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Pneumatic Automation in Modern Industrialisation: Curriculum Innovation and Skills Alignment in Mechanical Engineering Education

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Abstract

Pneumatic automation has become a crucial component in modern industrialization, offering a reliable and efficient means of controlling and automating various industrial processes. Being akin to mechanical engineering education in universities, one expects its full inclusion into the curriculum of such universities. However, a study conducted by this paper showed that the best universities for Mechanical Engineering in Nigeria teach Fluid/Applied Fluid Mechanics but not Pneumatics as a core course. This paper not only explores the fundamentals of pneumatic systems, their circuits and applications, but also the advantages and benefits of Pneumatic Automation in modern industrial development for sustainability. The paper calls for the proper inclusion of pneumatic studies in the curriculum of mechanical engineering education. The curriculum of a total number of 68 best universities that offer Mechanical Engineering in Nigeria, as listed by EduRank, was fairly looked into to find if they included pneumatic study as a core course. However, there was no specific indication of pneumatics as a core course in all the listed universities; rather, allied courses like Fluid and Applied Fluid mechanics were taught to students. Undoubtedly, while Fluid Mechanics and Pneumatics complement each other, Fluid/Applied Fluid Mechanics deal with fluid fundamental principles like fluid dynamics, hydraulic systems, turbo-machinery as in fluid power systems, Pneumatic study specifically focuses on the use of compressed air to transmit power, which includes design and control of pneumatic systems and components, circuits and system analysis. Pneumatic applications are typically used in industrial automation, robotics, process control and mechatronics. So by implication, as long as air is being used as a medium for transmission of power in industries, acquisition of pneumatic knowledge and skills remains the bedrock for efficient operation, proper maintenance and sustainability of such industries. Pneumatic courses and skills prepare mechanical engineers for industries like manufacturing, automotive, and aerospace, where pneumatic systems are widely used and, as such, deserve adequate inclusion in the mechanical engineering curriculum.

***Keywords**: Pneumatic Automation, Mechanical Engineering Education, Industrial Sustainability, Curriculum Development, Fluid and Applied Fluid Mechanics*

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1. Introduction

Pneumatic automation refers to the use of compressed air or gas to automate industrial processes, machinery, and equipment. It involves the application of pneumatic systems, components, and controls to perform specific tasks, such as:

1. Motion control: linear or rotary motion
2. Actuation: opening/closing valves, cylinders, or grippers
3. Process control: regulating pressure, flow, or speed

A pneumatics course is highly relevant to the mechanical engineering curriculum, offering practical applications in:

1. Automation and control systems
2. Industrial machinery design
3. Robotics and mechatronics
4. Fluid power systems

It provides essential knowledge on:

1. Pneumatic system design
2. Component selection
3. Circuit analysis
4. Troubleshooting

Pneumatic automation is widely used in various industries, including manufacturing, packaging, food processing, and automotive, to improve efficiency, productivity, and safety [1]

1.2 Key Components include:
1. Compressors
2. Air tanks
3. Valves (solenoid, manual, or pneumatic)
4. Actuators (cylinders, air motors)
5. Sensors and controls

Benefits are:
1. Increased efficiency
2. Improved productivity
3. Reduced labour costs
4. Enhanced safety
5. Flexibility and adaptability

Pneumatic automation, according to [2], is a reliable and cost-effective solution for many industrial applications. For years now, pneumatic actuation has become a crucial component in modern industrial automation, offering a reliable, efficient, and cost-effective solution for various applications. Compared to other actuation methods, such as electric or hydraulic, pneumatic actuation provides unique advantages that make it an attractive choice for many industries. The advantages of pneumatic actuation include cost-effectiveness because pneumatic systems are often less expensive to install and maintain compared to electric or hydraulic systems. In terms of reliability, pneumatic actuators are simple in design, reducing the likelihood of complex failures and making them more reliable in harsh industrial environments.

Pneumatic systems are flexible and can be easily adapted to various applications, including linear and rotary motion, and can be integrated with other automation components. Pneumatic actuators can provide high speeds and forces, making them suitable for applications that require rapid motion or heavy loads. Pneumatic systems are often safer than electric or hydraulic systems, as they do not pose electrical shock hazards or risk of oil leaks [3]

1.3 Applications of Pneumatic Actuation
Writing on applications of pneumatic actuations, [4] stated that Pneumatic actuation is widely used in various industries, including:

1. Manufacturing: assembly lines, material handling, and machine tools
2. Packaging: filling, capping, and labelling machines
3. Food Processing: sorting, packaging, and conveying systems
4. Automotive: assembly lines, testing, and inspection systems
5. Pharmaceutical: filling, capping, and packaging machines

1.4 Comparison to Other Actuation Methods
While electric and hydraulic actuation methods have their own advantages, pneumatic actuation offers a unique combination of cost-effectiveness, reliability, and flexibility that makes it an attractive choice for many industrial applications. Electric actuation, for example, may offer higher precision and control, but may be more expensive and complex. Hydraulic actuation, on the other hand, may provide high forces and stiffness, but may require more maintenance and pose environmental risks due to oil leaks [5]

1.5 Pneumatic Systems
A pneumatic system is a system that uses compressed air to transmit and control energy. Pneumatic systems are used in controlling train doors, automatic production lines, mechanical clamps, etc., as shown in the Figure. 1

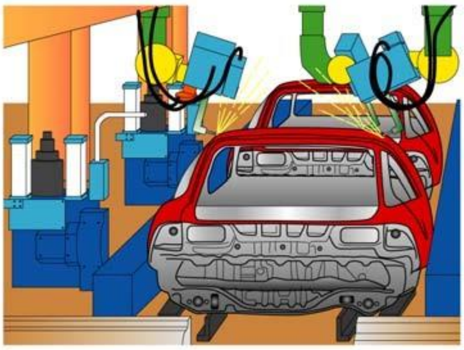


Figure 1: Common pneumatic systems used in the industrial sector (a) [6]
(a) Automobile production lines (b) Pneumatic system of an automatic machine

1.5.1 The advantages of pneumatic systems
According to [4] and [7], pneumatic control systems are widely used in our society, especially in the industrial sectors for the driving of automatic machines. Pneumatic systems have a lot of advantages.

(i) High effectiveness
Numerous firms have installed movable compressors and compressed air supplies on their production lines. Our atmosphere has an infinite amount of air that can be compressed. However, the use of compressed air is not restricted by distance, as it can easily be transported through pipes. After use, compressed air can be released directly into the atmosphere without the need for processing. [8]

(ii) High durability and reliability
Pneumatic components are extremely durable and cannot be damaged easily. Compared to electromotive components, pneumatic components are more durable and reliable [9].

(iii) Simple design

The designs of pneumatic components are relatively simple. They are thus more suitable for use in simple automatic control systems.

(iv) High adaptability to a harsh environment

Compared to the elements of other systems, compressed air is less affected by high temperature, dust, corrosion, etc.

(v) Safety

Pneumatic systems are safer than electromotive systems because they can work in an inflammable environment without causing fire or explosion. Apart from that, overloading in the pneumatic system will only lead to sliding or cessation of operation. Unlike electromotive components, pneumatic components do not burn or get overheated when overloaded [10].

(vi) Easy selection of speed and pressure

The speeds of rectilinear and oscillating movement of pneumatic systems are easy to adjust and subject to few limitations. The pressure and the volume of air can easily be adjusted by a pressure regulator.

(vii) Environmentally friendly

The operations of pneumatic systems do not produce pollutants. The air released is also processed in special ways. Therefore, pneumatic systems can work in environments that demand a high level of cleanliness. One example is the production lines of integrated circuits. [9].

(viii) Economical

As pneumatic components are not expensive, the costs of pneumatic systems are quite low. Moreover, as pneumatic systems are very durable, the cost of repair is significantly lower than that of other systems.

1.6 Limitations of pneumatic systems

Although pneumatic systems possess a lot of advantages, they are also subject to many limitations.

i. IIIIRelatively low accuracy

Pneumatic systems are dependent on the volume of compressed air since they rely on the force that compressed air provides to operate. The system's overall accuracy may suffer from an inaccurate air supply since compressed or heated air can have different volumes [9].

ii. Low loading

As the cylinders of pneumatic components are not very large, a pneumatic system cannot drive loads that are too heavy.

iii. Processing required before use

Compressed air must be processed before use to ensure the absence of water vapour or dust. Otherwise, the moving parts of the pneumatic components may wear out quickly due to friction and rust.

iv. Uneven moving speed

As air can easily be compressed, the moving speeds of the pistons are relatively uneven.

v. Noise

Noise will be produced when compressed air is released from the pneumatic components. [10].

1.7 Main pneumatic components

1. **Motion components (Actuators):** These components convert the potential energy of compressed air into mechanical motion, such as linear movement (e.g., cylinders) or rotational movement (e.g., motors) [5].
2. **Control components (Valves):** These components are used to regulate, direct, or control the flow, pressure, and direction of the compressed air within the system

All main pneumatic components can be represented by simple pneumatic symbols. Each symbol shows only the function of the component it represents, but not its structure. Pneumatic symbols can be combined to form pneumatic diagrams. A pneumatic diagram describes the relations between each pneumatic component, that is, the design of the system.

2 The Production and Transportation of Compressed Air

Compressors and pressure-regulating devices are two examples of parts that create and move compressed air.

(a) Compressor

Air can be compressed to the necessary pressures using a compressor. As seen in Figure 2, it may transform the mechanical energy from engines and motors into the potential energy in compressed air. Compressed air can be supplied to different pneumatic components by a single central compressor. The compressed air is then sent from the cylinder to the pneumatic components via pipes. There are two types of compressors: rotary and reciprocating..

(a) (b) (c)

Figure 2: Pneumatic components
(a) Compressor used in schools (b) Compressor used in laboratories of a compressor [11]. (c) Pneumatic symbol

2.1 Pressure regulating component

Each component that makes up the pressure-regulating components has a unique pneumatic symbol:

(i) Filter – can remove impurities from compressed air before it is fed to the pneumatic components.
(ii) Pressure regulator – to stabilise the pressure and regulate the operation of pneumatic components
(iii) Lubricator – To provide lubrication for pneumatic components

Figure 3: Pressure regulating component [12]

2.2 The consumption of compressed air

Examples of components that consume compressed air include execution components (cylinders), directional control valves and assistant valves.

i. Execution component

Rectilinear or rotating movement is made possible by pneumatic execution components. Pneumatic motors and cylinder pistons are a few examples of pneumatic execution components. Cylinder pistons generate rectilinear motion, whereas pneumatic motors rotate continuously. Cylinders come in a variety of forms, including single-acting and double-acting cylinders [11].

ii. Single-acting cylinder

A single-acting cylinder has only one entrance that allows compressed air to flow through. Therefore, it can only produce thrust in one direction, as shown in Figure 4. The piston rod is propelled in the opposite direction by an internal spring, or by the external force provided by mechanical movement or the weight of a load, as shown in Figure 5.

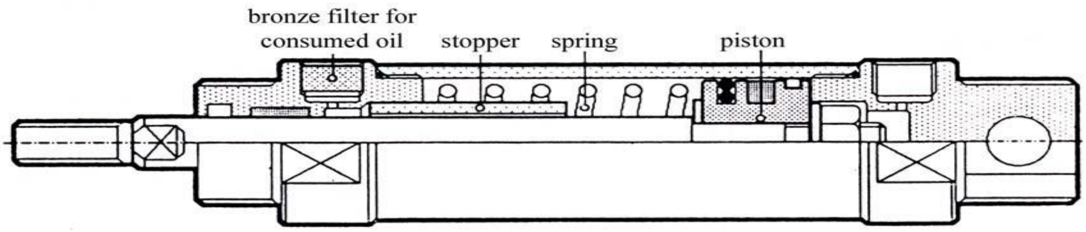
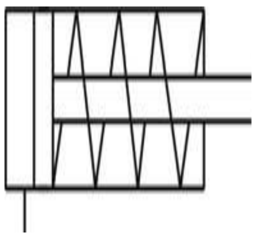


Figure 4: Cross-section of a single-acting cylinder [13].



(a) Single-acting cylinder.

(b) Pneumatic symbol of a single-acting cylinder

Figure 5: Single-acting Cylinder and Pneumatic symbol of a single-acting cylinder

The thrust from the piston rod is greatly lowered because it has to overcome the force from the spring. Therefore, to provide the driving force for machines, the diameter of the cylinder should be increased. In order to match the length of the spring, the length of the cylinder should also be increased, thus limiting the length of the path. Single-acting cylinders are used in stamping, printing, moving materials, etc [13].

iii. Double-acting cylinder

In a double-acting cylinder, air pressure is applied alternately to the relative surface of the piston, producing a propelling force and a retracting force as depicted in Figure 6. As the effective area of the piston is small, the thrust produced during retraction is relatively weak. The impeccable tubes of double-acting cylinders are usually made of steel, as shown in Figure 7. The working surfaces are also polished and coated with chromium to reduce friction.

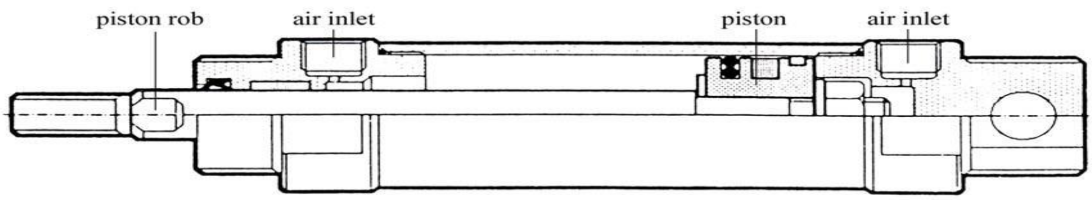


Figure 6: Cross-section of a double-acting cylinder [13].

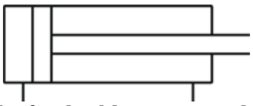



Figure 7 (a) Double-acting cylinder [13]. (b) Pneumatic symbol of a double-acting cylinder

iv. Directional control valve

Directional control valves ensure the flow of air between air ports by opening, closing and switching their internal connections. Their classification is determined by the number of ports, the number of switching positions, the normal position of the valve and its method of operation. Common types of directional control valves include 2/2, 3/2, 5/2, etc. The first number represents the number of ports; the second number represents the number of positions. A directional control valve that has two ports and five positions can be represented by the drawing in Figure 8, as well as its own unique pneumatic symbol. [13].

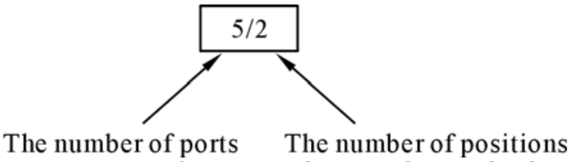
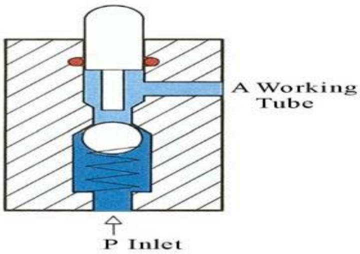


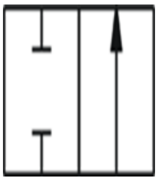
Figure 8: Describing a 5/2 directional control valve and (b) a 2/2 Directional control valve

The structure of a 2/2 directional control valve is very simple. It uses the thrust from the spring to open and close the valve, stopping compressed air from flowing towards working tube ‘A’ from air inlet ‘P’. When a force is applied to the control axis, the valve will be pushed open, connecting ‘P’ with ‘A’ as shown in Figure 9. The force applied to the control axis has to overcome both air pressure and the repulsive force of the spring. The control valve can be driven manually or mechanically, and restored to its original position by the spring.

(a) 2/2 directional control valve



(b) Cross section



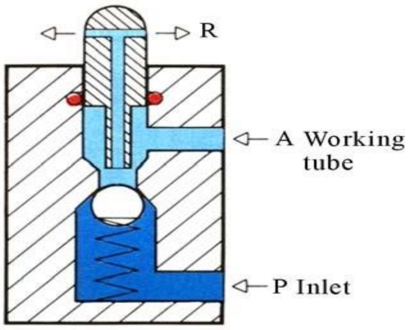
(c) Pneumatic symbol of a 2/2 directional control valve [14]

Figure 9: Structure of a 2/2 directional control valve

v. 3/2 directional control valve

A 3/2 directional control valve can be used to control a single-acting cylinder, as seen in the Figure. 10. The open valves in the middle will close until ‘P’ and ‘A’ are connected. Then another valve will open the sealed base between ‘A’ and ‘R’ (exhaust). The valves can be driven manually, mechanically, electrically or pneumatically. 3/2 directional control valves can further be divided into two classes: Normally open type (N.O.) and normally closed type (N.C.), as shown in Figure 11.

(a) 3/2 directional control valve



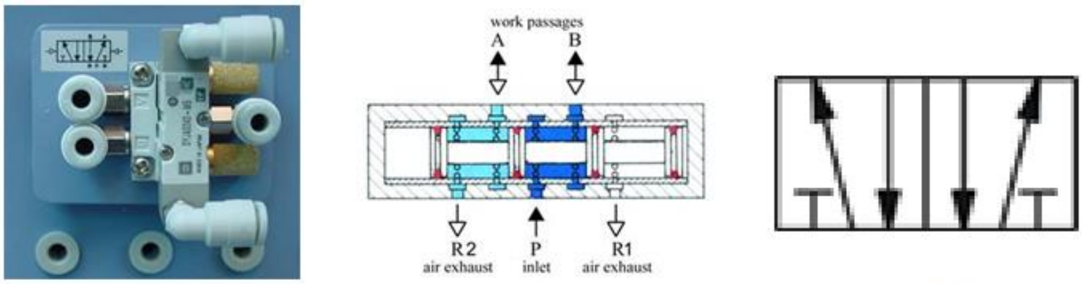
(b) Cross section [14]

Figure. 10: A 3/2 directional control valve can be used to control a single-acting cylinder

(a) Normally closed type (b) Normally open type 5/2 Directional control valve

Figure 11: Pneumatic symbols [14].

When a pressure pulse is input into the pressure control port 'P', the spool will move to the left, connecting the inlet 'P' and work passage 'B'. Work passage 'A' will then make a release of air through 'R1' and 'R2'. The directional valves will remain in this operational position until signals to the contrary are received. Therefore, this type of directional control valve is said to have the function of 'memory'.



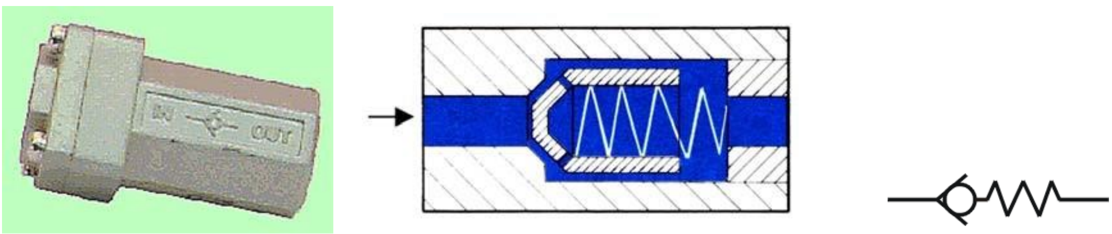
(a) (b) (c)

Figure 12 Pneumatic symbol for control valve [14].

As shown in Figure 12, (a) 5/2 directional control valve, (b) cross-section, (c)
A control valve is a valve that controls the flow of air. Examples include non-return valves, flow control valves, shuttle valves, etc.

vi. Non-return valve

A non-return valve allows air to flow in one direction only. When air flows in the opposite direction, the valve will close. Another name for a non-return valve is a poppet valve, as shown in Figure 13.

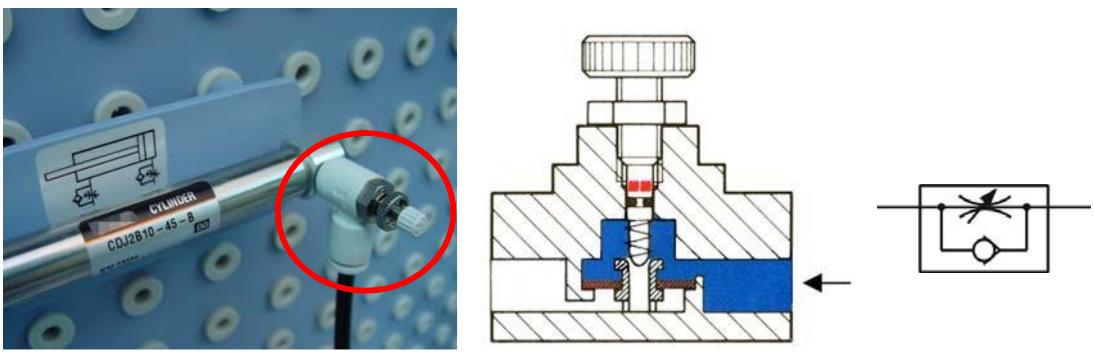


(a) Non-return valve (b) Cross section (c) Pneumatic symbol

Figure 13: a non-return valve with its cross-section drawing and pneumatic symbol [14].

vi. Flow control valve

A flow control valve is formed by a non-return valve and a variable throttle, as shown in Figure 14.

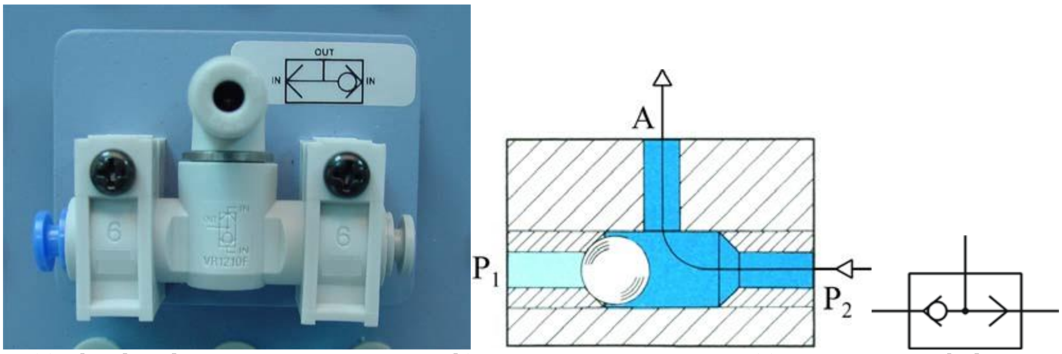


(a) Flow control valve (b) Cross section (c) Pneumatic symbol

Figure 14: flow control valve with its cross-section drawing and pneumatic symbol [14].

vii. Shuttle valve

Shuttle valves are also known as double control or single control non-return valves. A shuttle valve has two air inlets, ‘P_1’ and ‘P_2’ and one air outlet ‘A’. When compressed air enters through ‘P_1’, the sphere will seal and block the other inlet ‘P_2’. Air can then flow from ‘P_1’ to ‘A’. When the contrary happens, the sphere will block inlet ‘P_1’, allowing air to flow from ‘P_2’ to ‘A’ only.



(a) Shuttle valve (b) Cross section (c) Pneumatic symbol.

Figure 15: A shuttle valve with its cross-section drawing and pneumatic symbol [15].

2.3 Principles of pneumatic control

2.3.1 Pneumatic circuit

Pneumatic control systems can be designed in the form of pneumatic circuits. A pneumatic circuit is formed by various pneumatic components, such as cylinders, directional control valves, flow control valves, etc. Pneumatic circuits have the following functions:

1. To control the injection and release of compressed air in the cylinders.
2. To use one valve to control another valve.

2.3.2 Pneumatic circuit diagram

A pneumatic circuit diagram uses pneumatic symbols to describe its design. Some basic rules must be followed when drawing pneumatic diagrams.

2.4 Basic rules

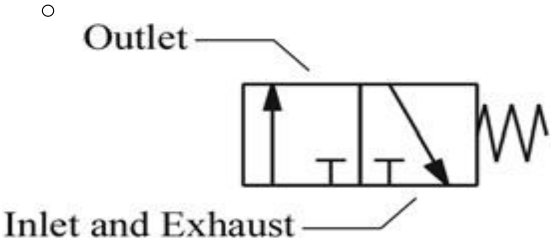
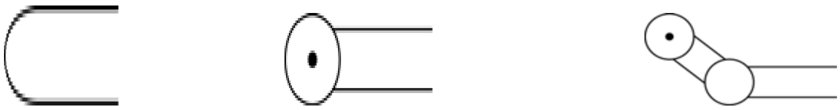
- A pneumatic circuit diagram represents the circuit in static form and assumes there is no supply of pressure. The placement of the pneumatic components on the circuit also follows this assumption.
- The pneumatic symbol of a directional control valve is formed by one or more squares. The inlet and exhaust are drawn underneath the square, while the outlet is drawn on the top. Each function of the valve (the position of the valve) shall be represented by a square. If there are two or more functions, the squares should be arranged horizontally as shown in Figure 16.
- 

Figure 16: A 3/2 directional control valve(normally closed type)

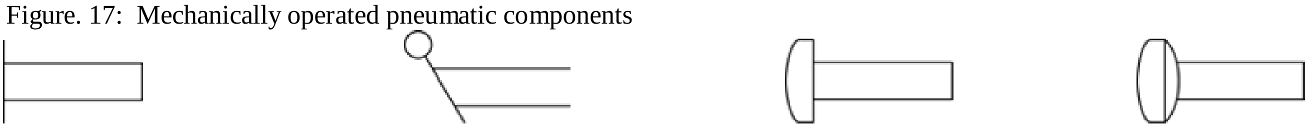
Arrows "↓↖" are used to indicate the flow direction of air current. If the external port is not connected to the internal parts, the symbol “┬” is used. The symbol “⨀” underneath the square represents the air input, while the symbol “▽” represents the Exhaust.

The pneumatic symbols of operational components should be drawn on the outside of the squares. They can be divided into two classes: mechanical and manual, as shown in the Figure. 17 and 18, respectively.



(a) Vertical piston lever (b) Pulley lever (c) Unilateral pulley lever

Figure. 17: Mechanically operated pneumatic components



(a) Standard (b) Lever (c) Button (d) Pull & push

Figure 18: Manually operated pneumatic components

Pneumatic operation signal pressure lines should be drawn on one side of the squares, while triangles are used to represent the direction of air flow as depicted in Figure 19.

Figure 19: Pneumatic operation signal pressure line

2.5 Basic principles

Figure 20 shows some of the basic principles of drawing pneumatic circuit diagrams. The numbers in the diagram correspond to the following points:

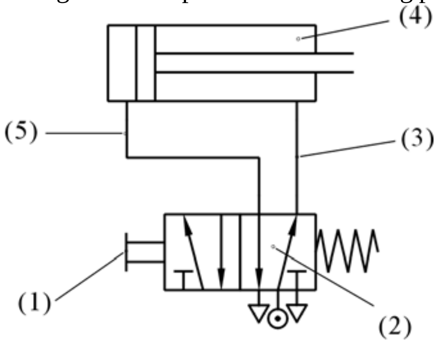


Figure 20: Basic principles of drawing pneumatic circuit diagrams

The basic operation is systematic as follows;

- When the manual switch is not operated, the spring will restore the valve to its original position.
- From the position of the spring, one can deduce that the block is operating. The other block will not operate until the switch is pushed on.
- Air pressure exists along this line because it is connected to the source of compressed air.
- As this cylinder cavity and piston rod are under the influence of pressure, the piston rod is in its restored position.
- The rear cylinder cavity and this line are connected to the exhaust, where air is released.

2.6 The setting of circuit diagrams

When drawing a complete circuit diagram, one should place the pneumatic components on different levels and positions, so the relations between the components can be expressed clearly. This is called the setting of circuit diagrams. A circuit diagram is usually divided into three levels: power level, logic level and signal input level, as shown in the Figure. 21

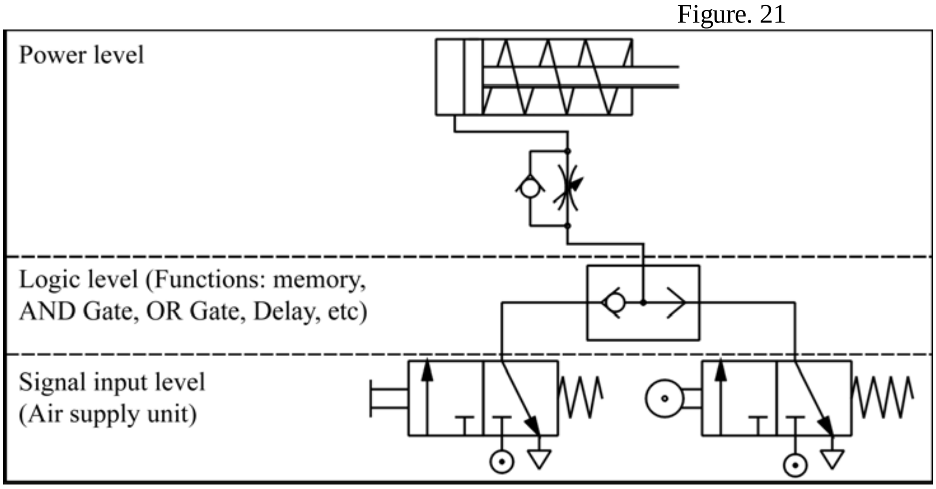
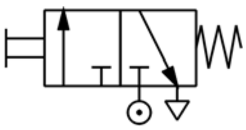


Figure 21: Circuit diagram [14].

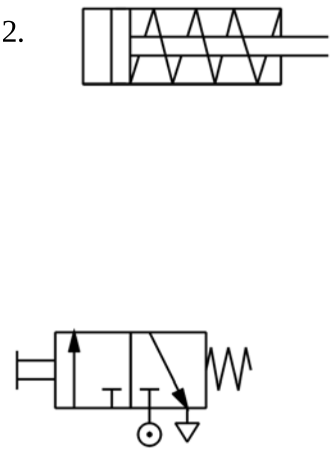
The basic rules of circuit diagram setting are as follows:

1.



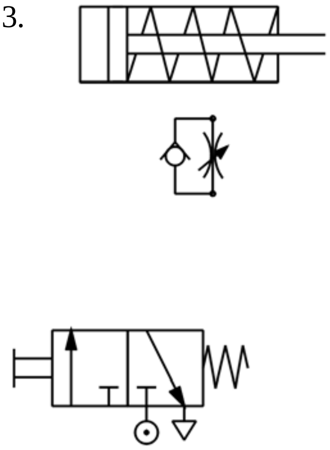
In a pneumatic circuit, the flow of energy is from the bottom to the top. Therefore, the air supply unit should be put at the bottom left corner.

2.



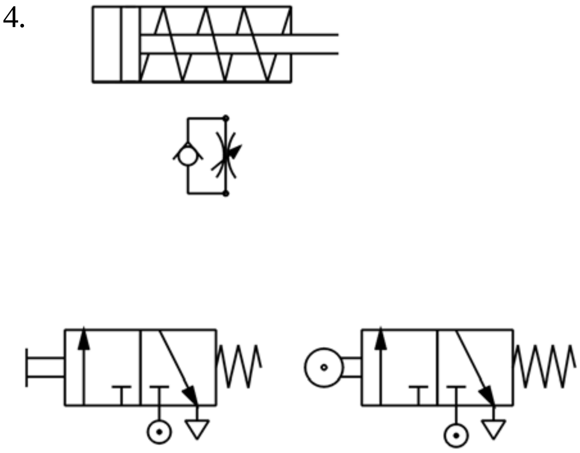
The work cycle should be drawn from left to right. The first operating cylinder should be placed at the upper left corner.

3.



Power control valves should be drawn directly under the cylinder controlled by them, forming a power unit.

4.



Control cylinders and operational valves (signal components) driven by power control valves should be placed at the lower levels of the diagram.

2.7 Different kinds of basic circuits

A basic circuit is a pneumatic circuit designed to perform basic tasks, such as flow amplification, signal inversion, memory, delay, single-acting cylinder control, double-acting cylinder control, etc.

Flow amplification

Cylinders with a large capacity require a larger flow of air, which can be hazardous to users. It is unsafe to manually operate pneumatic directional control valves with large flow capacity. Instead, we should first manually operate a small control valve and use it to operate the pneumatic control system with a large flow capacity. This is called flow amplification, which can greatly ensure the safety of the operators. During operation, valves with large flow capacity should be placed near the cylinder, while valves with smaller flow capacity should be placed on control boards some distances away. Figure 22 shows a basic flow amplification circuit. Notice how different components are placed on different levels.

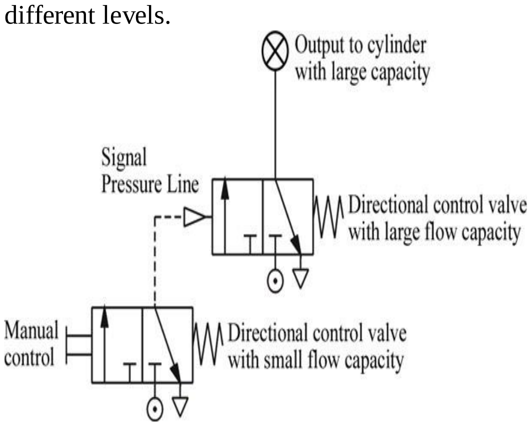


Figure 22: Flow amplification system

Signal inversion

The pneumatic diagram in Figure 23 shows how directional control valves can be switched. When operating control valve 1, control valve 2 will stop producing pressure output. When control valve 1 ceases operation and is restored to its original position, control valve 2 will resume its output. Therefore, at any given time, the pressure output of control valve 1 is the exact opposite of that of control valve 2, as shown in Figure 23.

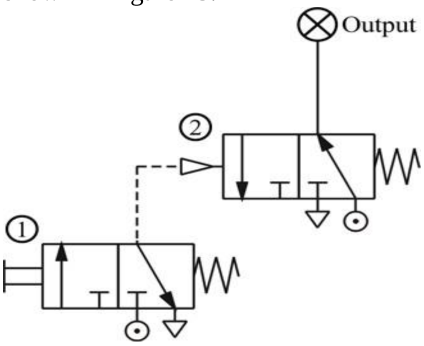


Figure 23: Signal inversion system

Memory Function

Memory is a common basic function. It can keep a component at a certain state permanently until there is a change in signals. Figure 24 shows a memory function circuit. When control valve 1 is operated momentarily (that is, pressed for a short time), the output signal of the 5/2 directional control valve 3 will be set to ON. The signal will stay that way until control valve 2 is operated momentarily and generates another signal to replace it, causing it to stay permanently at OFF.

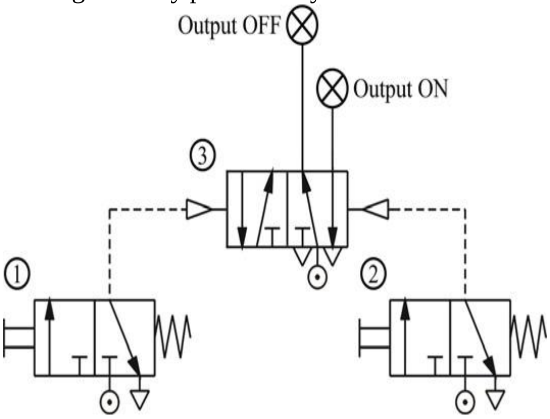


Figure 24: Memory function circuit [23].

Delay function

A pneumatic delay circuit can delay the operating time of the next control valve. Its principle of operation involves the use of an orifice to slow down the flow of air and control the time of pneumatic operation. Delay functions can be divided into two classes: ON-signal delay and OFF-signal delay.

ON-signal delay
Figure 25 shows the circuit diagram of an ON-signal delay circuit, which delays the output of the next control valve. When control valve 1 is operated, the one-way flow control valve will slow down the flow of air, thus delaying the signal output of the outlet of control valve 2 (A), resulting in a persistent ON-signal. The time when control valve 2 will be restored to its original position is not affected.

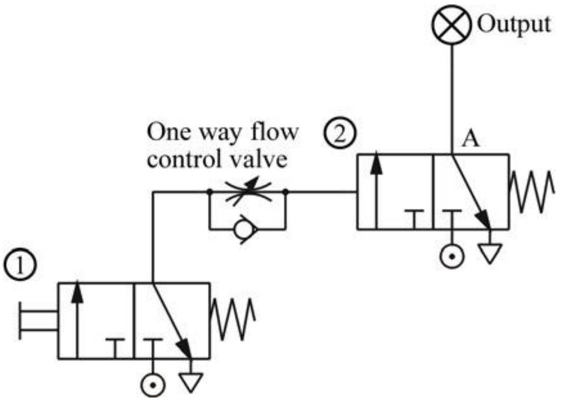


Figure 25: Circuit diagram of an ON-signal delay circuit.

2.8 OFF-signal Delay
Figure 26 shows the circuit diagram of an OFF-signal delay circuit, which delays the output of the next control valve. This circuit is similar to an ON-signal delay circuit. The only difference is that the one-way flow control valve is connected in the opposite direction. Therefore, when control valve 1 is operated, the outlet of control valve 2 (A) will continue to output signals. However, when control valve 2 is restored to its original position, the release of air is slowed down by the one-way flow control valve, resulting in a persistent OFF-signal.

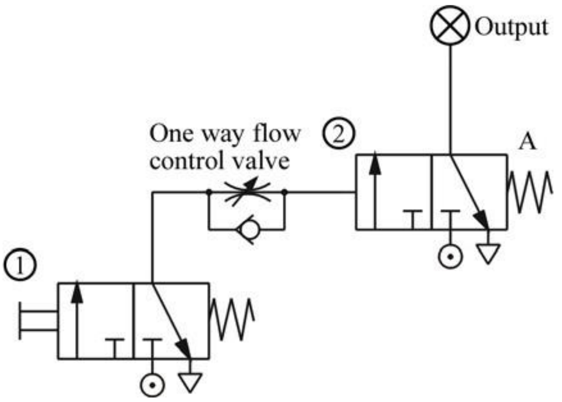


Figure 26: Circuit diagram of an OFF-signal delay circuit

Single-acting cylinder control
Single-acting cylinders can be controlled manually. However, they can also be controlled by two or more valves. This is called logic control. Examples of logic control include 'OR' function, 'AND' function, 'NOT' function, etc.

Direct control and speed control
If a single-acting cylinder is connected to a manual 3/2 directional control valve, when the control valve is operated, it will cause the cylinder to work as shown in Figure 27. Therefore, the circuit allows the cylinder to be controlled manually.

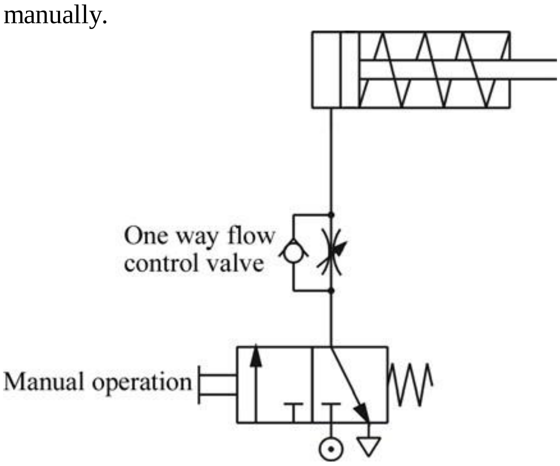


Figure 27: Direct control of a single-acting cylinder [15]
The only way to change the extension speed of the piston of a single-acting cylinder is to restrict the flow of air at the inlet and use the spring to determine the speed of retraction. Therefore, a one-way flow control valve is placed in the circuit to control the speed.

2.9 OR Function
The single-acting cylinder in Figure. 28 can be operated by two different circuits. Examples include manual operation and relying on automatic circuit signals, that is, when either control valve
1 or control valve 2 is operated, the cylinder will work. Therefore, the circuit in Figure 28 possesses the OR function. However, if the outputs of two 3/2 directional control valves are connected through the port of a triode, the air current from control valve 1 will be released through the exhaust of control valve 2, and so the cylinder will not work. This problem can be solved by connecting a shuttle valve to the port of the triode.

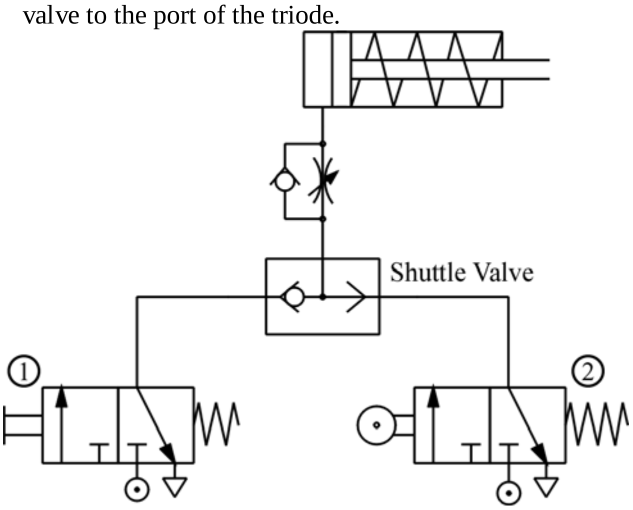


Figure 28: Circuit diagram of an OR function circuit

2.10 AND Function
Another name for an AND function is interlock control. This means control is possible only when two conditions are satisfied. A classic example is a pneumatic system that

works only when its safety door is closed and its manual control valve is operated. The flow passage will open only when both control valves are operated. Figure 29 shows the circuit diagram of an AND function circuit. The cylinder will work only when both valves 1 and 2 are operated.

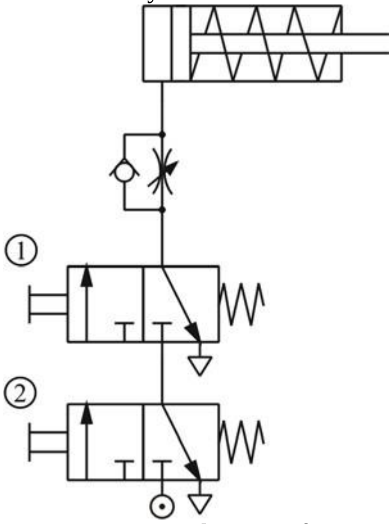


Figure 29 Circuit diagram of an AND function circuit [15]

2.11 NOT Function

Another name for a NOT function is inverse control. In order to hold or lock an operating conveyor or a similar machine, the cylinder must be locked until a signal for cancelling the lock is received. Therefore, the signal for cancelling the lock should be operated by a normally open type control valve. However, to cancel the lock, the same signal must also cancel the locks on other devices, like the indication signal 3 in Figure 30. Figure 30 shows how the normally closed type control valve 1 can be used to cut off the normally open type control valve 2 and achieve the goal of changing the signal.

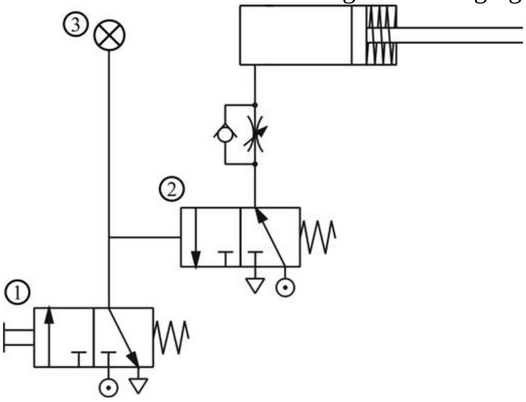


Figure 30: Circuit diagram for a NOT function circuit [16]

2.12 Double-acting cylinder

Direct control

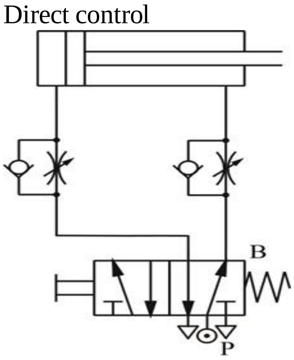


Figure 31: Circuit diagram of a double-acting cylinder direct control circuit

The only difference between a single-acting cylinder and a double-acting cylinder is that a double-acting cylinder uses a 5/2 directional control valve instead of a 3/2 directional control valve, as shown in Figure 31. Usually, when a double-acting cylinder is not operated, outlet 'B' and inlet 'P' will be connected. In this circuit, whenever the operation button is pushed manually, the double-acting cylinder will move back and forth once.

In order to control the speed in both directions, flow control valves are connected to the inlets on both sides of the cylinder. The direction of the flow control valve is opposite to that of the release of air by the flow control valve of the single-acting cylinder. Compared to the throttle inlet, the flow control valve is tougher and more stable. Connecting the circuit in this way allows the input of sufficient air pressure and energy to drive the piston.

2.13 Single control

A cylinder always has to maintain its position in a lot of situations, even after the operational signal has disappeared. This can be achieved by the use of a circuit that possesses the memory function. As shown in Figure 32, the extension path of a double-acting cylinder is activated by control valve 1, while retraction is governed by control valve 2. Control valve 3, on the other hand, maintains the position of the cylinder by maintaining its own position. Control valve 3 will be changed only when one of the manual control valves is pushed. If both control valves 1 and 2 are operated at the same time, control valve 3 will be subject to the same pressure and will remain in its original position.

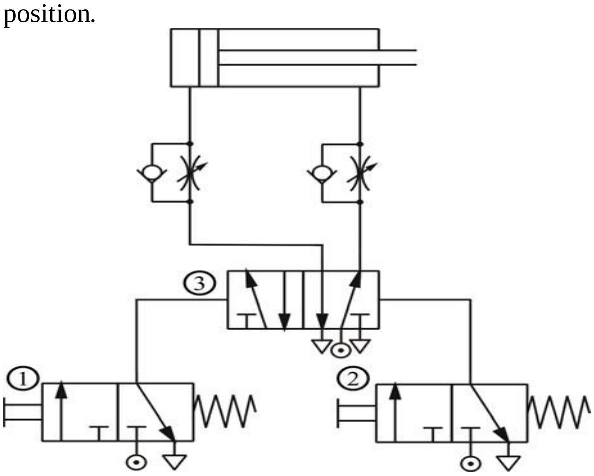


Figure 32: Circuit that maintains the position of a double-acting cylinder [16]

3. *The Application of Pneumatic Systems*

The application of pneumatic systems is very extensive. The following are some examples.

Transport System

Figure 33a shows a simplified industrial transport system [17]. When the button switch is pushed, the cylinder will push one of the goods from the shelf onto the transfer belt. When the button switch is released, the cylinder will retract automatically. Fig. 33b shows the circuit diagram of the transport system.

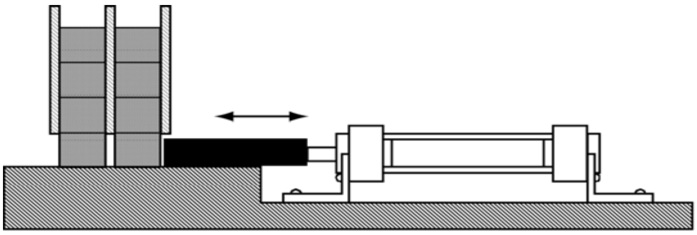
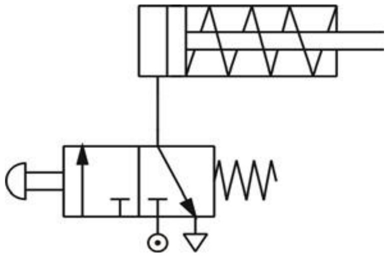


Figure 33 :(a) Operation of a pneumatic transport system



(b) Pneumatic circuit diagram of a pneumatic transport system

Vehicle door operation system

Pneumatic systems can be used to operate the doors of public vehicles, as shown in Figure 34a. Assuming that the opening and closing of the doors are controlled by two button switches, ON and OFF. When the button switch ON is pressed, the doors will open. When the button switch OFF is pushed, the doors will close. Figure 34b shows a pneumatic system that can be used to operate the doors of vehicles [18].

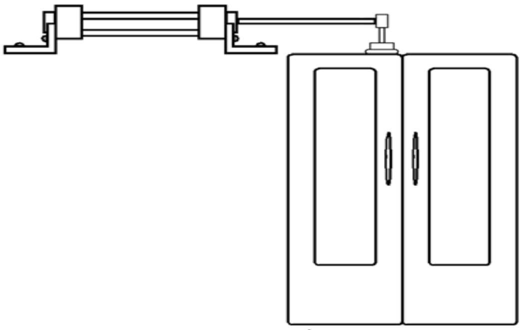
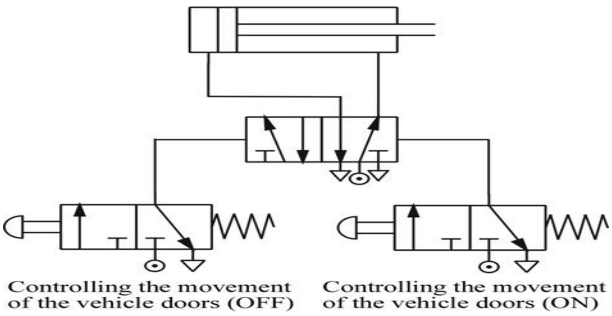


Figure 34: (a) Operation of a pneumatic system that the movement of vehicle doors [19].



(b) Pneumatic circuit diagram controls

3.1 Safety measures when using pneumatic control systems

- Compressed air can cause serious damage to the human body if it enters the body through ducts like the oral cavity or ears.
- Never spray compressed air onto anyone.
- Under high temperatures, compressed air can pass through human skin.
- Compressed air released from the exhaust contains particles and oil droplets, which can cause damage to the eyes.
- Even though the pressure of compressed air in pipes and reservoirs is relatively low, when the container loses its entirety, fierce explosions may still occur.
- Before switching on a compressed air supply unit, one should thoroughly inspect the whole circuit to see if there are any loose parts, abnormal pressure or damaged pipes.
- A loose pipe may shake violently due to the high pressure built up inside it. Therefore, each time before the system pressure is increased, a thorough inspection of the entire circuit is required to prevent accidents.
- As the force produced by pneumatic cylinders is relatively large, and the action is usually very fast, you may suffer serious injuries if you get hit by a cylinder.
- Switches should be installed on the compressed air supply unit to allow easy and speedy control of air flow.
- In case of a leakage, the compressed air supply unit should be turned off immediately
- The compressed air supply unit must be turned off before changes can be made to the system.
- Stay clear of the moving parts of the system. Never try to move the driving parts in the mechanical operation valve with your hand [20].

3.2 The significance of the Pneumatic course in the Mechanical Engineering education curriculum:

1. Understanding Industrial Automation: Pneumatic systems are widely used in industrial automation, and studying pneumatics helps mechanical engineers understand the principles and applications of automation in various industries.

2. Design and Development of Pneumatic Systems: A pneumatics course enables mechanical engineers to design and develop pneumatic systems, including circuit design, component selection, and system integration [24]

3. Troubleshooting and Maintenance: Knowledge of pneumatics helps mechanical engineers troubleshoot and maintain pneumatic systems, reducing downtime and increasing productivity [25]

4. Improved Efficiency and Productivity: Pneumatic systems can improve efficiency and productivity in various industries, and studying pneumatics helps mechanical engineers understand how to optimise system performance.

5. Safety and Reliability: Pneumatic systems can be designed to be safe and reliable, and studying pneumatics helps

mechanical engineers understand how to design and operate systems that meet safety and reliability standards [25].

6. Integration with other systems: Pneumatic systems often integrate with other systems, such as electrical, hydraulic, or mechanical systems, and studying pneumatics helps mechanical engineers understand how to integrate these systems effectively.

7. Practical Applications: Pneumatics has numerous practical applications in various industries, including manufacturing, packaging, food processing, and automotive, and studying pneumatics helps mechanical engineers understand these applications [26]

8. Development of Problem-Solving Skills: Studying pneumatics requires mechanical engineers to develop problem-solving skills, including circuit analysis, troubleshooting, and system design.

9. Preparation for Industry: Pneumatic systems are an essential part of Industry, and studying pneumatics helps mechanical engineers understand the principles and applications of Industry.
10. Enhanced Career Opportunities: Knowledge of pneumatics can enhance career opportunities for mechanical engineers in various industries, including manufacturing, automation, and process control.

By including pneumatics in the mechanical engineering curriculum, students can gain a comprehensive understanding of pneumatic systems, their applications, and their importance in various industries [27].

3.3 EduRank University Ranking

There is are list of the best 68 universities in Nigeria [29] ranked based on their research performance in Mechanical Engineering. According to [29], a graph of 229K citations received by 28.6K academic papers made by 68 universities in Nigeria was used to calculate publications' ratings, which were then adjusted for release dates and added to final scores. Be that as it may, this paper adopted this ranking as a reference for its study and evaluation.
Efforts were made by the writer to go through most of these universities' curricula to see if pneumatics were included as core courses, but what was prevalent were Fluid/Applied fluid mechanics as core courses for 300 to 500-level undergraduate students. However, the ranking did not distinguish between undergraduate and graduate programs, nor does it adjust for current majors offered. Though there were some complementary topics but the very essence of pneumatics was still missing, especially in the area of its practicality.
This paper thinks that the likely results of not including the pneumatics course in mechanical engineering education, according to [30], could lead to:

- Lack of understanding of pneumatic systems: Mechanical engineers may not fully comprehend the principles, design, and applications of pneumatic systems.
- Inadequate skills in automation: Pneumatics is a key component of industrial automation. Without knowledge of pneumatics, mechanical engineers may struggle to design and implement automated systems.
- Limited career opportunities: Mechanical engineers without knowledge of pneumatics may be less competitive in industries that heavily rely on pneumatic systems, such as manufacturing, packaging, and process control.
- Difficulty in troubleshooting and maintenance: Mechanical engineers may struggle to troubleshoot and maintain pneumatic systems, leading to increased downtime and reduced productivity [31]
- Inability to design efficient systems: Without knowledge of pneumatics, mechanical engineers may not be able to design efficient systems that utilise pneumatic components, leading to reduced system performance.
- Dependence on others for pneumatic system design*: Mechanical engineers may need to rely on others to design and implement pneumatic systems, limiting their autonomy and problem-solving abilities.
- Missed opportunities for innovation
- Without knowledge of pneumatics, mechanical engineers may miss opportunities to innovate and improve pneumatic systems, leading to stagnation in industrial automation and process control. [32]

By not including pneumatics in mechanical engineering education, graduates may be less prepared to meet the demands of industries that rely heavily on pneumatic systems.

4. Conclusion

Pneumatic automation offers numerous advantages and benefits in modern industrialization, including reliability, cost-effectiveness, flexibility, safety, and ease of maintenance. By automating industrial processes, pneumatic automation can increase productivity, improve quality, reduce labour costs, improve safety, and increase efficiency.

This paper not only explores the fundamentals of pneumatic and associated practical circuits and applications but also the advantages and benefits of Pneumatic Automation in modern industrial development and sustainability.
Due to its very importance in the global industrial economic growth, the knowledge and skills in pneumatic studies remain paramount for proper maintenance and servicing of all industries whose operations depend on the transmission of fluids to do work. And the field being akin to mechanical engineering education, its inclusion in the curriculum of the mechanical engineering course outline should not be overemphasized and should be adequately complemented with other allied courses, such as fluid mechanics.
In summary, pneumatic actuation plays a vital role in modern industry, offering a reliable, efficient, and cost-effective solution for various applications. Its advantages in terms of cost-effectiveness, reliability, flexibility, speed, and force make it an attractive choice for many industries and its applications continue to grow and expand into new areas. However, by not including pneumatics in mechanical engineering education, graduates may be less prepared to meet the demands of industries that rely heavily on pneumatic systems.

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Data Availability The authors confirm that the data supporting the findings of this study are available within the article.

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