The general definition of a system is a set or group of principles, beliefs, things or parts that form a whole, such as a system of government, an accounting system, a mountain system, or the digestive system. The parts of a system work together to produce a desired end result. This chapter introduces the basic design, structure, and operation of fluid power systems.

Objectives
After completing this chapter, you will be able to:
■ Explain the functions of fluid power systems.
■ Identify the basic structure of fluid power systems.
■ List the basic component groups involved in the structure of fluid power systems.
■ Describe the function of the components involved in basic fluid power systems.
■ Describe the similarities and differences of hydraulic and pneumatic systems.
■ Explain the operation of basic hydraulic and pneumatic systems.

Selected Key Terms
The following terms will be used in this chapter. As you read the text, record the meaning and importance of each. Additionally, you may use other sources, such as manufacturer literature, an encyclopedia, or the Internet, to obtain more information.
- actuators
- adapters
- component groups
- compressor
- conductors
- control valves
- cylinders
- directional control valves
- filters
- fittings
- flow control valves
- fluid conductor
- fluid maintenance devices
- heat exchanger
- hoses
- lubricator
- mechanical coupler
- motors
- pipes
- power unit
- pressure control valves
- pressure regulator
- prime mover
- pump
- receiver
- reservoir
- separator
- system functions
- tubes

Internet Resources
  Eaton Fluid Power Group
  Start up and maintenance manual for one model of Eaton hydraulic power unit. Shows the information available for installation and operation.
- www.science.howstuffworks.com/hydraulic.htm
  How Stuff Works, Inc.
  Provides a variety of articles on how hydraulic machines work. Includes basic concepts as well as short videos on machine operation.
- www.hydraulicspneumatics.com
  Hydraulics and Pneumatics magazine
  Contains articles covering many aspects of both hydraulic and pneumatic components and systems.
- www.energymanagertraining.com/equipment_all/compressors/07_ca.htm
  Ingersoll-Rand
  Review of the essential items involved in stationary compressor-station design and operation. Click through to the home page to identify worldwide applications and installations.
- www.ifps.org/education/whitepapers
  International Fluid Power Society
  Downloadable papers devoted to various fluid power topics. Papers have been developed by a number of individuals and companies.
- www.nfpa.com/education/edu_learningopps_selfpacedfundamentalspneumatic.asp
  National Fluid Power Association
  Introduces basic concepts, terminology, applications, and automation processes used throughout the fluid power industry.
Functions of Fluid Power Systems

Fluid power systems are made up of component groups containing parts designed to perform specific tasks. These component groups act together to perform the work desired by the system designer. The work may involve simple or complex tasks, but the component groups perform specific system functions that are basic to all fluid power systems. There are five functions that are basic to system operation of any fluid power system, Figure 2-1:

- Energy conversion.
- Fluid distribution.
- Fluid control.
- Work performance.
- Fluid conditioning.

Each of these functions must be performed by a fluid power system if the system is to operate efficiently and provide a reasonable service life. The operating environment, power output, and complexity of the system establish the number of components required to perform a particular function.

Energy Conversion

Fluid power systems do not generate energy, but transform it into a form that can be used to complete a task. The process begins with a prime mover pressurizing a fluid. It ends with an actuator using the energy stored in the pressurized fluid to perform work.

Fluid Distribution

The operation of fluid power systems requires the distribution of fluid to the components in the system. Various types of lines are involved in this function. Valves and other components also serve to assist in fluid distribution.

Fluid Control

Fluid power systems require the control and regulation of the fluid in the system to perform the tasks desired by the system designer. A number of different components are used to control fluid flow rate, direction, and pressure in a system. Control of these three elements allow the system to provide the desired operating characteristics.

Work Performance

Using the energy stored in the pressurized fluid of the system is the primary function of a fluid power system. This process involves actuators that convert the energy stored in the fluid to linear or rotary motion to perform the desired work.

Fluid Conditioning

Fluid power system performance and service life require a fluid that is clean and provides lubrication to system components. This function involves storing fluid, removing dirt and other contaminants, and maintaining proper system operating temperature.

Structure of Fluid Power Systems

The physical appearance of fluid power systems vary considerably, depending on the type of fluid used, application, and power output. However, each system is structured using component groups that perform the various system functions. The structure of typical fluid power systems involves five component groups, Figure 2-2:

- Power unit.
- Actuators.
- Conductors.

Control Valves

Three different types of valves are required to perform the fluid control function in a fluid power system. The valves in the control valves group are:

- Directional control valves.
- Pressure control valves.
- Flow control valves.

Directional control valves provide control over fluid flow direction in sections of a system to start, stop, and change the direction of actuator movement. Pressure control valves are used to limit the maximum pressure of the system or in a section of the system. Flow control valves provide control over fluid flow rate in a section of a system to control the rate of movement of an actuator.
Fluid Conditioning

The fluid conditioning group involves maintaining and conditioning system fluid. This requires removal of dirt and moisture from the fluid and assuring proper operating temperature. Specially designed components are available to perform these tasks. However, basic systems often maintain the fluid using other system components that perform the task as a secondary function. Filters are used to remove dirt and moisture from systems, although a properly designed reservoir can perform this task under certain conditions. Maintaining the proper system operating temperature can require the use of a heat exchanger. However, this task is usually performed by dispensing heat through the reservoir, system lines, and other components.

Basic System Components

Fluid power systems are constructed of various components that perform the specific system functions. The number and appearance of components required to perform these functions varies considerably depending on the complexity and accuracy of the work performed, the environment in which the system operates, and the manufacturer of the component. Understanding the operation of fluid power systems requires an understanding of the construction and operation of the components that form the structural groups of the system. Refer to Figures 2-3 and 2-4.

Power Unit

The appearance and structure of the power unit in a fluid power system can vary considerably, depending on the application of the system. In basic systems, the power unit consists of a prime mover, pump, reservoir or receiver, mechanical coupler, and the fluid conductors required to make the unit operational. Terminology and design vary somewhat between pneumatic and hydraulic systems, but direct comparisons can be made between the two systems. For example, in pneumatic systems, the power unit is generally referred to as the compressor, Figure 2-5. On the other hand, in hydraulic systems, the power unit is called a pump, Figure 2-6.

Figure 2-5. A typical pneumatic system compressor unit (power unit). The prime mover in this application is a gasoline engine.

Figure 2-6. A basic hydraulic fluid power system. Note the components and their relationships to each other.

The prime mover of a system is usually an electric motor or an internal combustion engine. However, gas or steam turbines may be used to power large industrial operations. System size, operating environment, and mobility are factors that determine the device selected as the prime mover. Prime movers range from fractional horsepower electric motors and small single cylinder gasoline engines to gas turbines producing thousands of horsepower.

The pump or compressor is the heart of a fluid power system. These components produce the fluid
flow used to transmit energy from the prime mover throughout the system. As the prime mover turns the pump or compressor, varying pressure conditions are created within the units that cause fluid to enter, move through, and then exit into the system. One of several different designs may be used in a fluid power system, Figure 2-7. However, each design involves an intake area in which a lower-than-atmospheric pressure is created and an outlet area in which a higher-than-atmospheric pressure is generated.

The reservoir is the storage area for oil in a hydraulic system. The unit may be a simple box-like container or it may be a cavity in the base of a machine that serves to store system fluid. A pneumatic system uses a receiver to store compressed air. This unit is usually a cylindrical tank. The reservoir or receiver also plays other important roles in system operation, such as contributing to system temperature control and fluid cleaning.

The other components that complete the basic power unit are a mechanical coupler and fluid conductors. The mechanical coupler is used to connect and align the power output shaft of the prime mover and the pump or compressor shaft to assure smooth transmission of energy between the components. A fluid conductor is used to move fluid from the reservoir to the pump and from the compressor to the receiver.

**Actuators**

Actuators are the components that convert the energy in the system fluid to mechanical movement to perform the work for which the system was designed. Cylinders and motors are the two basic types of actuators used in fluid power systems. Cylinders provide linear motion, while motors provide rotary movement. A variety of specially designed actuators provide combinations of these motions for specific applications.

**Cylinders**

A basic cylinder consists of a cylinder body, cylinder end caps, piston, piston rod, ports, and seals, Figure 2-8. A closed chamber is produced in the cylinder body when the end caps are attached to the body. The piston rod is attached to the piston and this assembly is located in the chamber with the rod extending through one of the end caps. The closed chamber is divided into two parts by the piston. Appropriate seals are located between the end caps and cylinder, piston and cylinder, and piston rod and end cap.

Forcing fluid into the cylinder through a port causes the piston rod to move out of the cylinder on the extension stroke and back into the cylinder on the retraction stroke. This produces linear motion for use in a machine, Figure 2-9 shows a cylinder used in the steering system of a lawn tractor.

**Motors**

Fluid power motors have many of the same basic design characteristics as pumps. There are several different motor designs, ranging from simple to very complex. A basic motor consists of a housing, rotating elements, power output shaft, ports, and seals. The housing provides a closed chamber to retain system fluid. The rotating elements divide the housing chamber into intake and outlet sections. The power output shaft is attached to the rotating elements. Ports are provided in both the intake and outlet sections of the housing chamber. Seals are provided to prevent leakage of fluid between the housing and rotating elements and between the housing and the power output shaft.

Forcing fluid into the motor causes the rotating elements to turn the power output shaft. This produces rotary motion for use in a machine, Figure 2-10 shows a fluid power motor in an agricultural application.

**Figure 2-6.** A typical basic hydraulic system power unit. (Continental Hydraulics)

**Figure 2-7.** The internal parts of a vane-type pump. The vane design is used in both hydraulic pumps and pneumatic compressors. (Continental Hydraulics)

**Figure 2-8.** A cross section of a fluid power cylinder. (Used with permission of CNH America LLC)

**Figure 2-9.** A typical fluid power cylinder. This cylinder is used to assist the steering of a lawn tractor.

**Figure 2-10.** A typical fluid power motor (red component). The construction of motors and pumps is similar. Several different designs are used in fluid power systems.
Conductors

Conductors confine the system fluid as it is distributed throughout the system. Pipes, tubes, and hoses are the three general types of conductors used in fluid power systems. Special manifolds consisting of multiple passageways are used in systems where space and weight are important factors. The type of conductor used depends on the type of fluid, system pressure, required component movement, and the environment in which the system operates. This group of components also includes a variety of fittings and adapters to allow easy assembly while assuring a system free from leaks.

Pipes are rigid conductors commonly used in stationary fluid power installations. Piping is lower in cost than most other conductors with comparable specifications. The pipe designed for use in fluid power systems is made from mild steel. It is manufactured as seamless.

Tubes are similar to pipes, but are considered to be semirigid. Tubing for use as a conductor in fluid power installations is made from thin steel. Tubing is lightweight, easy to install, has a good appearance, and develops few leaks during system operation, Figure 2-11.

Hoses are flexible conductors made from layers of materials. They contain system fluid while withstanding system pressure and allowing easy movement of system components. Hose construction includes an inner tube to contain the fluid, a middle section of braided fabric or wire to withstand pressure, and an outer layer of material for protection from dirt and abrasion, Figure 2-12.

Fittings and adapters are needed to assemble conductors and other system components. Fittings are considered the parts needed to assemble similar conductors, while adapters are required when connecting different types of conductors or when attaching conductors to system components.

Control Valves

Control valves are the components that make it possible to establish the direction of movement and the maximum force and speed of a system actuator. These characteristics are achieved by controlling fluid flow direction, pressure, and flow rate in the system. Many different designs of valves are available to achieve these characteristics. These designs range from simple, basic valves to extremely complex devices. However, each of these designs can be placed under a basic classification of directional control, pressure control, or flow control.

Directional control valves regulate the direction of actuator movement by creating flow paths to and from the actuator. A basic control valve consists of a valve body, internal elements that open and close fluid flow paths through the valve, an external device for shifting the internal elements, ports to connect the valve to the system, and sealing devices to prevent fluid leakage, Figure 2-13.

When a directional control valve is used in a fluid power system, it directs fluid to one side of the internal elements of an actuator, causing the actuator to move in one direction. Fluid from the other side of the actuator’s internal elements flows through the valve and is returned to the system (or atmosphere). Shifting the valve creates a flow path to the opposite side of the internal elements of the actuator, causing the actuator to move in the opposite direction.

Pressure control valves regulate pressure in the system or a part of the system. These components are used to control maximum system pressure, limit pressure in a part of the system, or delay the movement of an actuator until a desired pressure is reached. A basic pressure control valve consists of a valve body, internal elements that control fluid flow through the valve, an external device to allow adjustment of the valve, ports to connect the valve to the system, and appropriate sealing devices.

In a hydraulic system, the basic pressure control device is called a pressure regulator, Figure 2-15. Regulators are located at each workstation in a hydraulic system. A regulator is an open valve that allows air to move through without resistance until a desired pressure is reached. Once the desired pressure is reached, the internal elements of the regulator begin to close, allowing only enough air to pass through to maintain the desired pressure.

Flow control valves regulate fluid flow in the system or a part of the system. These valves control the volume of flow by varying the size of an orifice in the passageway through which the system fluid flows. A basic flow control valve consists of a valve body, internal elements to control flow through the valve, an external mechanism to allow adjustment of the valve, ports to connect the valve into the system, and appropriate seals to prevent fluid leakage, Figure 2-16.

The passageway in a basic flow control valve provides an open route for fluid flow through the valve. The volume of fluid flow through the valve.
Fluid Power is controlled by the size of the passageway opening. Adjusting the size of the passageway varies the flow volume, which controls the speed of system actuator(s). The larger the opening, the higher the volume of flow through the valve and the higher the speed of the actuator(s).

Fluid Conditioning Devices

Various devices are used to assure the system fluid is free of contaminants and operating within an acceptable temperature range. Proper care of the fluid has a major effect on the performance and service life of components and the overall system. The type of conditioning devices required in a system is directly related to the complexity of the components and the environment in which the system operates.

Filters are the most common conditioning devices incorporated in fluid power systems, Figure 2-17. They remove foreign particles and other contaminants. Filters are located in various places of a system to safeguard specific components, as well as the overall system. Three typical locations are:

- In the intake line for the system.
- In high-pressure working lines.
- In the lines that return fluid from system actuators.

A basic filter consists of a filter housing, filter element, bypass valve, and ports to connect the filter into the system. Many different filter designs are used in fluid power systems. In a typical basic filter, fluid enters the filter housing through the inlet port, is routed through the filter element, which removes contaminants, and is then directed back into the system through the outlet port. If the filter element becomes clogged with contaminants, the bypass valve opens and routes fluid around the filter element.

A pneumatic system includes two additional fluid conditioning devices: a separator and a lubricator. The separator removes water droplets from the compressed air. The filter and separator are often combined in one unit called a separator-filter. The lubricator adds a fine mist of oil to the air for lubrication of system components, Figure 2-18.

The hydraulic system reservoir also serves as an important component for fluid maintenance. A well-designed reservoir helps control temperature by dissipating heat, trapping contaminants, and allowing air trapped in the system oil to separate and escape.

The receiver also serves as a fluid maintenance device in the pneumatic system. The receiver allows water droplets and other contaminants to settle out of the compressed air. The device also helps control the temperature of the system by allowing heat to dissipate.

Basic System Operation

Individual fluid power components must be assembled into a system to convert, distribute, and control the energy provided by the prime mover and produce the work desired from a machine. The basic systems described in this section include components from each of the five component groups and provide directional, pressure, and speed control of an actuator. Basic system examples are provided for both hydraulic and pneumatic systems to illustrate the structural characteristics of each system and the inherent differences between the systems.

Basic Hydraulic System

A basic hydraulic system is illustrated in Figure 2-19. The system includes an electric motor that serves as the prime mover. The prime mover produces the energy needed to operate the system and perform the work required of the actuator. The system contains basic components from each of the component groups to allow operation and control of a cylinder.

As the electric motor turns the pump, pressure differences are created within the system.
As a result, oil moves from the reservoir into the intake line of the pump and through a system filter where impurities are removed. Continued rotation of the pump forces oil into the system lines (conductors) where it is distributed to other system components.

The first system component the oil encounters as it is forced through the system lines is the pressure control valve, which is used to set system pressure. Next is the directional control valve. This valve directs the oil to the actuator (a cylinder in this example). Forcing oil into the actuator causes the actuator piston and rod to move (either extend or retract). Oil already in the actuator on the other side of the piston is moved out into system lines and returned to the reservoir through the directional control valve.

The speed at which an actuator moves depends on the rate of oil flow into the actuator. In a basic system, actuator extension speed is controlled by placing a flow control valve in the line between the directional control valve and the actuator. Closing the valve reduces the size of the orifice, which restricts oil flow though the valve. This restricted flow reduces the rate of actuator movement. Opening the valve enlarges the size of the orifice, which increases oil flow and the rate of actuator movement.

Restricting flow using a flow control valve affects the system in ways other than controlling actuator speed. The pump moves more oil into the system in front of the flow control valve than the lines and valves in that part of the system can accommodate. Attempting to force the oil into an inadequate space causes system pressure to rise high enough to damage system components. A pressure control valve located between the pump and the directional control valve protects the system from this potentially damaging high pressure. The pressure control valve is set at a pressure that is safe and appropriate for the system. The internal elements of the pressure control valve begin to open when system pressure approaches the valve setting. Oil that cannot be moved into the actuator passes through the pressure control valve and is returned to the reservoir. See Figure 2-22.

The pressure increase causes the pressure control valve to open, returning excess oil to the reservoir. The flow control valve continues to supply a set volume of oil to the actuator until the actuator is fully extended or the load on the actuator slows or stops movement.

During retraction of the actuator the oil returning to the reservoir must pass through the flow control valve. Oil movement through the valve orifice is reversed, but continues to be at a reduced flow rate, which slows the retraction speed of the actuator. A one-way check valve is often included in a flow control valve to allow free flow of oil around the restrictive orifice. This design allows the actuator to be retracted at maximum speed.

This system illustrates the structure and operation of a typical basic hydraulic system. The size, arrangement, and complexity of components varies from system to system, but the basic system functions remain the same.

**Basic Pneumatic System**

A basic pneumatic system is illustrated in Figure 2-23. The system includes an electric motor as the prime mover, which provides the energy to compress the air used for system operation. The system also contains basic components from each of the other component groups to allow operation and control of a cylinder.
As the electric motor turns the compressor, pressure differences are created within the system. As a result, atmospheric air enters the compressor through an intake-line filter that removes airborne dirt. The compressor compresses the air and forces it into an air receiver. The air is held in the receiver in compressed form until it is distributed through lines to other system components. See Figure 2-24. A pressure switch controls the prime mover. The compressor functions only when additional air is needed to maintain the desired pressure in the receiver and the distribution lines leading to system workstations.

The first system component the compressed air encounters after it moves out of the receiver through system lines to a workstation is a separator-filter. See Figure 2-25. This component removes droplets of condensed water and any remaining dirt particles. The air then moves to a regulator, which controls the operating pressure at the workstation. The operating pressure maintained by the regulator is always less than the pressure at the receiver.

The compressed air next moves to the lubricator. This device adds a fine mist of oil to the air. The oil lubricates any components through which the air flows. A directional control valve is the next component in the basic pneumatic circuit. This valve directs the air to the actuator, such as a piston in a cylinder, causing the actuator to move. Existing air from the other side of the piston is returned through a system line to the same valve where it is exhausted to the atmosphere. Shifting the directional control valve directs airflow to the opposite side of the piston, which reverses the actuator. Air from the other side of the piston is exhausted to the atmosphere through the valve. See Figure 2-26. When the actuator is fully extended or retracted, it simply stops moving. The actuator also stops moving when it encounters a load heavier than it can move. This is possible because of the compressibility characteristic of air and the overall design of the pneumatic system.
Accurate control of actuator speed in a pneumatic system is difficult because of the compressibility of air. To provide the best control in a basic system, the flow control valve is placed in the return line between the actuator and the directional control valve. Adjusting the flow control valve changes the size of an orifice in the valve. The larger the orifice, the higher the airflow and the higher the actuator speed. Reducing the orifice size reduces actuator speed.

During actuator operation, air is routed through the flow control valve before it is returned to the directional control valve, where it is then exhausted to the atmosphere. This placement of the flow control creates pressure on both sides of the actuator piston, which produces a more-uniform actuator speed. During actuator retraction, system airflow must pass through the flow control valve before entering the actuator. Flow through the valve orifice is reversed, but the size of the orifice still controls the airflow rate, slowing the retraction speed of the actuator. A one-way check valve allowing free flow of air around the restrictive orifice is often used to allow the actuator to be retracted at maximum speed.

This system illustrates the structure and operation of a typical pneumatic system. The size, complexity and arrangement of the components varies from system to system, but the basic system functions remain the same.

**Chapter Test**

Answer the following questions. Write your answers on a separate sheet of paper.

1. Fluid power systems are made up of ______ containing parts designed to perform specific tasks.
2. The tasks of fluid power system component groups can be classified under one of five functions. List these five functions.
3. The fluid control function of a fluid power system controls system pressure and fluid flow ______ and ______.
4. The number and appearance of components in a fluid power system is influenced by the type of ______, application, and ______.
5. The basic actuators used in fluid power systems are ______ and ______.
6. Fluids are distributed throughout a fluid power system by components referred to as ______.
7. Shifting a(n) ______ control valve creates a new fluid flow path in the system, which controls actuator movement.
8. The basic pressure control valve in a hydraulic system is a(n) ______ valve that does not ______ until a desired system operating pressure is reached.
9. The maximum pressure in a basic pneumatic system is set by a(n) ______ that remains ______ until the desired pressure is reached.
10. Flow control valves control the volume of flow by varying the size of a(n) ______ through which system fluid flows.
11. Fluid power system filters may be located in one or more of three typical locations. List these three locations.
12. Removal of water droplets from pneumatic systems is the responsibility of the ______.
13. During retraction of a cylinder, free flow around a flow control valve is provided by a one-way ______.
14. In the pneumatic fluid power system, after the pressurized system air has completed its work, it is exhausted to the ______.
15. In a pneumatic system, a preset maximum system pressure is established by a(n) ______ electrical switch, which controls the operation of the compressor.