Industrial Hydraulic Systems
Industrial Hydraulic Systems
-Theory and Practice

JOJI PARAMBATH
Dedicated to

my loving wife Ranjini and my sons Swaran and Siddarth
Preface

The textbook provides an in-depth coverage of conventional hydraulic systems encompassing fixed displacement pumps, control valves, and actuators as well as the most modern hydraulic systems encompassing more efficient variable-displacement pumps, electro-hydraulic proportional valves and/or servo valves with integrated electronics. The coverage is further supplemented by many typical hydraulic and electro-hydraulic circuits. The details of different types of auxiliary devices such as reservoirs, filters, accumulators and piping have also been described in this book. Topics on hydrostatic transmission, cartridge valves, load sensing pump controls, fluids, filters, and seals are given in detail. Design aspects, installation, and maintenance of hydraulic systems are added to make the book more useful to actual practitioners of hydraulic systems. Understanding the fundamental laws and principles allows the reader to use the basic theoretical concepts in practical applications. The unique feature of this textbook is that all quantities are given in the SI system as well as in the English system of units. This book provides an extensive coverage of fluid power to designers, engineers, technicians, and, students of engineering colleges, polytechnics, and vocational training institutes. This book is designed especially with an academic interest in mind. A large number of numerical examples, design problems, and sections for ‘Test your Knowledge’, end of chapter ‘Multiple Choice Questions’, and ‘Short answer Questions’ are included. This book is intended to provide the most current information available on hydraulic technology. A chapter-wise brief follows:

Chapter 1 Industrial Power Systems: From time immemorial, scientists and technologists have been searching for suitable energy sources for the economic and technological development. Apart from the mechanical power transmission system, three other major power transmission systems have been developed for transmitting power in all types of industrial and mobile machinery and equipment. These are electrical, pneumatic and hydraulic power transmission systems. This chapter explains the fundamentals of electrical, hydraulic, and pneumatic power transmission systems. This chapter also presents a brief explanation of different types of power systems.

Chapter 2 Introduction to Hydraulics: The basic concepts of hydraulics are not new. The ancient Greeks understood the power of flowing water. They invented water wheels to harness the energy of flowing water. However, modern industrial hydraulic systems, appropriately called ‘oil hydraulic systems’, utilize oil rather than water as the medium for energy transfer. A study of the underlying principles of hydraulics is most necessary for the proper understanding of the industrial hydraulic systems. This chapter explains the fundamental principles of pressure and flow. This chapter also presents a brief explanation of hydraulic fluids with their most important properties, such as viscosity, viscosity index, and bulk modulus. The basic ideas of laminar and turbulent flows are also given. Finally, the chapter presents the applications, advantages, and disadvantages of hydraulic power systems. A brief explanation of a typical hydraulic system is given for the initial familiarization of the system. A short note on standardization makes an added attraction for this chapter.

Chapter 3 Hydraulic fluids: Since the first use of water as the hydraulic power medium in the 18th century, hydraulics has become an essential branch of engineering science. Greater technological advances have been achieved in the development of numerous fluids for meeting the exacting requirements of hydraulic applications. All hydraulic systems, however, have a common need for protection against harmful contaminants. Good contamination control means cost-effective filtration and fluid analysis. The initial sections of this chapter explain, in detail, the functions, types, characteristics, and selection of hydraulic fluids. The subsequent sections present topics on fluid contamination, the effect of contamination on fluids, fluid analysis, and the quality standards of fluids.
Chapter 4 Basic Hydraulic Filtration Principles: Filters need to be the integral parts of hydraulic systems to ensure the proper operation of their pumps, valves, and actuators. As the requirements of the hydraulic systems are demanding, the prescribed cleanliness levels of their fluid media must be achieved under all operating conditions. For this reason, it is important to understand the different types of hydraulic filters and their performance ratings. This chapter presents the principles of hydraulic system filtration. These principles include the materials of filter media, various designs of filters, and the typical locations of filters in hydraulic systems. This chapter also describes the filter element performance ratings, such as the beta ratio and efficiency, and the multi-pass test to determine such ratings.

Chapter 5 Hydraulic Reservoirs & Accessories: As the usage of hydraulic systems are becoming more widespread, there is a greater need for understanding the function and operation of the essential parts of these systems including power packs. Then we can deal with them confidently. A basic power unit consists of a reservoir to store the fluid, a prime mover to power the system, a pump to move the fluid, a relief valve or pump compensator to control the maximum system pressure, a filter to clean the fluid and plumbing to convey the fluid to components. This chapter takes up a detailed discussion of hydraulic power packs and their constituent parts including reservoirs. This chapter also gives a brief note on the topic of sound reduction techniques in hydraulic systems.

Chapter 6 Hydraulic Pumps: The fundamental purpose of a hydraulic system is to convert the mechanical power from the prime mover into fluid power with the help of a power pack. The power pack that includes a pump is an essential component of the system. As industries face a steadily increasing demand for improved profitability and efficiency, it is imperative to design hydraulic systems with pumps that provide the high-pressure fluid required for these systems. This chapter takes up a detailed discussion on hydraulic pumps that include gear, vane, and piston pumps, and their variants. That is; the operation, constructional features, and the advantages and disadvantages of various types of pumps are explained. A useful explanation of pump cavitation is also given, in brief.

Chapter 7 Hydraulic Pressure Regulation: Several types of pressure control valves have been developed for the accurate pressure controls in hydraulic systems. Apart from the pressure-related controls, regulating the pressure in hydraulic systems is an important safety function, and this objective can easily be achieved by using pressure relief valves (PRVs). This chapter explains the operational characteristics of PRVs. The types, behaviour, characteristic curves, advantages, and disadvantages of PRVs are given for an in-depth study. This chapter also covers the topic on the sizing of PRVs. The functions and applications of other types of pressure control valves are discussed thoroughly in Chapter 12.

Chapter 8 Hydraulic Linear Actuators: Modern manufacturing plants and innumerable other applications require some rapid and controllable linear or rotary mechanical motion with an enormous amount of motive force for carrying out some useful tasks. This motive power can be achieved through the use of hydraulic actuators designed to work at high operating pressures. Hydraulic cylinders are simple, low-cost, and easy-to-install devices that are ideal for generating powerful linear movements. Manufacturers are bringing out various types of actuators with innovative features to make them more reliable, efficient, and safe. The latest industrial hydraulic cylinders can incorporate sensor feedback and electro-hydraulic servo valves for the sophisticated speed control and position control of the associated loads. This chapter deals with hydraulic cylinders of varying designs. The principles of operation, constructional details, and classification of the hydraulic cylinders are explained in detail. This chapter also covers the topics on the applications, advantages, and safety requirements of the cylinders.

Chapter 9 Hydraulic Rotary Actuators: The discussion on hydraulic actuators continued in this chapter with the explanation of rotary actuators. Hydraulic motors are rugged devices that transform the hydraulic power into rotary mechanical power. This chapter deals with hydraulic rotary actuators
of varying designs. The principles of operation, constructional details, and classification of semi-rotary actuators and motors are explained in detail. This chapter also covers topics on the applications, advantages, and safety requirements of the motors.

Chapter 10 Directional Control Valves and Control Circuits: Valves are critical control components used in modern industrial and mobile hydraulic applications in order to control their motion and force output. Typically the requirements are the bi-directional movement, speed control, and pressure-dependent control of the hydraulic actuators. Building a complete control solution may require different types of valves. A wide range of discrete control valves is available for obtaining the direction, pressure, and flow controls. These valves include the directional control valves, non-return valves, flow control valves, and various pressure control valves. This chapter describes the construction, operation, and application of many types of hydraulic directional control (DC) valves including the non-return valves. Hydraulic circuits given in this book may be used as a resource for reinforcing your understanding of hydraulic circuits and as a starting point for fresh designs.

Chapter 11 Flow Control Valves and Control Circuits: This chapter describes the construction, operation, and use of many types of flow control valves. They may vary in construction and design from the simple needle valve to the sophisticated pressure-compensated/temperature-compensated variable flow control valve. These valves are essentially used for getting the speed control and regenerative function in hydraulic systems. This chapter also explains various speed control methods of hydraulic actuators, such as the meter-in, meter-out, and bleed-off methods. Further, this chapter describes the theory and operation of regenerative circuits.

Chapter 12 Pressure Control Valves and Control Circuits: This chapter describes the construction, operation, and application of many types of pressure control valves, such as the pressure reducing valves, sequence valves, unloading valves, counterbalance valves, and brake valves. Several circuits are used in hydraulic systems to get many useful pressure control functions. Simple hydraulic circuits with these types of valves, designed for reducing pressure in some part of the circuit, the sequencing of operations, the unloading of the system pump, and the load holding feature, are illustrated in this chapter to lay a firm foundation for the understanding and development of more complex hydraulic circuits.

Chapter 13 Hydraulic Accumulators: Hydraulic accumulators are a kind of energy modulating devices used in hydraulic systems. When connected to a hydraulic system, the accumulator is meant for performing many vital functions, such as acting as a shock absorber and as a reserve of power in the system. Manufacturers are bringing out different types of accumulators and accessories to suit many application requirements of the hydraulic industry. This chapter describes the types, constructional details, and features of accumulators, in detail.

Chapter 14 Hydraulic Seals: Seals are used in all sorts of hydraulic devices involving linear or rotary motions, mainly to prevent leakage. Even though they form the vital elements in any hydraulic equipment, they are often not given the significance they deserve. Seals with different geometrical shapes and complex material formulations are available in the market, or they can be custom-made to meet the requirements. A proper sealing system is required to be selected out of various options by a designer for the efficient performance of a hydraulic device that is being designed. This chapter presents an elaborate treatment of hydraulic seals for the linear and rotary applications. The process of polymerization and the types of polymers and their characteristics are described. This chapter, further, explains the different requirements of hydraulic seals and the factors that are to be considered for the selection of seals. The classification of seals based on various parameters is elaborated. Finally, issues concerned with rotary seals are presented at the end of this chapter.

Chapter 15 Hydraulic Fluid Conductors and Fittings: Fluid conductors interconnect components of a hydraulic system for the safe and leak-free transmission of high-pressure hydraulic fluid throughout the system. As hydraulic systems are getting more and more complicated with their
operation under increased temperatures and in limited spaces, not only the fluid conductors must put up with these adverse conditions, but also handle the high working pressures, peak surge pressures, and peak flow rates. A vast number of hydraulic applications, demands numerous types of conductors to satisfy the varying individual working requirements and conditions. This chapter presents the necessary information about the constructional features, performance specifications, and other details of pipes, tubing, and hoses and their fittings.

Chapter 16 Electro-hydraulic Systems: An electro-hydraulic system, in general, consists of an electrical or electronic control part controlling a hydraulic power part. Integrating the power density of hydraulic systems with the controlling possibilities of the electric systems opens up a new world of opportunities for the high-performing hydraulic power systems. In this hybrid technology, solenoid valves or proportional valves or servo-valves are used as interfaces between the control part and the power part. The conventional solenoid valve acts as a converter that generates hydraulic outputs in response to electrical input signals. Control and feedback elements like push-buttons (PBs), relays, sensors, and timers are used in the electro-hydraulic systems. This chapter explains the functioning of primary solenoid valves and various electrical control components. Many typical electro-hydraulic circuits are also developed to illustrate various applications of electro-hydraulics.

Chapter 17 Programmable Logic Controllers (PLCs): The emergence of PLCs with more capabilities opened up the door to many control options. This chapter explains the hardware and the software features of PLCs, in an easy-to-understand manner. Many examples are worked out in this chapter explaining how the PLCs can be employed as interfaces between the input and output devices in hydraulic systems.

Chapter 18 Proportional valves: Trends in the valve industry today is towards the use of intelligent hydraulics. With this objective in mind, there is a widespread development of proportional valves complete with transducers and electronic regulators. This chapter explores the technology used in proportional valves and sheds some light on their benefits and shortcomings.

Chapter 19 Servo valves: High-performance closed-loop servo valve technology has become the norm in machine automation, where the requirements are greater precision, faster operation, and simpler adjustment. The high-performance valve in the hydraulic field is represented by an electro-hydraulic servo valve. This chapter explains the technology used in the state-of-the-art servo valves and their benefits and shortcomings.

Chapter 20 Load Sensing Systems: As with other power transmission technologies, the primary goal in designing hydraulic systems is to use less energy and do more work. Designs range from the conventional circuits to special arrangements such as load sensing and regeneration for high-end hydraulic systems for conserving energy. This chapter explains the operation of simple load sensing systems in a simplified manner and with suitable examples.

Chapter 21 Cartridge Valve Systems: With the introduction of cartridge valves in the 1950s, an important innovative approach to the design of hydraulic valves has begun. Initially, the cartridge valve was intended to perform a single function, and therefore a cavity was designed to encompass the valve. Later, the cartridge valve technology has grown to include the multi-function features and the integrated circuit features with many cartridge valves incorporated in a single manifold block. In the recent years, the cartridges valve technology has seen many improvements to reduce the leakage, and its complexity and size, and to increase its reliability, efficiency, and cost-effectiveness. This chapter describes the concepts and constructional features of the basic and the multifunction cartridge valves. The circuit ideas of a variety of multi-function cartridge valves are also presented. This chapter also describes the characteristics of the integrated manifold blocks.

Chapter 22 Hydraulic Applications and Design Features: Where a significant force is required to move an object, there we find the hydraulic actuator. The modern digital control technologies are successfully combined with the power of hydraulics. This integration has increased the application
areas of hydraulics ranging from the small assembly processes to the sophisticated steel and paper mill applications. This chapter highlights various categories of hydraulic applications, and the fundamental and design issues, in a generalized manner. It all starts with a foray into the application spectrum of the hydraulic technology. It is then followed by an explanation of the typical application concepts and the basic operations involved in these applications. This chapter also explains the design aspects of hydraulic systems. Some examples of designing typical hydraulic systems are given in the chapter.

**Chapter 23 Maintenance, Troubleshooting & Safety of Hydraulic Systems:** As modern hydraulic systems are designed with close tolerances, their proper maintenance is the first line of defense to prevent component failures and improve their reliability. The knowledge of various maintenance practices and troubleshooting techniques is essential for a technician to maintain the hydraulic equipment efficiently. This chapter explains all aspects of maintenance, troubleshooting, and safety of hydraulic systems, in a systematic way to make this book more useful on the shop floor.

The author has referred to innumerable articles, catalogs, documents, and handbooks published by hydraulic equipment manufacturers for the incorporating latest information in the book. Many of them are acknowledged in the references at the end of the chapters. Many companies and organizations have given their permissions to use their graphics, and the author wishes to thank them profusely. The author is indebted to his colleagues at Foremen Training Institute (FTI), Bangalore and many industrial experts for the discussions he had with them which helped to clarify points cropped up during the preparation of the book. First of all, the author would like to thank Shri S D Lahiri, Director (AT), DGT, New Delhi for providing great motivation. Next, the author would like to thank Shri J Mukhopadhyay, Shri Ramakrishne Gowda, and Shri Bharat Swamy for critically reviewing the text matter. Appreciation also goes to Mr. Jeff Young, CEO, Universal Publishers Inc. and his excellent publishing team for their support. The author would like to acknowledge the great work done by the Graphic Designer Shri. Harpreet Singh (http://www.DezinoGraphics.com) and his team member Shri. Amit Mukherjee. The author owes a word of thanks to his family and friends for their support.

The author requests all prospective readers offer their valuable comments and suggestions for further improvements. Finally, the book has been completed, and the author hopes you enjoy reading it. Have fun and good luck!

**JOJI PARAMBATH**
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Chapter 1 Industrial Power Systems

LEARNING OBJECTIVES
Upon completing this chapter, you should be able to:

• Specify the necessary components of industrial power systems.
• Describe the power system and control system functions.
• Understand the meaning of mechanization and automation.
• Explain the term fluid power and its primary functions.
• Describe the function of an electrical power system.
• Describe the function of a pneumatic power system.
• Describe the function of a hydraulic power system.
• Differentiate the pneumatic and hydraulic systems.
• Appreciate the combined representation of power systems.
• Compare the electric, hydraulic and pneumatic power systems.

Introduction
Modern industrial production systems are designed to carry out a wide variety of work operations like clamping, moving, lifting, drilling, and turning. Moreover, several applications in mobile systems, aerospace, marine systems, and mining also involve various kinds of work activities. A prime mover provides the muscle power required for driving a load in a production machine. The prime mover is essentially an actuator that is part of a power transmission system consisting of a power source and a control system. Usually, the power source is not at the point where the work operation is to be carried out. The power must be conveyed to the machine’s point of work through the power (or energy) transmission system in a controlled manner. Figure 1.1 shows the basic components of a typical power transmission system. The following sections explain the function and types of power transmission systems.

Power Transmission Systems – Function & Types
The primary function of a power transmission system is to transmit power from its power source to connected loads in a controlled way. Apart from the mechanical means of power transmission, such as clutch pedals or gears, power can also be transmitted through an electron or air or oil medium. Accordingly, there are three main types of power transmission systems. They are (1) electrical, (2) pneumatic, and (3) hydraulic power transmission systems. Remember, pneumatic and hydraulic power systems are commonly categorized under the heading ‘fluid power systems’. A power transmission medium is, usually, modulated by a control system. The subsequent sections give the function, representation, and control options for each type of the power transmission systems. A combined representation of various power transmission systems is given in a subsequent section. A comparison of various power transmission systems is also given at the end of the chapter.
**Electrical Power System**

In the electrical power transmission system, power is transmitted through the medium of electrons flowing through a conductor to an electrical load (motor). The essential elements of the electrical power transmission system are the power source, control elements, and the load. Figure 1.2 depicts the electrical power transmission system. In this system, the power developing device is a generator. Control devices, such as pushbuttons, relays, contactors, timers, sensors, and pressure switches are used to modulate the power transmission medium. Finally, the electric motor converts the transmitted power into rotary mechanical power to perform some useful work. Linear motion can also be obtained from the rotary device, albeit in a cumbersome manner, by employing devices, such as rack-and-pins or belts. Electric motors are easy to control in small systems, and they can be the least expensive.

![Figure 1.2 | A block diagram showing the essential elements of an electrical power system.](image)

**Fluid Power System**

Fluid power involves the employment of a fluid medium, such as air or oil, in a controlled manner to get some useful work. Two specialized areas, namely pneumatics and hydraulics, cover the scope and definition of the term ‘fluid power’. The forces generated by the fluid power systems can be rapidly transmitted over some distance with small losses through a network of pipelines, hoses, and tubing. However, it may be noted that these two branches of the fluid power are fundamentally different in their behavior and performance. Fluid power systems offer many advantages, especially for systems that require high-speed linear motions or smooth position control or holding of heavy loads. They also eliminate the need for a complicated system of gears and levers. These systems help to build compact machines as compared to the case of employing purely electrical or mechanical means of power transmission. The fluid power can also be effectively combined with other technologies through solenoid valves, sensors, transducers, microprocessors, and PLCs. However, the fluid power systems suffer from some disadvantages, such as the contamination of their fluid medium and high cost.

Many applications of fluid power can be seen in our everyday lives. The fluid power is, in fact, the driving force in most industrial and mobile applications. A bulldozer or an excavator used for moving soil where a new project is being built, a chair with a lever for easily moving it up and down, a dentist drill for removing the cavity of a tooth, and the brake used in a car or a truck are examples where the fluid power can be used.

**Pneumatic Power System:** In a pneumatic power transmission, the energy contained in the pressurized air medium is transmitted through piping to a pneumatic actuator. ‘Pneumatics’ is the technological field pertaining to gaseous pressure and flow. Figure 1.3 shows the critical elements of the pneumatic system. It consists of (1) a power source, (2) control valves, and (3) actuators. In this system, a compressor is used as the power source to increase the pressure of a small volume of compressible air to the required level. Remember that the increase in the pressure of the pneumatic system takes place quite slowly. The slow response of the air compressor in developing the system pressure necessitates the storage of compressed air in a receiver tank. The energy that is stored in the receiver tank in the form of compressed air can, then, be transmitted in a controlled manner, through piping, to the pneumatic actuator to perform some useful work.
Two significant advantages of pneumatic systems are that (1) they can produce linear motion without any difficulty and (2) fast-acting systems can be developed using the high-speed pneumatic actuators. Speed control can also be achieved easily by using simple flow control valves. However, a pneumatic system is not suitable for providing a uniform motion. Operating pressures in pneumatics are much lower than that used in hydraulics for the main reason of economic prudence. As the pneumatic systems are designed as low-pressure systems, they are capable of generating only small magnitudes of forces economically. Therefore, the pneumatic systems are ideal for applications that involve small magnitudes of linear forces, but high-speed operations.

**Hydraulic Power System:** In a hydraulic power transmission, the energy is transmitted through the medium of pressurized fluid (oil) to a hydraulic actuator. ‘Hydraulics’ is the technological field pertaining to liquid pressure and flow. Figure 1.4 depicts the basic elements of a hydraulic system. It consists of (1) a power source, (2) control valves, and (3) actuators. In this system, a pump is used as the power source to create the flow and subsequently raise the pressure of the enclosed incompressible oil medium to the required level almost instantaneously. The hydraulic energy can, then, be transmitted through the pressurized oil medium, in a controlled manner, to the hydraulic actuator to perform some useful work.

Like the pneumatic system, the major advantage of the hydraulic power transmission system is that it can generate the linear motion readily through the primary actuator, cylinder. However, the operating pressures in hydraulics are much higher than that used in pneumatics. Therefore, the high-pressure hydraulic systems are capable of generating large magnitudes of forces economically, to drive heavy loads. The speed control of the actuator in the hydraulic system can also be achieved conveniently by regulating the flow rate of the oil medium to the actuator. Precise control of the speed of the actuator even at low values is another advantage of the system. Therefore, hydraulic systems are used in industrial and mobile applications that involve vast amounts of linear forces and the need for extremely accurate controls.

**Control System Functions**

A control system performs many control functions through its controller to govern or regulate industrial work processes. These control functions can be realized through either the open-loop control system or the closed-loop control system. Designers employ the open-loop control in every manual control system, where an operator is always present to initiate actions, such as when to start or when to stop the system. However, in the closed-loop control, as used in an automatic control system, the system controls itself by the feedback of its condition. Remember, the industrial work processes have evolved over a period. The following section explains the evolution of the industrial work processes.
Mechanization and Automation

Industrial work-processes have evolved from manual to mechanization to automation. In the mechanization of a work process, the mechanical work is taken over by a machine that provides the necessary working energy. Automation is the condition of a machine that is being controlled automatically either with limited human intervention or without human intervention at all. Accordingly, the automation can be categorized as either semi-automation or full (complete) automation. In the semi-automation, the machine automatically carries out several recurring steps in the processing of a workpiece through its processor. In this case, the presence of an operator is necessary to initiate every cycle of operations. In the complete automation, the machine takes over the entire work process automatically by means of ‘programmed’ commands to its processor. Automatic pilot devices, like sensors, thermostats, level switches, and pressure switches are invariably used in automation systems to provide information concerning the process variables to their processors.

Motion Control Systems

An important branch of modern automation systems is the motion control system. It is a system that controls the position, velocity, force or pressure associated with a machine. A motion control system uses some mechanical, electric, pneumatic, or hydraulic drives or a combination of these devices. A motion controller is the brain of the motion control system. It is responsible for calculating and generating the output commands for the desired motion path or trajectory. The motion control system is the complex part of robotics and modern CNC machines. It is also extensively used in the printing, packaging, textile, and semiconductor industries.

Combined Representation of Power Transmission Systems

The previous sections explained the functions of electrical, pneumatic and hydraulic power systems. A combined representation of these power systems is now given in Figure 1.5 for demonstrating the inter-relations among these systems. This representation helps the reader to get an overall idea of industrial power systems.

Figure 1.5 | A block diagram showing the combined representations of power transmission systems.
A typical power transmission system consists of a power section and a control section involving power and control signals respectively. The primary function of the control section is to process the control signals in the system through a controller and regulate or control the power section through a final control element. The final control element acts as the interface between the control part and the power part. The control signals can be electrical, electronic, pneumatic or hydraulic in nature, each of which may be in the analog or digital form. It may be noted that bold lines are used to show power signals and shaded lines are used to show control signals in the Figure.

**Comparison of Different Power Transmission Systems**

Choosing the right and efficient form of energy for the drive system in the industry is not an easy task. Its selection depends on various factors. Table 1.1 gives a comparison of different forms of energy medium based on some important criteria as mentioned.

| Table 1.1 | Comparison of different power transmission systems |
| --- | --- | --- |
| **Criteria / Power system** | **Electrical** | **Hydraulic** | **Pneumatic** |
| Energy production | Hydro, fossil-fuelled, nuclear | Pump, electrically-driven | Compressor, electrically-driven |
| Availability of energy transmission medium | Available everywhere | Obtaining and disposing of oil is costly | Air is freely available |
| Maximum distance for energy transmission | Large distance, even beyond 1000 km | Up to 100 m | Up to 1000 m |
| Cost of energy | Smallest | High | Highest |
| Speed control | Limited | Good, especially for slow speed range | Easy, but uniform rate of speed is difficult |
| Linear force | Using rotary to linear conversion devices - Lower forces, lower efficiency, and large size | Using cylinders - Large forces due to high pressure and the possibility of large strokes | Using cylinders - Limited forces due to low pressure, but capable of high-speed operation |
| Rotary force (Torque) | Using electric motors | Using hydraulic motors | Using air motors |
| Overloading | A serious problem | With a relief valve, loadable until standstill | Loadable until standstill |
| Sensitivity to variations in temperature | Insensitive | Sensitive | Relatively insensitive |
| Leakage | Lethal accident risk at high voltages | Loss of energy and environmental fouling | Loss of energy |
Test your knowledge: #1.1

1. ______ is the most suitable power transmission system for designing a machine involving high-speed linear motions.

2. ________________ is the power transmission system where a push at one end of its stiff medium causes the corresponding amount of force to appear at the other end.

3. ___________ power system transmits power is a form of pressurized oil or air.

4. ____________ is the technique of controlling a machine without human intervention.

5. ___________ is the interface between the ‘power section’ and ‘control section’ of a power transmission system.

[Choose from: Automation, Electrical, Fluid, Final control element, Hydraulics, Mechatronics, Motion control, PLC, Pneumatics, Sensor]

Objective Type Questions

1. Large magnitude of linear forces can be obtained easily in:
   a. Mechanical power transmission systems.
   b. Electrical power transmission systems.
   c. Pneumatic power transmission systems.
   d. Hydraulic power transmission systems.

2. Which of the following power transmission systems does provide a fast-acting production system?
   a. Mechanical power transmission system.
   b. Electrical power transmission system.
   c. Pneumatic power transmission system.
   d. Hydraulic power transmission system.

3. Which of the following statements is incorrect?
   a. Pneumatic systems are overload-safe.
   b. Hydraulic systems are insensitive to variations in temperature.
   c. Pneumatic systems are capable of providing high-speed operation.
   d. Hydraulic energy can be transmitted economically typically up to 100 m.

4. Which of the following statements is correct?
   a. The electrical power system provides linear motions in an optimum manner.
   b. The pneumatic power system provides uniform motion of its actuators.
   c. The hydraulic power system is not suitable for getting rotary motions.
   d. A motion control system calculates and generates output commands for the desired trajectory of motion.

5. The function of a controller in a power system is to:
   a. Transmit power through the system.
   b. Regulate the pressure in the system.
   c. Govern the main power system through commands.
   d. Sense the output parameter of the system.
Questions
1. What is an industrial prime mover?
2. What are the essential components of industrial power transmission systems? Explain with a block diagram.
3. What is the primary function of power transmission systems?
4. What are the ways of transmitting power to industrial equipment?
5. State how energy transmissions take place in electrical, hydraulic and pneumatic systems.
6. What is a fluid power system? Explain briefly.
7. What are the main divisions of fluid power systems?
8. List some important basic functions performed by fluid power systems.
9. Give any two examples of how you would use fluid power in your everyday lives.
10. What is the major advantage of fluid power systems?
11. Fluid power systems have many drawbacks. Name any four of them.
12. List any four applications of fluid power systems.
13. List a few advantages of pneumatically-operated systems or machines.
14. List two applications of pneumatics with which you are familiar.
15. List two applications of oil hydraulics.
16. Force developed by a hydraulic cylinder is typically greater than that by a pneumatic cylinder of the same size. Give a reason.
17. Movement of hydraulic cylinders is smooth and steady as compared to pneumatic cylinders. Give a reason.
18. Describe some unique problems faced by fluid power systems.
19. Compare hydraulic and pneumatic systems?
20. Explain why you require ‘control systems’ in power transmission systems.
21. Briefly, describe the evolution of industrial work processes.
22. What do you understand by mechanization and automation?
23. Differentiate between ‘semi-automation’ and ‘complete automation’.
24. Explain the roles played by mechanization and automation in the evolution of industrial work processes.
25. Give one example each of ‘semi-automatic control’ and ‘fully automatic control’.
26. What is a motion control system? Explain briefly.
27. Mention three advantages of hydraulic systems as compared to other power systems?
28. Depict the most general parts of electrical energy transmission system with its block diagram and describe the primary function of each component.
29. Draw the essential blocks of pneumatic energy transmission system and explain.
30. Depict the most important elements of hydraulic energy transmission system with the help of a block diagram and describe the primary function of each element.
31. Compare electrical, hydraulic, and pneumatic power transmission systems in respect of the following parameters: (1) Maximum energy transmission distance, (2) Cost of energy production, (3) Linear force, and (4) Speed control.

References
Chapter 2 Introduction to Hydraulics

LEARNING OBJECTIVES
Upon completing this chapter, you should be able to:
- Define the term ‘hydraulics’.
- Explain the power transmission technique used in hydraulic systems.
- Understand the fundamental aspects of hydraulic fluids.
- Apply Pascal’s law for the analysis of hydraulic systems.
- Explain how pressure is generated in hydraulic systems.
- Explain how force is developed in hydraulic systems.
- Differentiate between laminar and turbulent flows.
- State the importance of the Reynolds number for marking the borderline between the laminar and turbulent flows.
- Understand the effect of viscosity on hydraulic fluids.
- State the importance of specifying the viscosity indices (VIs) of fluids.
- Describe the basic elements of a typical hydraulic system.
- Discuss the advantages and disadvantages of hydraulic power.
- Understand the importance of standardization.

Introduction
Hydraulics is the branch of engineering sciences concerned with the transmission of energy, using incompressible fluids, for performing some useful mechanical tasks. Hydraulic systems conventionally involve the generation of pressures and the development and control of the enormous amount of forces. The conventional hydraulics can well be integrated with electronics as well as cartridge valve technology for adapting to the demanding requirements of many modern-day applications. Hydraulic technology has now advanced into a full-grown branch of engineering sciences with the development of powerful pumps, smarter valves, and precise actuators. You may note that engineers built this technology around a number of fundamental laws and concepts. Further, this technology must conform to various national and international standards.

This chapter, with the systematic presentation of the basic ideas of mechanics, fluids, pressure, flow, and force, aims to help the reader lay a firm foundation for his/her hydraulic knowledge. This basic knowledge is necessary for the systematic understanding of the complex hydraulic components/systems described in the succeeding chapters. A typical hydraulic system is also described with a schematic diagram and its corresponding circuit diagram, more or less at the closing stages of the chapter. The advantages and disadvantages of hydraulic systems are also presented towards the end of the chapter.

In the field of hydraulics, there are two primary classes of systems based on the behaviour of their power transmission media. They are (1) hydrodynamics and (2) hydrostatics. The differentiating characteristics of these two systems are presented in the following section.

Hydrodynamics Vs Hydrostatics
Hydrodynamics stands for the study of liquids in motion with high flow rates, but with low pressures. It is concerned with such matters as friction and turbulence generated by the flow of liquids through pipes and water flowing through nozzles. For example, a water wheel, as shown in Figure 2.1(a), represents a hydrodynamic device where power is transmitted by the impact owing to the kinetic energy of a high-speed stream of liquid from an impeller directed against its vanes.

Hydrostatics stands for the study of fluids at rest. It involves topics on buoyancy and flotation, the study of pressure on dams and submerged devices, and the design and development of industrial...
and mobile hydraulic equipment. Hydrostatic systems usually operate through confined fluids under high pressures, but with low flow rates. The relative incompressibility of the fluids is a necessity in these systems. In the hydrostatic system, as illustrated in Figure 2.1(b), exerting a ‘push’ onto a confined incompressible fluid transmits power. The fluid must flow to cause the motion, but the flow is only secondary to the force output. You may observe that the power transmission takes place because the confined fluid is subjected to the pressure. Most of the industrial hydraulic machines in use today, work hydrostatically.

**Hydraulics – Definition**

The term hydraulics is derived from the Greek ‘hydruleikos’, meaning water flowing through a pipe. So, hydraulics may be defined, in a broad sense, as the science of transmitting force or motion or both through the medium of pressurized liquid to power or control machines. Study of hydraulics is all about knowing how to produce a definite pressure by using the force generated by a power source and the reverse process of how to develop and control a force to drive a load by using the pressure.

**Advent of Oil Hydraulics**

Initially, water was used as the medium of energy transfer in industrial hydraulic systems. Water has the main advantage of fire-resistance. However, it has many limiting features, such as low lubricity and narrow range of working temperatures. Further, it promotes the rusting and corrosion of the metal parts that are exposed to it. These limitations prevented the use of water as the energy transfer medium in hydraulic systems.

Therefore, system manufacturers were on the lookout for more appropriate types of fluids for hydraulic systems. Petroleum-based oils, developed in the late nineteenth century, were found to be highly incompressible and capable of operating at high pressures. Moreover, they were found to have suitable viscosity range, and good lubricating, corrosion-resistant, and heat-transfer properties. As the advantages of the petroleum oils were so overwhelming, system designers started using them for the industrial hydraulic systems. That marked the beginning of ‘Industrial Hydraulics’ or ‘Oil Hydraulics’.

The introduction of seal materials based on synthetic rubber enabled the widespread use of compatible mineral oils in a majority of modern hydraulic systems. The exceptions are applications where fire-resistance or biodegradability of the fluid is of paramount importance.

**Basic Hydraulic Systems**

A pump, as used in a hydraulic system, is required to provide the most important function of drawing the fluid from the system reservoir and then pushing it into the system. Any resistance encountered by the flow results in the development of pressure in the system. The resistance to flow develops due to a variety of reasons including the applied load on an actuator in the system. The high-pressure fluid for a hydraulic system can be provided under a constant-flow condition or a constant-pressure condition or under varying conditions of pressure and flow to match the applied load in the system as