systems, and steering systems. This chapter considers various types of mining equipment such as coal mine roadheaders, mining crushers, and rotary drilling rigs. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 14: Municipal and Hauling Trucks**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in MUNICIPAL and HAULING TRUCKS. Among the presented concepts are implement functions, hoisting functions, brake functions, travel drive systems, steering systems, and cooling systems. This chapter considers the selected types of vehicles such as municipal garbage trucks, and mining haul trucks. The chapter also presents the effort for replacing the conventional functions to run as hybrid or electrified functions. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 15: Concrete Pumps and Mixes**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in CONCRETE PUMPS and MIXERS. Among the presented concepts are running the drum to mix the concrete and pump the concrete into tubes. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 16: Tractors and AG Machines**

This chapter aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in TRACTORS and AG MACHINES. Among the presented concepts are various implement functions and travel drive systems, steering systems, cooling systems, and attachments. This chapter considers various types of AG machines such as Tractors, Crop Sprayers, Combine Harvesters, Cotton

Pickers, Sugarcane Machines, Corn Harvesting Machines, Silage Machines, Forestry Machines, and Cattle Feed Mixers.

### **Chapter 17: Tunnel Boring Machines**

This chapter overviews the basic construction and operation of TUNNEL BORING MACHINES. It also presents the hydraulic system that controls the thrust cylinders. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 18: Aerospace Applications**

Hydraulic systems are widely used in AEROSPACE APPLICATIONS, whether on the aircraft itself or the other equipment that serves the aircraft on the ground. This chapter presents an example of the hydraulic-powered functions on the aircraft, such as flight control, landing gear, steering, shock absorbing, and braking. This chapter also presents ground services trucks, such as runway snow blowers/brooms, and runway vacuum cleaners. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 19: Marine and Military Applications**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in MARINE AND MILITARY APPLICATIONS. Among the presented concepts are steering systems, winch drives, propulsion systems, stabilizing, missile launchers, rescue and recovery armored vehicles, armored vehicle-launched bridges, air defense mobile radars, and gun elevation systems. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

### **Chapter 20: Railways Applications**

This chapter, aided by examples from industry, presents and explains the hydraulic-driven functions, hydraulic systems layout, and the related hydraulic circuit diagrams in RAILWAYS APPLICATIONS. Among the presented concepts are the dampers in suspension systems, track switching mechanisms, and tie replacement machines. This chapter also presents alternative designs (if applicable) to replace the conventional functions to run as hybrid or electrified functions for the purpose of reducing emission and improving fuel efficiency & machine performance.

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|------------|-------|---------|--------------------|-------|--------------------------|
| Chapter 1  | 38    | 26      | 34                 | 6298  | 339                      |
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| Chapter 3  | 14    | 13      | 15                 | 1778  | 172                      |
| Chapter 4  | 24    | 25      | 28                 | 4344  | 211                      |
| Chapter 5  | 106   | 81      | 86                 | 14752 | 352                      |
| Chapter 6  | 56    | 65      | 60                 | 6658  | 145                      |
| Chapter 7  | 32    | 28      | 30                 | 3464  | 177                      |
| Chapter 8  | 18    | 26      | 18                 | 2107  | 186                      |
| Chapter 9  | 24    | 25      | 27                 | 3832  | 194                      |
| Chapter 10 | 52    | 45      | 47                 | 5630  | 238                      |
| Chapter 11 | 24    | 25      | 27                 | 2402  | 172                      |
| Chapter 12 | 28    | 32      | 36                 | 2742  | 186                      |
| Chapter 13 | 10    | 11      | 12                 | 1077  | 197                      |
| Chapter 14 | 42    | 39      | 42                 | 4518  | 198                      |
| Chapter 15 | 14    | 14      | 19                 | 1968  | 175                      |
| Chapter 16 | 68    | 71      | 71                 | 8039  | 253                      |
| Chapter 17 | 4     | 3       | 5                  | 677   | 152                      |
| Chapter 18 | 28    | 32      | 34                 | 4012  | 194                      |
| Chapter 19 | 18    | 18      | 24                 | 2564  | 174                      |
| Chapter 20 | 12    | 15      | 11                 | 1662  | 175                      |
| Others     | 28    | 0       | 0                  | 0     | 4192                     |
| Total      | 672   | 628     | 657                | 82972 | 4192 Hours/24 = 175 Days |

## Equipment Models:

|                                                                                     |                                                                                      |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| <p><b>Excavators</b><br/><b>Model X1-CAT-385C</b></p>                               | <p><b>Shovels</b><br/><b>Shovels-Model X2-CAT-RH400-6090</b></p>                     |
|    |    |
| <p><b>Excavators</b><br/><b>Model X3-Hitachi-850/870</b></p>                        | <p><b>Excavators</b><br/><b>Model X4-Hitachi-EX1200-7B</b></p>                       |
|  |  |
| <p><b>Shovels</b><br/><b>Model X5-Hitachi-EX8000-6</b></p>                          | <p><b>Excavators</b><br/><b>Model-X6-Hitachi (John Deere)</b></p>                    |
|  |  |

|                                                                                     |                                                                                      |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| <p><b>Dozers</b><br/><b>Model-X7-CAT-D11R</b></p>                                   | <p><b>Dozers</b><br/><b>Model-X8-CAT-D8T</b></p>                                     |
|    |    |
| <p><b>Dozers</b><br/><b>Model-X9-CAT-D8R</b></p>                                    | <p><b>Graders</b><br/><b>Model-X10-CAT-H</b></p>                                     |
|  |  |
| <p><b>Graders</b><br/><b>Model-X11-CAT-M</b></p>                                    | <p><b>Mining Trucks</b><br/><b>Model-X12-CAT-797</b></p>                             |
|  |  |

|                                                                                                                                                      |                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Mining Trucks</b><br/><b>Model-X13-Kumatsu-830E</b></p>       | <p><b>Mining Trucks</b><br/><b>Model-X14-Liebherr-T-282B</b></p>  |
| <p><b>Corp Sprayers</b><br/><b>Model-X15-John Deere-R4038</b></p>  | <p><b>Excavators</b><br/><b>Model X16-Kumatsu-PC210</b></p>      |
| <p><b>Scissor Lifts</b><br/><b>Model X17-Genie-GS-1930</b></p>    |                                                                                                                                                     |

## ABOUT THE AUTHOR (IFPS Hall of Fam Recipient)



**Medhat Khalil, Ph.D.**, is the Program Manager of Fluid Power Education at the Center for Professional Education (CPE) in Milwaukee School of Engineering (MSOE) in Milwaukee, Wisconsin, USA. His academic background includes bachelor's and master's degrees in mechanical engineering earned in Cairo, Egypt, followed by a Ph.D. in Mechanical Engineering and a Postdoctoral Industrial Research Fellowship at Concordia University in Montreal, Quebec, Canada.

Dr. Khalil has extensive academic and industrial experience in fluid power engineering, with particular emphasis on hydraulic systems, professional education, system design, modeling, and simulation. Throughout his career, he has taught fluid power courses to industry professionals in the United States, Canada, India, Mexico, Saudi Arabia, and the United Arab Emirates.

He has worked with internationally recognized organizations, including Rexroth in Egypt and CAE Inc. in Canada. His engineering work has included the design of hydraulic systems and the development of analytical and educational software. He also has extensive experience in modeling and simulation of dynamic systems using MATLAB and Simulink.

Dr. Khalil holds professional certifications from the International Fluid Power Society (IFPS), including Certified Fluid Power Hydraulic Specialist (CFPHS) and Certified Fluid Power Accredited Instructor (CFPAI). His professional affiliations and activities have included the National Fluid Power Association (NFPA), the American Society of Mechanical Engineers (ASME), and the Center for Compact and Efficient Fluid Power (CCEFP).

He is the developer of the **Universal Fluid Power Trainer**, a state-of-the-art training stand designed to support practical fluid power training and instruction.

In recognition of his contributions to fluid power education and industry, Dr. Khalil received the **Pioneers in Fluid Power** recognition from the National Fluid Power Association in 2012 and was inducted into the **Fluid Power Hall of Fame** by the International Fluid Power Society in 2021.

