Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-13: Pneumatic and hydraulic systems

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Actuation systems

Actuation systems are essential components of control systems that play a pivotal role in converting the electronic or electrical signals generated by a microprocessor or control system into physical actions or movements to control a machine or device. They bridge the gap between the abstract control signals and the tangible, real-world response required to achieve a specific task or function.

To provide a clearer definition:

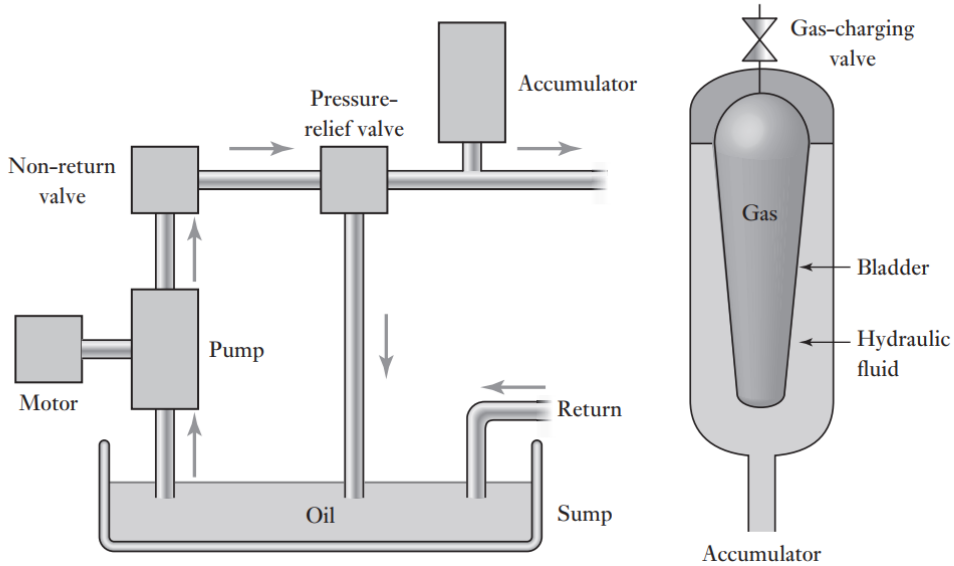
1. **Input Signal**: Actuation systems take an input signal, typically generated by a microprocessor or control system, which represents the desired action or control.
2. **Transformation**: They perform the necessary transformation of this input signal into a form that can drive a mechanical, electrical, or hydraulic action. The specific transformation method depends on the nature of the control required. For instance, it might convert electrical signals into linear motion, rotational movement, or fluid flow regulation, depending on the application.
3. **Controlling Action**: The primary purpose of an actuation system is to generate a controlling action. This controlling action could involve moving a mechanical load, adjusting a valve or damper, regulating the flow of a liquid or gas, or performing any other physical task needed to achieve the desired system response.
4. **Interface**: Actuation systems often act as the interface between the control system's electronic signals and the mechanical or physical components of the machine or device being controlled.

Hydraulic System

A hydraulic system is a mechanical system that utilizes the properties of pressurized fluid (usually oil) to transmit power and control mechanical components. Let's clarify the components and operation of a hydraulic system using an example:

Components of a Hydraulic System:

1. **Electric Motor**: An electric motor is used to drive a hydraulic pump. It converts electrical energy into mechanical energy to create fluid pressure in the hydraulic system.
2. **Hydraulic Pump**: The pump draws oil from a sump and pressurizes it. This pressurized oil is essential for generating the force and motion needed in hydraulic systems.
3. **Non-Return Valve**: This valve is positioned to prevent the backflow of oil from the hydraulic system to the pump. It ensures that the pressurized oil flows only in one direction.
4. **Accumulator**: The accumulator serves as a storage and pressure-regulating component. It holds hydraulic fluid under pressure and helps stabilize pressure fluctuations in the system.
5. **Pressure-Relief Valve**: This valve is a safety mechanism designed to release excess pressure in the system, ensuring it doesn't exceed safe levels.



(a) (b)

Operation of the Hydraulic System:

Suppose you have a hydraulic system in an industrial machine, such as a hydraulic press. When you want to perform a task, like compressing a material or lifting an object, here's how the system works:

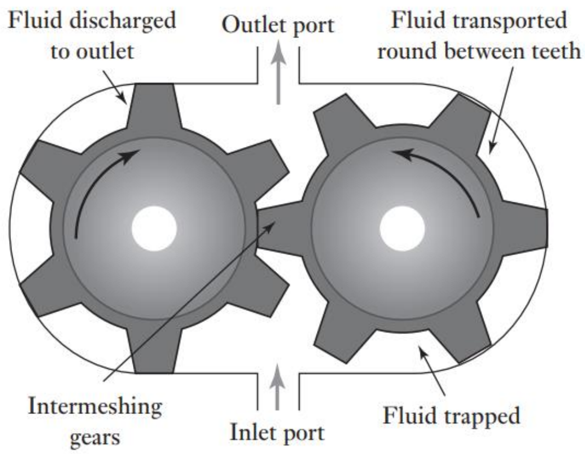
1. The electric motor drives the hydraulic pump, which draws oil from the sump. The pump pressurizes this oil.
2. The pressurized oil is then sent into the hydraulic system to perform the required mechanical action, such as moving a hydraulic cylinder, actuating a valve, or operating a hydraulic motor.
3. As the system operates, pressure may vary due to changes in the load or other factors. This is where the accumulator comes into play. It acts as a pressure stabilizer. If the pressure rises too high, the pressure-relief valve releases excess pressure to maintain safety. If the pressure drops, the accumulator helps maintain system pressure by allowing the bladder to expand, reducing the volume of oil and increasing its pressure.
4. The hydraulic system continues to perform its task, with the pressure remaining within safe and desired limits.

By using this hydraulic system, you can efficiently control heavy loads or precise movements, making it suitable for various applications such as industrial machinery, construction equipment, and automotive brake systems, among others. The accumulator, in particular, plays a crucial role in ensuring that pressure remains stable and safe for the system's operation.

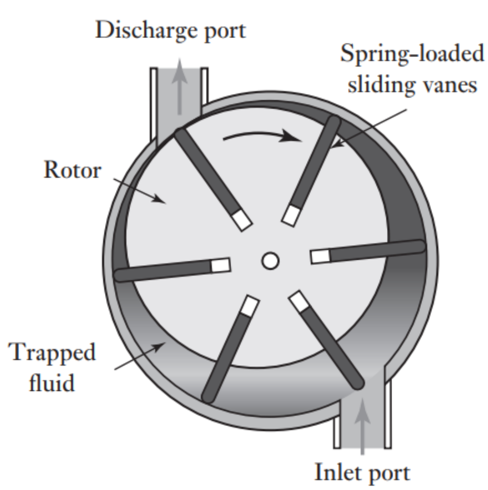
Hydraulic pumps and their characteristics

1. **Gear Pump**:
    - Construction: A gear pump consists of two closely meshing gear wheels that rotate in opposite directions.

- Operation: Fluid is trapped between the rotating gear teeth and the housing, forcing it to move from the inlet port to the outlet port.
- Characteristics: Gear pumps are low cost and robust. They typically operate at pressures below about 15 MPa and at 2400 rotations per minute (RPM). The maximum flow capacity is around 0.5 m^3/min.
- Limitations: Gear pumps are susceptible to leakage between the gear teeth and the casing, as well as between the interlocking teeth, which can limit their efficiency.

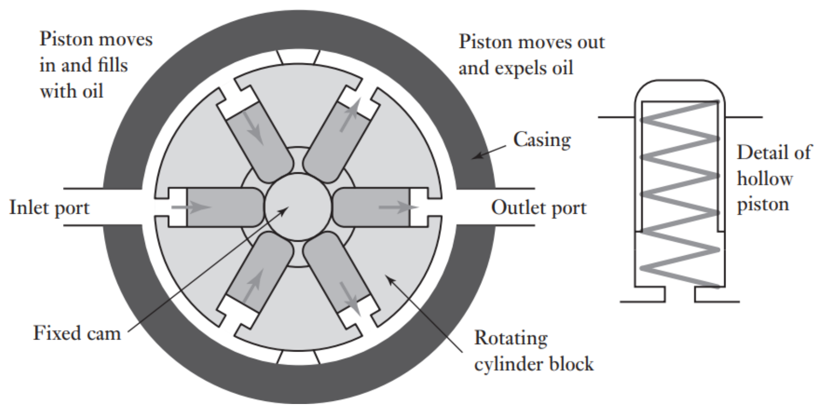


2. **Vane Pump**:
   - Construction: Vane pumps consist of spring-loaded sliding vanes slotted in a driven rotor.
   - Operation: As the rotor rotates, the vanes follow the contours of the casing, trapping fluid between successive vanes and the casing, and transporting it from the inlet port to the outlet port.
   - Characteristics: Vane pumps offer lower leakage compared to gear pumps, resulting in improved efficiency.



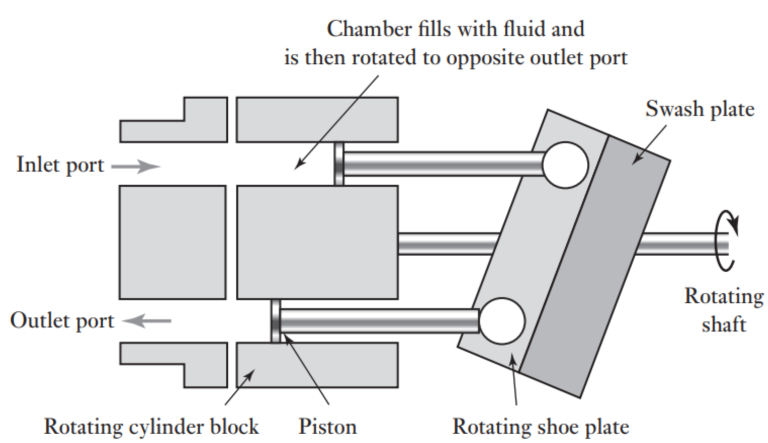
3. **Radial Piston Pump**:

- Construction: Radial piston pumps include a cylinder block that rotates around a stationary cam. Hollow pistons with spring return mechanisms move in and out within the cylinder block.
- Operation: The rotating cylinder block causes fluid to be drawn in from the inlet port and transported for ejection from the discharge port.
- Characteristics: These pumps are known for their high efficiency and can be used at higher hydraulic pressures compared to gear or vane pumps.



4. **Axial Piston Pump**:

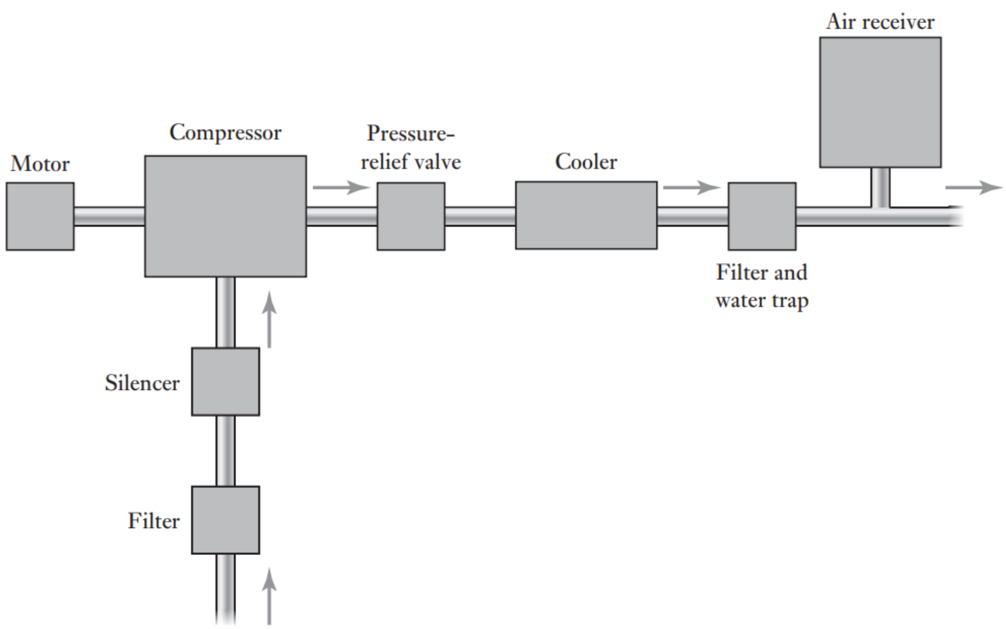
- Construction: Axial piston pumps have pistons that move axially (along the axis) rather than radially. The pistons are arranged axially in a rotating cylinder block.
- Operation: The movement of the pistons is controlled by contact with a swash plate, which is at an angle to the drive shaft. As the shaft rotates, the pistons are made to move, resulting in the suction of fluid when a piston is opposite the inlet port and expulsion when it is opposite the discharge port.
- Characteristics: Axial piston pumps are highly efficient and are suitable for higher hydraulic pressures.



Pneumatic System

A pneumatic system is a mechanical system that utilizes compressed air as a power source to perform various tasks, such as moving objects, actuating tools, or controlling equipment. Let's clarify the components and operation of a typical pneumatic power supply system using an example:

Components of a Pneumatic Power Supply System:



1. **Electric Motor**: An electric motor drives an air compressor, which is responsible for compressing air to create a source of high-pressure, compressed air.

2. **Air Compressor**: The air compressor is the heart of the pneumatic system. It draws in ambient air and compresses it to a higher pressure level, creating a source of stored energy in the form of compressed air.

3. **Air Inlet**: The air inlet to the compressor is likely to be equipped with a filter. The filter helps remove particulate matter and impurities from the incoming air, ensuring that the air supplied to the compressor is clean.

4. **Silencer**: A silencer is often used to reduce the noise generated by the air compressor during the compression process, making the system more operator-friendly.

5. **Pressure-Relief Valve**: This valve is a safety mechanism that protects the pneumatic system from excessive pressure. It opens to release excess pressure if it rises above a safe level, preventing damage to the system or equipment.

6. **Cooling System**: Since the air compressor increases the temperature of the compressed air, a cooling system may be employed to lower the temperature to an acceptable level. This can be crucial to prevent overheating and maintain system efficiency.

7. **Filter with Water Trap**: To ensure the compressed air is clean and free from contamination and moisture, a filter with a water trap is often used. It removes water vapor and any remaining impurities from the compressed air.

8. **Air Receiver**: An air receiver is essentially a storage tank that holds a reserve of compressed air. It helps increase the volume of air available in the system and acts as a buffer, smoothing out any short-term pressure fluctuations.

Operation of the Pneumatic Power Supply System:

Let's consider an example in manufacturing where a pneumatic system is used to power a variety of tools and machines. Here's how the system works:

1. The electric motor drives the air compressor, which sucks in ambient air through the filtered air inlet.

2. The air compressor pressurizes this incoming air, creating a supply of compressed air.

3. The compressed air is stored in the air receiver, which acts as a reservoir, ensuring a continuous and stable supply of compressed air.

4. Pressure fluctuations in the system are smoothed out by the air receiver.

5. The compressed air, now at a higher pressure and cleaned of impurities and moisture by the filter and water trap, is ready for use.

6. This high-pressure air can be directed to pneumatic tools or machines, where it is used to actuate cylinders, operate valves, move objects, or perform other mechanical tasks.

7. The pressure-relief valve acts as a safety feature, releasing excess pressure if it reaches an unsafe level.

Pneumatic systems find applications in various industries, including manufacturing, automotive, and aerospace, where clean and reliable compressed air is used to power a wide range of equipment and tools. The system components described above ensure the efficient and safe operation of the pneumatic power supply.

Different types of air compressors

1. **Reciprocating Compressor**:

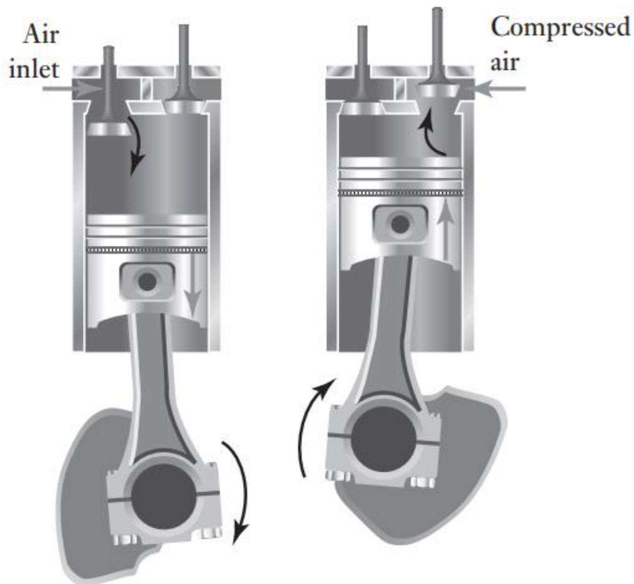
    - Construction: A reciprocating compressor uses a piston that reciprocates inside a cylinder.

    - Operation: During the intake stroke, the descending piston draws in air through a spring-loaded inlet valve. When the piston rises, the trapped air is compressed. When the pressure reaches a certain level, the spring-loaded outlet valve opens, allowing the compressed air to flow into the system.

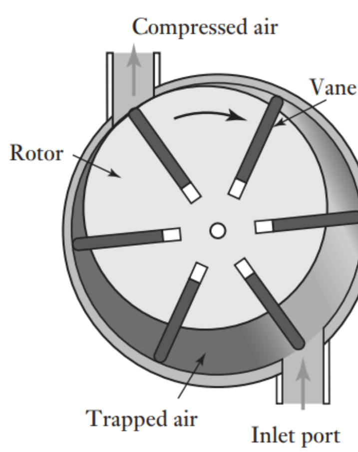
    - Characteristics:

        - Single-acting compressors produce one pulse of compressed air per piston stroke.

- Single-stage compressors go directly from atmospheric pressure to the required pressure in a single operation.
- Double-acting compressors produce pulses of compressed air on both the up and down strokes of the piston.
- For higher pressures, multiple stages are used. Typically, two stages are used for pressures up to about 10 to 15 bar.

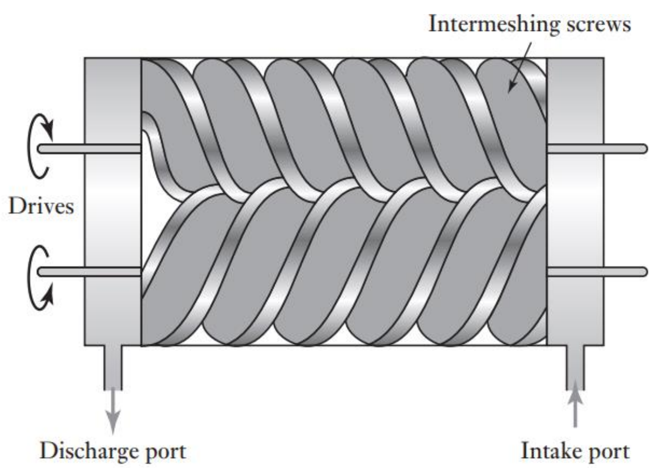


2. **Rotary Vane Compressor**:
   - Construction: A rotary vane compressor consists of a rotor with vanes that are free to slide in radial slots. The rotor is mounted eccentrically in a cylindrical chamber.
   - Operation: As the rotor rotates, air is trapped in pockets formed by the vanes. The pockets become smaller, compressing the air. Compressed air is then discharged from the compressor.



- Characteristics:
    - Single-stage rotary vane compressors are used for pressures up to about 800 kPa with flow rates ranging from 0.3 to 30 m^3/min of free air delivery.

3. **Rotary Screw Compressor**:
    - Construction: A rotary screw compressor consists of two intermeshing rotary screws that rotate in opposite directions.
    - Operation: As the screws rotate, air is drawn into the casing through the inlet port and is moved along the length of the screws. The space between the screws progressively becomes smaller, compressing the air. The compressed air is then discharged from the compressor.



- Characteristics:
    - Single-stage rotary screw compressors can be used for pressures up to about 1000 kPa with flow rates ranging from 1.4 to 60 m^3/min of free air delivery.

Valves

Valves are essential components in both hydraulic and pneumatic systems, responsible for controlling and regulating the flow of fluids (liquid in hydraulic systems and air or gas in pneumatic systems). There are two primary categories of valves, finite position valves and infinite position valves, each serving distinct purposes.

Finite Position Valves:

1. **On/Off Valves**: These valves have two positions, typically fully open or fully closed. They are used to allow or block fluid flow entirely. Examples include:
    - **Directional Control Valves**: These valves control the flow direction, enabling the fluid to be directed to different actuators or paths within the system. Common types include two-way, three-way, and four-way directional control valves.

- **Solenoid Valves**: Solenoid valves are often used to switch various hydraulic or pneumatic components on or off using an electromagnetic coil to control the valve's position.
- **Ball Valves**: Ball valves are simple mechanical valves that use a spherical ball to control flow. When the ball is turned 90 degrees, the flow is either completely opened or closed.

Infinite Position Valves:

2. **Proportional Valves**: These valves offer infinite control over the flow rate or actuator force, allowing precise adjustment between fully open and fully closed positions. Examples include:
   - **Proportional Directional Control Valves**: These valves allow you to vary the flow rate to control the speed and force of actuators. They are commonly used in applications requiring precise and variable control, such as controlling the movement of a hydraulic cylinder.
   - **Flow Control Valves**: Flow control valves regulate the rate of fluid flow, allowing you to adjust the speed of an actuator or control the flow rate in a process control scenario.
   - **Pressure Control Valves**: These valves control the pressure within the system, ensuring that it remains within specified limits.

Example:

Consider a hydraulic system used to control the movement of a robotic arm in a manufacturing facility:

- A directional control valve (finite position) is used to switch between extending and retracting the hydraulic cylinder that controls the arm's movement. It allows the flow of hydraulic fluid to be directed to the actuator or blocked, enabling precise control over the arm's motion.
- To control the speed of the arm's movement, a proportional directional control valve (infinite position) is employed. It allows for precise adjustment of the flow rate, enabling the operator to control the arm's speed with high accuracy.

In this example, the finite position valve is used for basic on/off control of the hydraulic cylinder, while the infinite position valve enables fine-tuned control over the arm's movement speed, making it suitable for delicate tasks that require variable force or precise positioning.

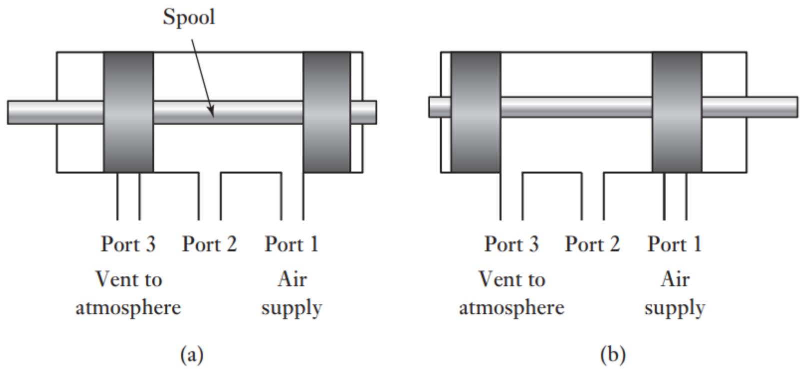
The choice between finite and infinite position valves depends on the specific requirements of the application, including the need for simple on/off control or variable and precise regulation of flow or force.

Directional control valves

Directional control valves play a crucial role in both pneumatic and hydraulic systems. These valves are primarily designed for switching the direction of fluid flow within a system, and they are often employed as on/off devices, which means they can be either completely open or completely closed. Below, we'll discuss two common types of directional control valves: spool valves and poppet valves.

1. Spool Valve:

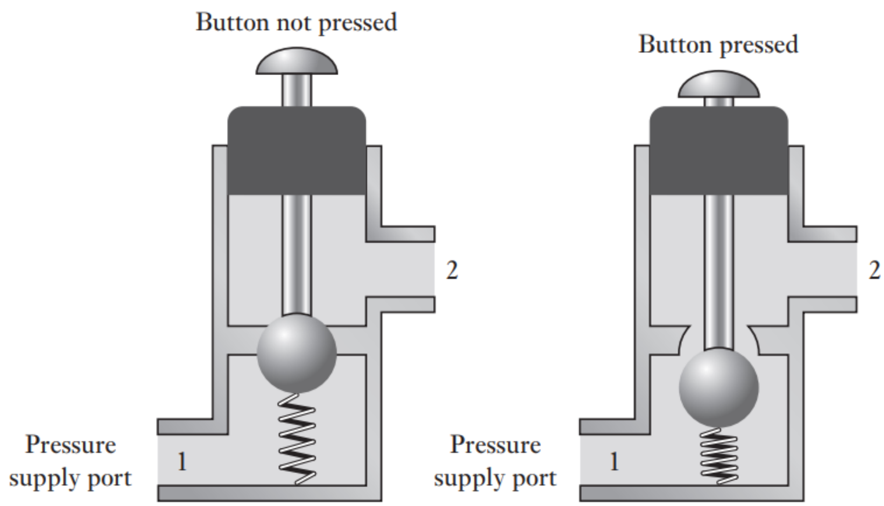
- **Operation**: A spool valve uses a horizontally moving spool within the valve body to control the flow of fluid. When the spool is in one position, it allows fluid flow between specific ports, and when moved to another position, it redirects the flow.



- **Example**:
  - In Figure (a), the air supply is connected to port 1, and port 3 is closed. This configuration pressurizes the device connected to port 2.
  - When the spool is shifted to the left, as shown in Figure (b), it cuts off the air supply to port 2 and connects port 2 to port 3, which is vented to the atmosphere. As a result, the air pressure in the system attached to port 2 is vented, reversing the flow. Thus, the spool valve allows for the reversal of fluid flow.
- **Variations**: There are rotary spool valves that use a rotating spool to open and close ports in a similar manner.

2. Poppet Valve:

- **Operation**: A poppet valve, like the one depicted in Figure, is typically in the closed condition with no connection between port 1 (pressure supply) and port 2 (the system).



- **Example**:
    - When the push-button is depressed, it forces the ball (or another element, such as a disc or cone) out of its seat. This action establishes a connection between port 1 and port 2, allowing fluid flow.
    - Releasing the push-button allows a spring to force the ball back against its seat, effectively closing off the flow.

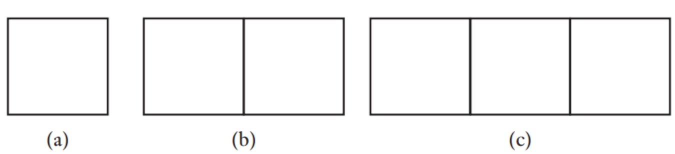
Directional control valves, whether spool or poppet valves, are critical for the proper operation of hydraulic and pneumatic systems, allowing for the controlled and precise switching of fluid flow direction. They can be actuated using various methods, including mechanical means (such as push-buttons or levers), electrical signals, or fluid pressure signals. These valves are fundamental components in creating sequenced control systems and ensuring that fluid flow is directed as needed within the system.

Valve symbols

Valve symbols are a standardized way to represent different types of valves in engineering and control systems. These symbols provide a clear and concise visual representation of a valve's function, the number of switching positions, and the flow paths it controls. Here's an explanation of the information conveyed by valve symbols and some specific examples:

Valve Symbol Components:

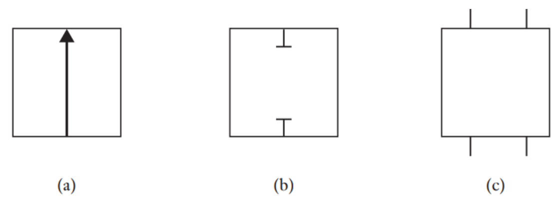
1. **Squares**: Squares in the valve symbol represent each of the valve's switching positions. The number of squares corresponds to the number of switching positions the valve has. For example, a two-position valve has two squares, as shown in Figure (b), and a three-position valve has three squares, as shown in Figure (c).



Valve-switching positions: (a) just one, (b) two, (c) three.

2. **Contents of Squares**:

In Figure, the diagram illustrates how flow paths are indicated within the squares of a valve symbol, showing the different air paths that are possible in each switched state of the valve. This is important for understanding how the valve functions and what happens in each position. Here's a clear explanation of the elements in Figure:



(a) Flow path, (b) flow shut-off, (c) initial connections.

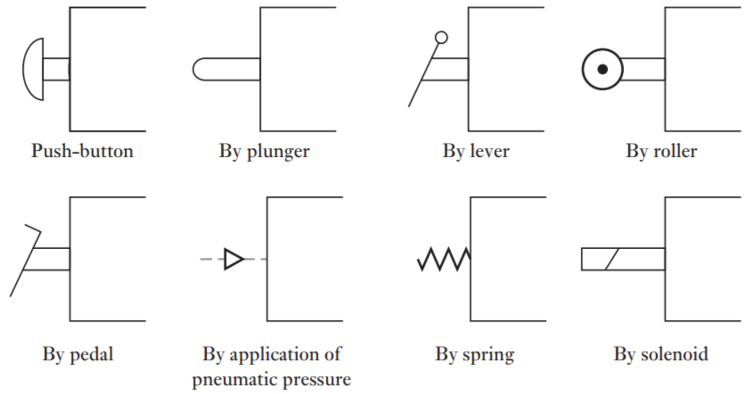
Squares: Each square represents a different switching position or state of the valve. The number of squares corresponds to the number of positions the valve has. In these squares, the possible flow paths are depicted.

Arrow-Headed Lines: Arrow-headed lines are used to indicate the directions of air flow within the valve symbol. The direction of the arrowhead shows how air flows from one port to another in each position of the valve. For example, if the arrow points from the left to the right, it indicates that air flows from the left port to the right port in that specific state.

Blocked-Off Lines: Blocked-off lines, often represented as lines with a perpendicular "stop" sign-like symbol (⊤), indicate closed flow paths. In other words, no air is allowed to pass through these paths in that particular switching position. The blocked-off lines prevent airflow between specific ports, closing off that path.

- In the first square (the left square), an arrow-headed line indicates that air flows from port 1 to port 2. This means that in this switching position, the valve allows air to pass from port 1 to port 2.
- In the second square (the right square), the same arrow-headed line shows that air flows from port 1 to port 2, indicating that this flow path remains open in this switching position.
- In both squares, there are no blocked-off lines, which means that the flow path between port 1 and port 2 is open and not obstructed in either switching position.

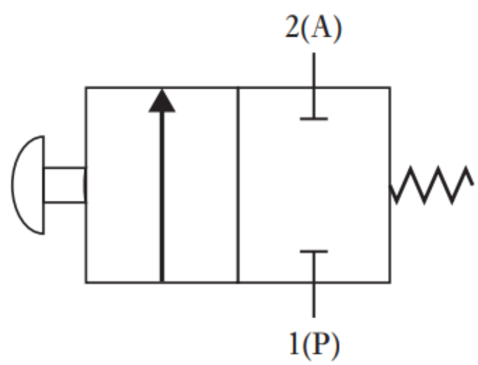
3. **Actuation Symbols**: Symbols may be added to the valve symbol to indicate how the valve is actuated or controlled.



Valve actuation symbols.

Example Scenarios:

1. **Poppet Valve**: In Figure, a poppet valve is shown with a ball and spring mechanism. When the push-button is pressed, it pushes the ball out of its seat, allowing flow between ports 1 and 2. Releasing the button causes the spring to push the ball back into its seat, closing off the flow.



The poppet valve symbol

In Figure, a poppet valve is illustrated, along with its switching situation and means of actuation. This type of valve is commonly used in pneumatic and hydraulic systems. Here's a clear explanation of how the poppet valve works in two different states, one with the button not pressed and one with the button pressed:

Initial State (Button Not Pressed):

- Port 1: Closed (No connection to port 2)
- Port 2: Closed (No connection to port 1)

In this state, the valve is in its initial position, and it's essentially closed. There is no direct path between ports 1 and 2, which means that no air or fluid can flow from one port to the other. This state is maintained by a spring, which keeps the valve in this closed position. It's like the valve is "at rest," blocking the flow between the two ports.

Actuated State (Button Pressed):

- Port 1: Connected to port 2
- Port 2: Connected to port 1

When the push-button is pressed, it actuates the valve, causing it to change to a different state. In this actuated state, there is a direct path between ports 1 and 2. Port 1 is now connected to port 2, and port 2 is connected to port 1.

Example Scenario: Let's imagine a practical example of this poppet valve in a pneumatic system:

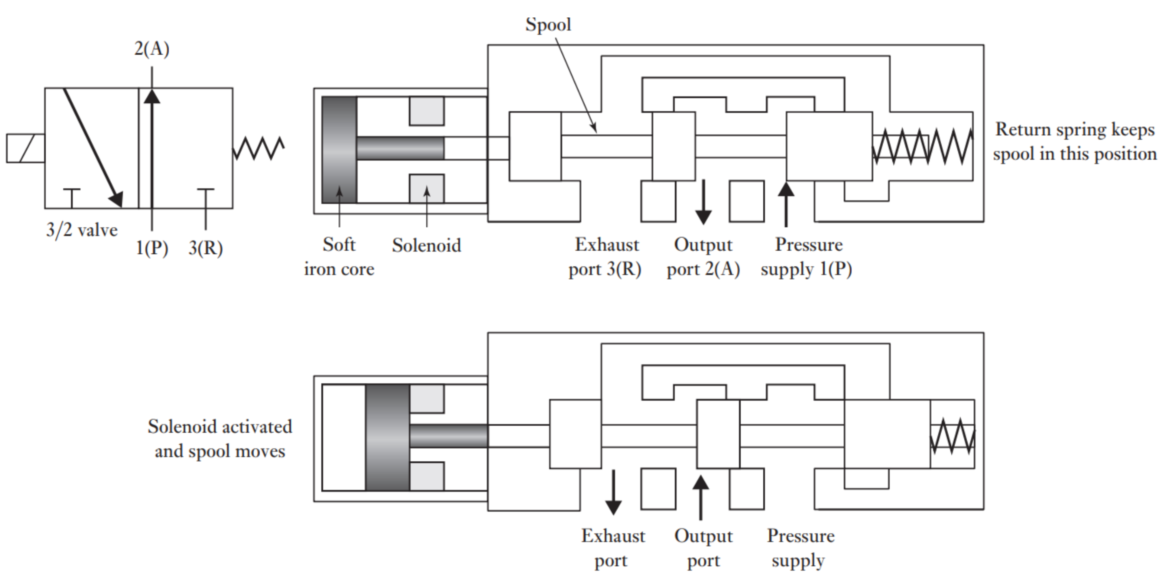
Suppose this valve is part of a pneumatic machine that needs to perform a specific action, such as lifting a platform. When the button is not pressed, the valve is in its initial state, keeping the ports closed and preventing air from flowing between them. This means that the platform remains stationary.

However, when an operator presses the button, the valve switches to the actuated state, allowing air to flow from port 1 to port 2 (or vice versa). This sudden flow of air activates a pneumatic cylinder, which in turn raises the platform. The platform will continue to rise as long as the button is pressed because the valve maintains the path between ports 1 and 2.

As soon as the operator releases the button, the spring inside the valve returns it to the initial state, closing the path between the ports. This stops the flow of air, and the platform remains in its elevated position. The valve returns to the rest position, and the system is ready for the next operation.

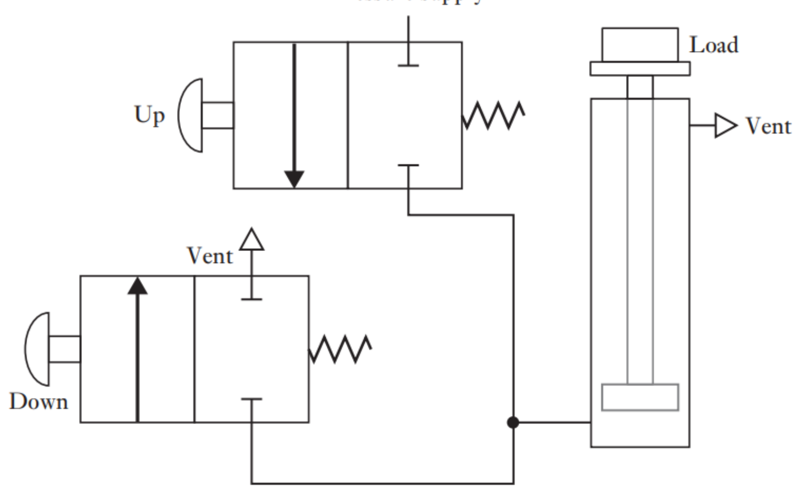
In this way, the poppet valve, when actuated by the push-button, controls the flow of air, enabling or stopping the desired action in a pneumatic system. These valves are commonly used in various applications where precise control over fluid or air flow is needed, and their operation can be easily managed by pressing a button or activating a control mechanism.

2. **Solenoid-Operated Spool Valve**: In Figure, a solenoid-operated spool valve is illustrated along with its symbol. The valve is actuated by a solenoid coil, and a spring returns it to its original position when the solenoid is not energized.



Single-solenoid valve

Example Scenario: Elevator Control



Let's consider a practical example of this pneumatic lift system, which is often analogous to controlling an elevator:

- When you press the button for going "Up," the "Up" valve allows air to flow from port 1 to port 2. The pneumatic pressure causes the elevator to ascend. The excess air not used in lifting the elevator is vented to the atmosphere to maintain controlled pressure.
- When you press the button for going "Down," the "Down" valve cuts off the air supply to port 2, causing the elevator to descend. Again, any excess air is vented, maintaining safe operation.

In this way, the push-button valves provide a simple yet effective means to control the direction of movement in a pneumatic lift system. The two valves, one for "Up" and one for "Down," allow for precise and convenient control of the load or object being lifted or lowered, which is a common application in various industries, including construction, manufacturing, and transportation.