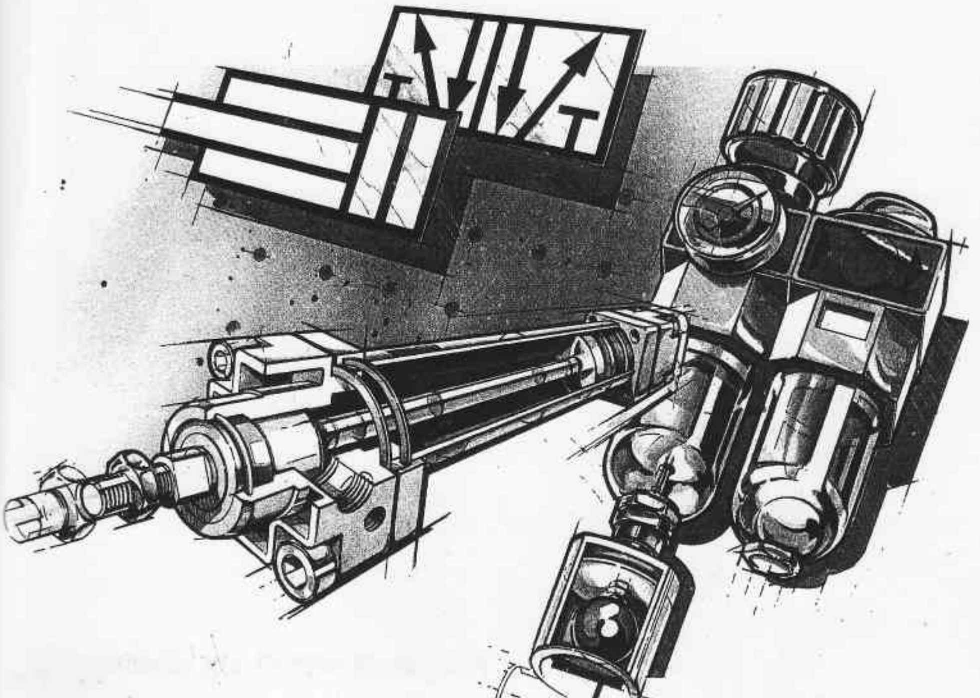
Learning System for Automation

Mrs. K.P. Agte

Pneumatics



Basic Level TP 101

Textbook

FESTO
DIDACTIC

Learning System for Automation

Pneumatics

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Section A: Course

Section B: Theory

Section C: Solutions

Notes regarding the concept behind the textbook

This textbook forms part of Festo Didactic's Learning System for Automation. It has been designed for training courses and is also suitable for the purpose of self-tuition.

The book is divided into the following sections:

Part A: Course
Part B: Theory
Part C: Solutions to the exercises

Part A: Course
The aim of the course is to provide students with the information which they will require in order to gain a thorough understanding of the subject concerned. This is achieved using both examples and exercises. These gradually increase in complexity and the student therefore is advised to work through them in sequence. Subjects which are dealt with in greater depth in the Theory section are marked in the text.

Part B: Theory
This section contains the basic theory relating to the subject area in question. Topics are set out in a logical manner. The student can either work through this section chapter by chapter or use it for reference purposes.

Part C: Solutions
This part contains the solutions to the exercises in Part A.

A comprehensive index is provided at the end of the textbook.

This textbook may be incorporated into an existing training programme.

Section A

Course

Chapter 1

Characteristics and applications of pneumatics

Pneumatics has for some considerable time been used for carrying out the simplest mechanical tasks, but in more recent times has played a more important role in the development of pneumatic technology for automation.

In the majority of applications compressed air is used for one or more of the following functions:

- The use of sensors to determine status of processes
- Information processing
- Switching of actuators by means of final control elements
- Carrying out work

Before the 1950s, pneumatics was most commonly used as a working medium in the form of stored energy. During the 1950s the sensing and processing roles developed in parallel with working requirements. This development enabled working operations to be controlled using sensors for the measurement of machine states and conditions. The development of sensors, processors and actuators has led to the introduction of pneumatic systems.

In parallel with the introduction of total systems, the individual elements have further developed with changes in material, manufacturing and design processes.

The pneumatic cylinder has a significant role as a linear drive unit, due to its relatively low cost, ease of installation, simple and robust construction and ready availability in various sizes and stroke lengths.

The pneumatic cylinder has the following general characteristics:

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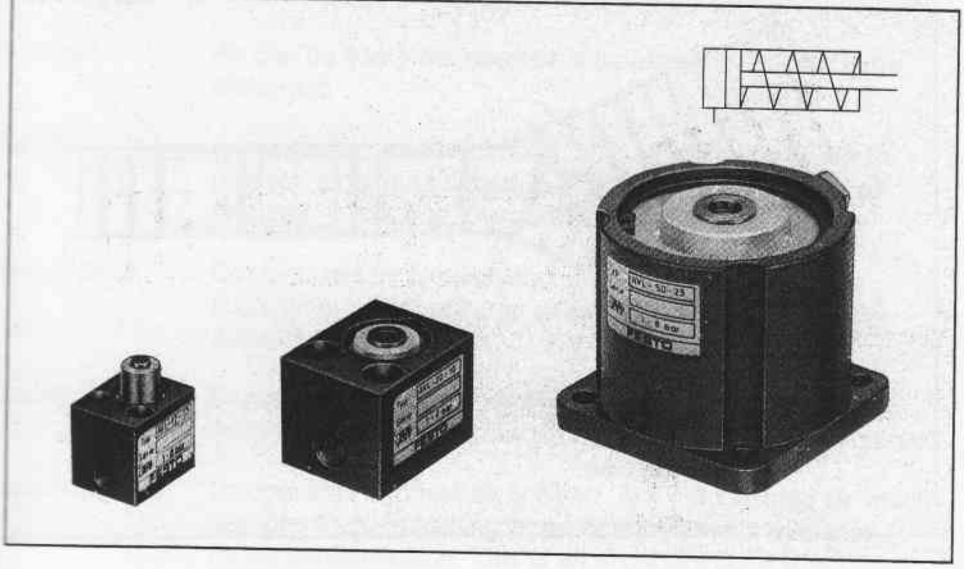
• Diameters	6 to 320 mm
• Stroke lengths	1 to 2000 mm
• Available forces	2 to 50000 N
• Piston speed	0.02 to 1 m/s

Pneumatic cylinder



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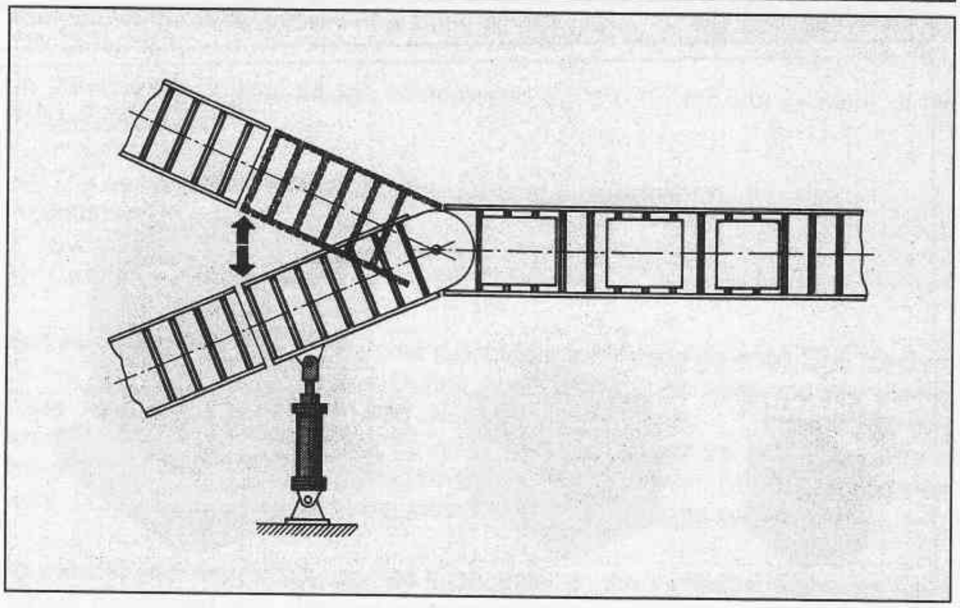
Pneumatic components can perform the following types of motion:

- Linear
- Swivel
- Rotary

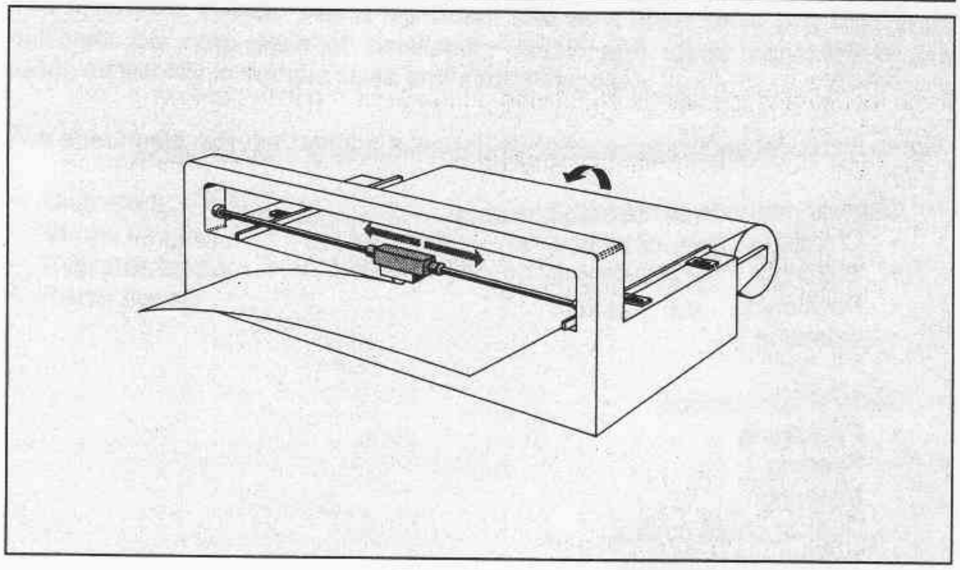
Some industrial applications employing pneumatics are listed below:

- General methods of material handling:
  - Clamping
  - Shifting
  - Positioning
  - Orienting
- General applications:
  - Packaging
  - Feeding
  - Metering
  - Door or chute control
  - Transfer of materials
  - Turning and inverting of parts
  - Sorting of parts
  - Stacking of components
  - Stamping and embossing of components

Line diverter for two tracks



Pneumatic cutter



Pneumatics is used in carrying out machining and working operations. For example:

- Drilling
- Turning
- Milling
- Sawing
- Finishing
- Forming
- Quality control

1.1. Pneumatics in review

Advantages and distinguishing characteristics of compressed air:

Availability :	Air is available practically everywhere in unlimited quantities.
Transport :	Air can be easily transported in pipelines, even over large distances.
Storage :	A compressor need not be in continuous operation. Compressed air can be stored in a reservoir and removed as required. In addition, the reservoir can be transportable.
Temperature :	Compressed air is relatively insensitive to temperature fluctuations. This ensures reliable operation, even under extreme conditions.
Explosion proof :	Compressed air offers minimal risk of explosion or fire, hence no expensive protection against explosion is required.
Cleanliness :	Unlubricated exhaust air is clean. Any unlubricated air which escapes through leaking pipes or components does not cause contamination. This is an important point when considering the food, wood and textile industries.
Components :	The operating components are of simple construction and are therefore relatively inexpensive.
Speed :	Compressed air is a very fast working medium. This enables high working speeds to be attained.
Adjustable :	With compressed air components, speeds and forces are infinitely variable.
Overload safe :	Pneumatic tools and operating components can be loaded to the point of stopping and are therefore overload safe.

In order to accurately define the areas of application of pneumatics, it is also necessary to be acquainted with the negative characteristics:

Preparation :
Compressed air requires good preparation. Dirt and condensate should not be present.

Compressible :
It is not always possible to achieve uniform and constant piston speeds with compressed air.

Force requirement :
Compressed air is economical only up to a certain force requirement. Under the normal working pressure of 6-7 bar (600 to 700 kPa) and dependent on the travel and speed, the output limit is between 20 000 and 30 000 Newtons.

Noise level :
The exhaust air is loud. This problem has now, however, been largely solved due to the development of sound absorption material and silencers.

Costs :
Compressed air is a relatively expensive means of conveying power. The high energy costs are partially compensated by inexpensive components and higher performance.

A comparison with other forms of energy is an essential part of the selection process when considering pneumatics as a control or working medium. This evaluation embraces the total system from the input signal (sensors) through the control part (processor) to the output devices (actuators). All factors must be considered such as:

- Work or output requirements
- Preferred control methods
- Resources and expertise available to support the project
- Systems currently installed which are to be integrated with the new project

Criteria for a working medium

Choice of working media :

- Electrics
- Hydraulics
- Pneumatics
- A combination of the above

B 6.1

Selection criteria for the working section :

- Force
- Stroke
- Type of motion (linear, rotary)
- Speed
- Size
- Service life
- Sensitivity
- Safety and reliability
- Energy costs
- Controllability
- Handling
- Storage

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Criteria for a control medium

Choice of control media :

- Mechanical
- Electrical
- Electronic
- Pneumatic, normal pressure
- Pneumatic, low pressure
- Hydraulic

B 6.1

Selection criteria for the control section :

- Reliability of components
- Sensitivity to environmental influences
- Ease of maintenance and repair
- Switching time of components
- Signal speed
- Space requirements
- Service life
- Training requirements of operators and maintainers
- Modification of the control system

1.2. Pneumatics and control system development

The product development in pneumatics can be considered in a number of areas:

- Actuators
- Sensors and input devices
- Processors
- Control systems
- Accessories

Each of these product groups are important in the development of pneumatic solutions. The demands are for system/component reliability but with:

- Accessibility for repair and/or maintenance, or
- Low cost of replacement
- Ease of mounting and connection
- Low planned maintenance requirements
- Interchangeability and flexibility
- Compact design
- Costs commensurate with the above
- Readily available
- Documentation support
- Minimum training required to support the product

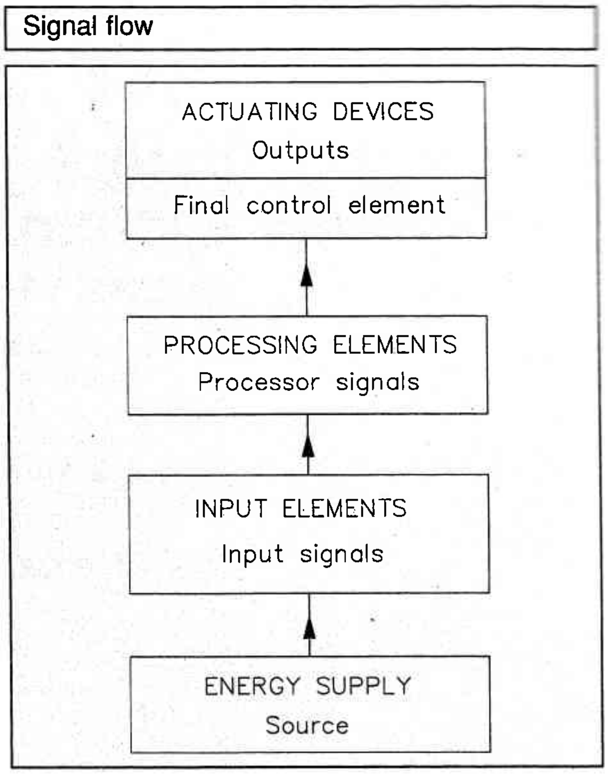
B 6.2

Chapter 2

Components of a pneumatic system

A pneumatic system can be broken down into a number of levels representing hardware and signal flow.

The various levels form a control path for signal flow from the signal (input) side to the work (output) side.



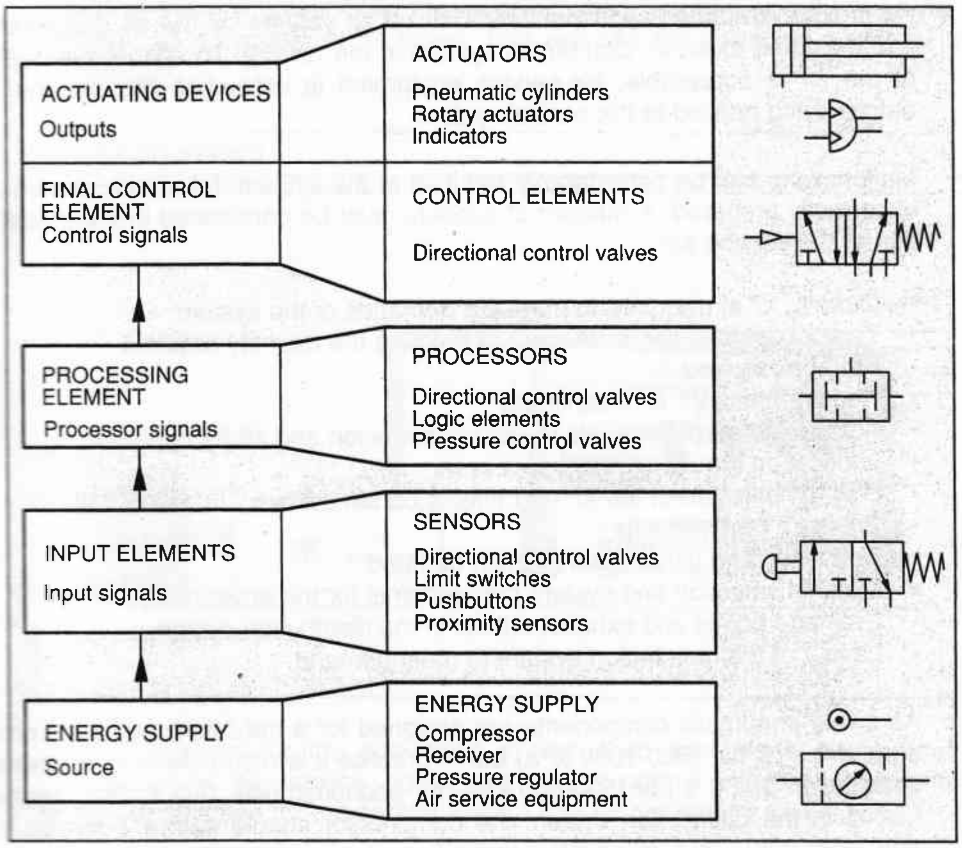
2.1. Pneumatic system structure and signal flow

The primary levels in a pneumatic system are:

- Energy supply
- Input elements (sensors)
- Processing elements (processors)
- Actuating devices (actuators)

The elements in the system are represented by symbols which indicate the function of the element. The symbols can be combined to represent a solution for a particular control task using the circuit diagram. The circuit is drawn with the same structure as the signal flow diagram above. At the actuator level the addition of the control element completes the structure. The control element controls the action of the actuator after receiving signals sent by the processor elements.

Pneumatic elements

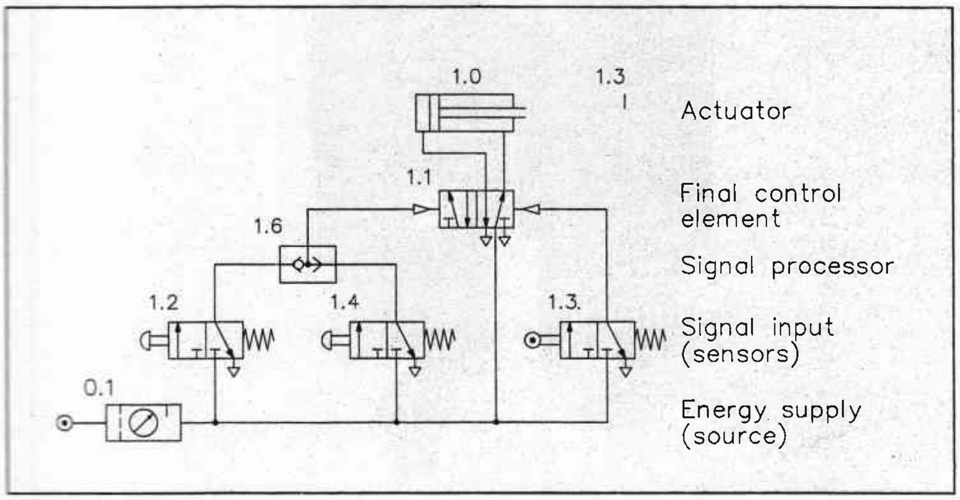


B 1.3

The directional control valve (DCV) may have a sensing, a processing or an actuating control function. If the DCV is used to control a cylinder motion, then it is a control element for the actuator group. If it is used in the function of processing signals, then it is defined as a processor element. If it is used to sense motions, then it is defined as a sensor. The distinguishing feature between each of these roles is normally the method of operating the valve and where the valve is situated in the circuit diagram.

B 3

Circuit diagram and pneumatic elements



2.2. Air generation and distribution

The air supply for a particular pneumatic application should be sufficient and of adequate quality.

B 2

Air is compressed to approximately 1/7th of its volume by the air compressor and delivered to an air distribution system in the factory. To ensure the quality of the air is acceptable, air service equipment is utilised to prepare the air before being applied to the control system.

Malfunctions can be considerably reduced in the system if the compressed air is correctly prepared. A number of aspects must be considered in the preparation of the service air:

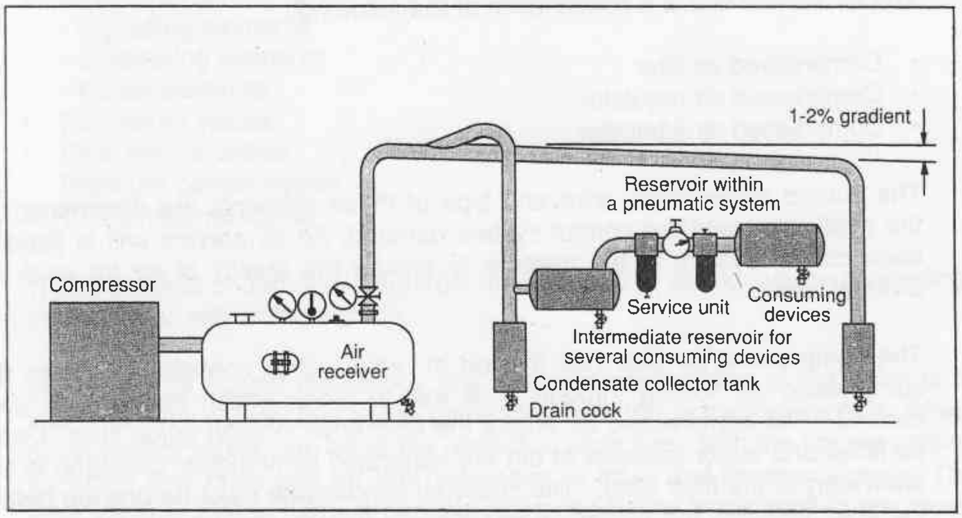
- Quantity of air required to meet the demands of the system
- Type of compressor to be used to produce the quantity required
- Storage required
- Requirements for air cleanliness
- Acceptable humidity levels to reduce corrosion and sticky operation
- Lubrication requirements, if necessary
- Low temperature of the air and effects on the system
- Pressure requirements
- Line sizes and valve sizes to meet demand
- Material selection and system requirements for the environment
- Drainage points and exhaust outlets in the distribution system
- Layout of the distribution system to meet demand.

As a rule pneumatic components are designed for a maximum operating pressure of 8 - 10 bar (800-1000 kPa) but in practice it is recommended to operate at between 5 and 6 bar (500-600 kPa) for economic use. Due to the pressure losses in the distribution system the compressor should deliver between 6.5 and 7 bar (650-700 kPa) to attain these figures.

An air receiver should be fitted to reduce pressure fluctuations. In normal operation the compressor fills the receiver when required and the receiver is available as a reserve at all times. This reduces the switching cycles of the compressor.

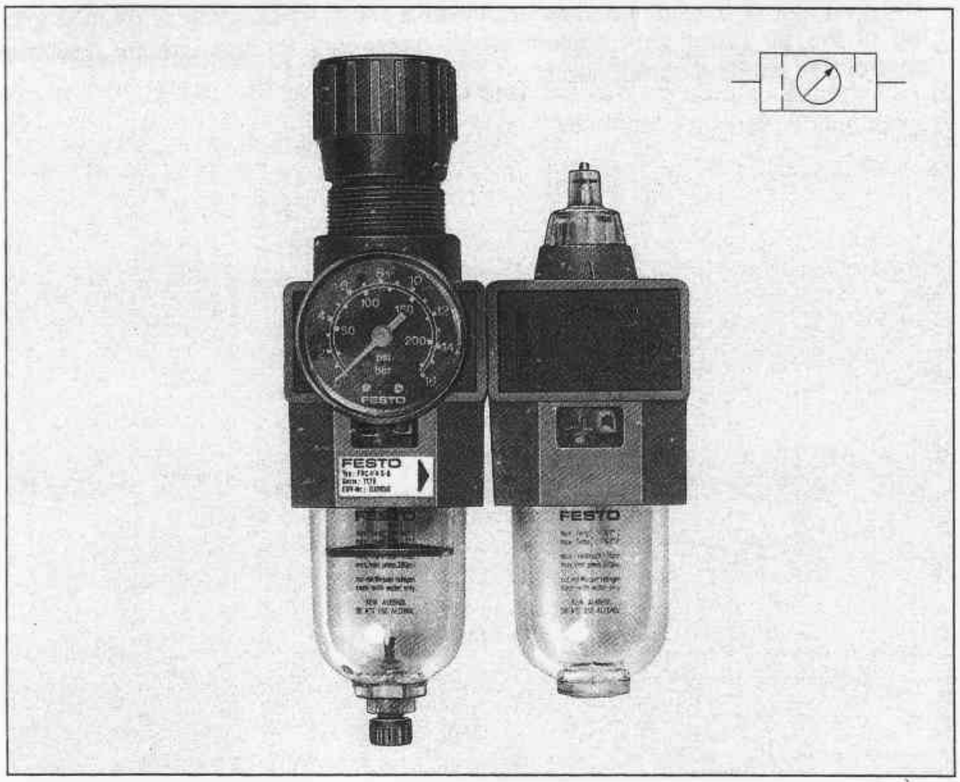
B 2.5

Air supply system



If oil is required for the pneumatic system then this should be separately metered using air service equipment. In a normal situation, components should be selected for the control system that do not require lubrication.

Air service unit



B 2.4

Due to the high demand at certain stages of the air distribution system, a ring main with cross-feed connections is recommended. In this way the fluctuations are reduced. The ring main should be laid out with a 1-2% gradient to allow drainage points for condensate from the compressor. If there is a relatively high condensate level, then air drying equipment should be fitted specifically to dry the air to the required quality. Condensate is a common cause of failure in pneumatic controls.

B 2.5

The air service unit is a combination of the following :

B 2.4

- Compressed air filter
- Compressed air regulator
- Compressed air lubricator.

The correct combination, size and type of these elements are determined by the application and the control system demand. An air service unit is fitted at each control system in the network to ensure the quality of air for each individual task.

Compressed air filter

The compressed air filter has the job of removing all contaminants from the compressed air flowing through it as well as water which has already condensed. The compressed air enters the filter bowl through guide slots. Liquid particles and larger particles of dirt are separated centrifugally collecting in the lower part of the filter bowl. The collected condensate must be drained before the level exceeds the maximum condensate mark, as it will otherwise be re-entrained in the air stream.

Compressed air regulator

The purpose of the regulator is to keep the operating pressure (secondary pressure) virtually constant regardless of fluctuations in the line pressure (primary pressure) and the air consumption.

Compressed air lubricator

The purpose of the lubricator is to deliver a metered quantity of oil mist into a leg of the air distribution system when necessary for the use by pneumatic control and working components.

2.3 Valves

Valves can be divided into a number of groups according to their function in relation to signal type, actuation method and construction. The primary function of the valve is to alter, generate or cancel signals for the purpose of sensing, processing and controlling. Additionally the valve is used as a power valve for the supply of working air to the actuator. Therefore the following categories are relevant:

- Directional control valves
  - Signalling elements
  - Processing elements
  - Power elements
- Non-return valves
- Flow control valves
- Pressure control valves
- Combinational valves

B 3

B 4

Directional control valves

The directional control valve controls the passage of air signals by generating, cancelling or redirecting signals.

In the field of control technology, the size and construction of the valve is of less importance than the signal generation and the actuation method. Directional control valves can be of the poppet or slide type, with the poppet utilised for small flow rates and for the generation of input and process signals. The slide valve is able to carry larger flow rates and hence lends itself to the power and actuator control role.

B 3

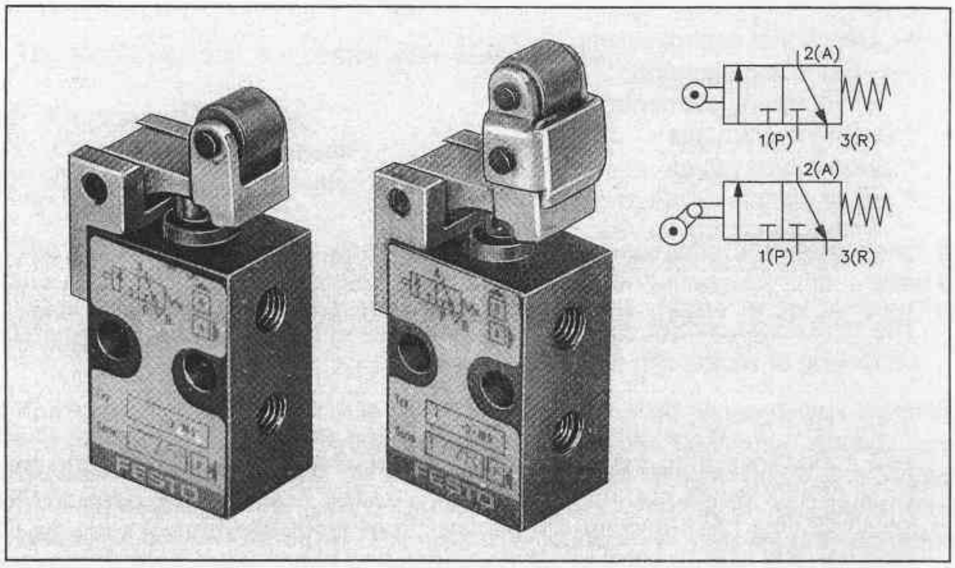
The way valve is described by :

- Number of ports or openings (ways): 2 way, 3 way, 4 way, 5 way, etc.
- Number of positions: 2 positions, 3 positions, etc.
- Methods of actuation of the valve: Manual, air pilot, solenoid, etc.
- Methods of return actuation: Spring return, air return, etc.
- Special features of operation: Manual overrides, etc.

B 3

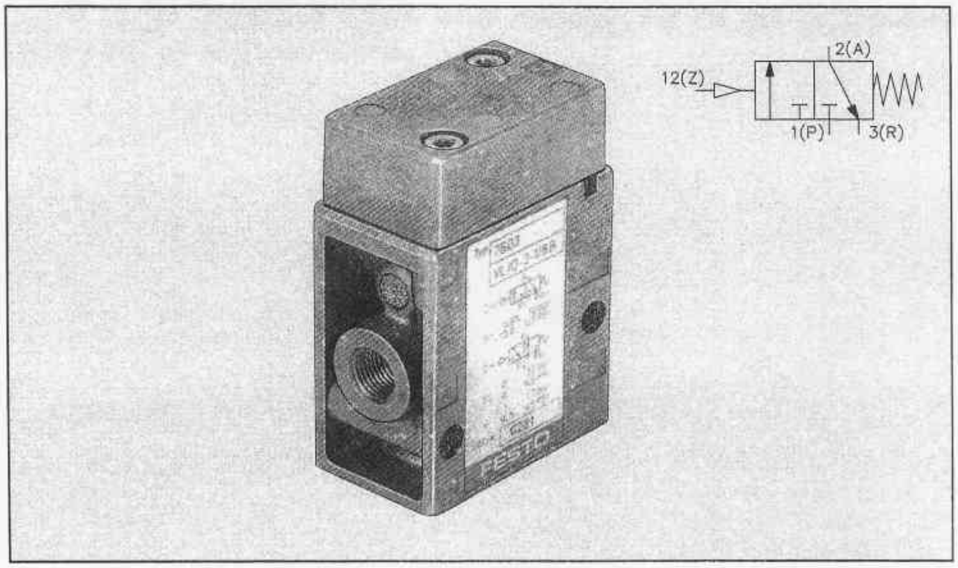
As a signal element the directional control valve is operated by for example, a roller lever to detect the piston rod position of a cylinder. The signal element can be small in size and create a small air pulse. A signal pulse created will be at full operating pressure but have a small flow rate.

3/2 way roller lever valve (without and with idle return)



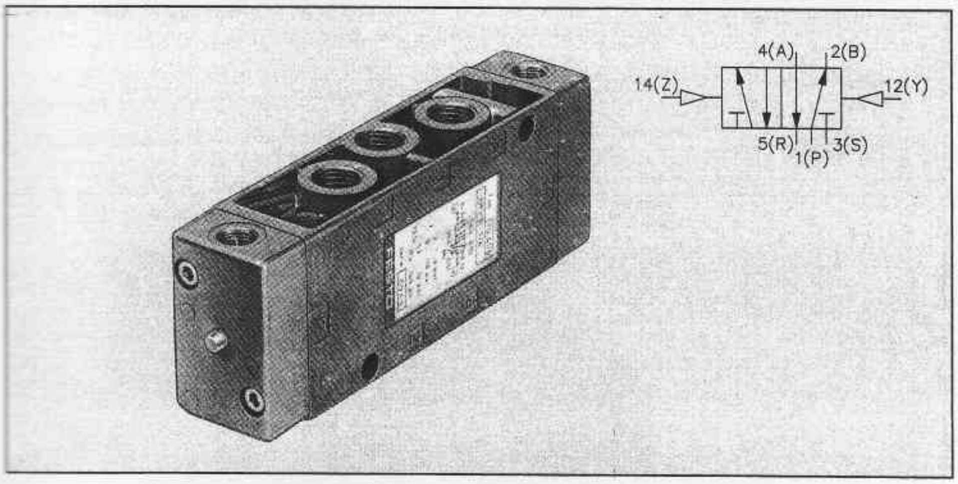
As a processing element the directional control valve redirects, generates or cancels signals depending on the signal inputs received. The processing element can be supplemented with additional elements, such as the AND-function and OR-function valves to create the desired control conditions.

3/2 way air actuated valve: single pilot valve



As a power element the directional control valve must deliver the required quantity of air to match the actuator requirements and hence there is a need for larger volume flow rates and therefore larger sizes. This may result in a larger supply port or manifold being used to deliver the air to the actuator.

5/2 way valve for cylinder control: double pilot valve



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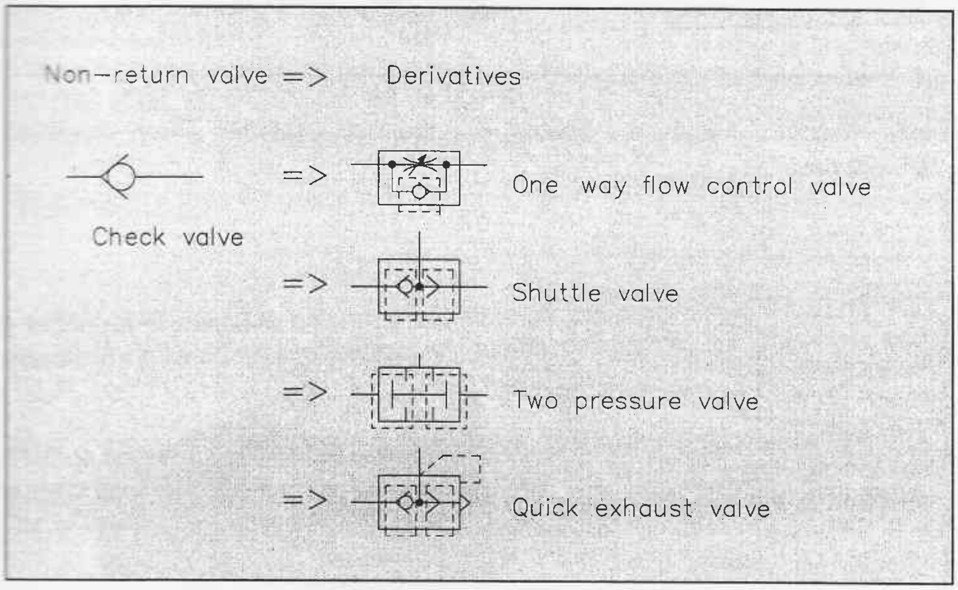
Non-return valve and its derivatives



B 4.1

Non-return valves

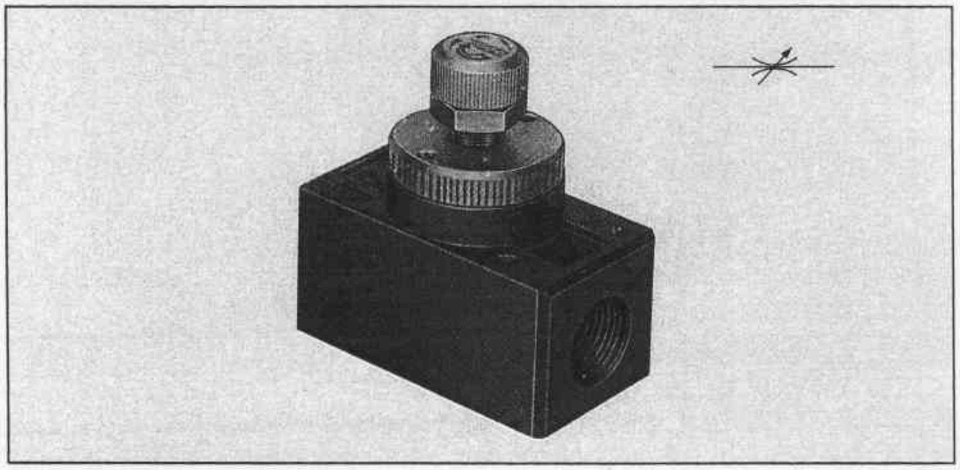
The non-return valve allows a signal to flow through the device in one direction and in the other direction blocks the flow. There are many variations in construction and size derived from the basic non-return valve. Other derived valves utilise features of the non-return valve by the incorporation of non-return elements. The non-return valve can be found as an element of the one way flow control valve, quick exhaust valve, shuttle valve and the two-pressure valve.

Flow control valves

B 4.2

The flow control valve restricts or throttles the air in a particular direction to reduce the flow rate of the air and hence control the signal flow. If the flow control valve is left wide open then the flow should be almost the same as if the restrictor is not fitted. In some cases it is possible to infinitely vary the restrictor from fully open to completely closed. If the flow control valve is fitted with a non-return valve then the function of flow-control is unidirectional with full free flow in one direction. A two way restrictor restricts the air in both directions of flow and is not fitted with the non-return valve. The flow control valve should be fitted as close to the working element as is possible and must be adjusted to match the requirements of the application.

Flow control valve



Pressure control valves

B 4.3

Pressure control valves are utilised in pneumatic systems. There are three main groups:

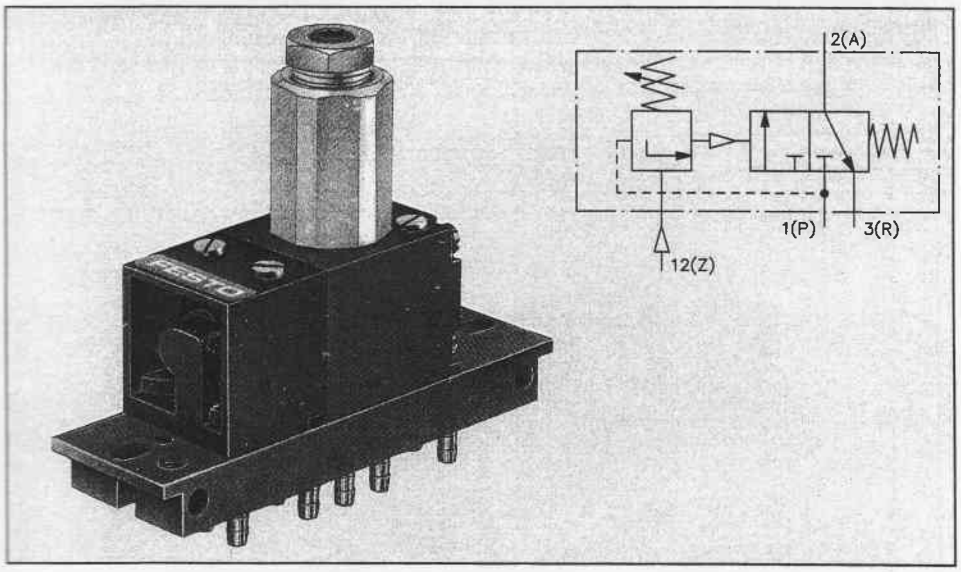
- Pressure regulating valves
- Pressure limiting valves
- Pressure sequence valves

The pressure regulating valve controls the operating pressure in a control circuit and keeps the pressure constant irrespective of any pressure fluctuations in the system.

The pressure limiting valves are utilised on the up-stream side of the compressor to ensure the receiver pressure is limited, for safety, and that the supply pressure to the system is set to the correct pressure.

The sequence valve senses the pressure of any external line and compares the pressure of the line against a preset adjustable value, creating a signal when the preset limit is reached.

Pressure sequence valve

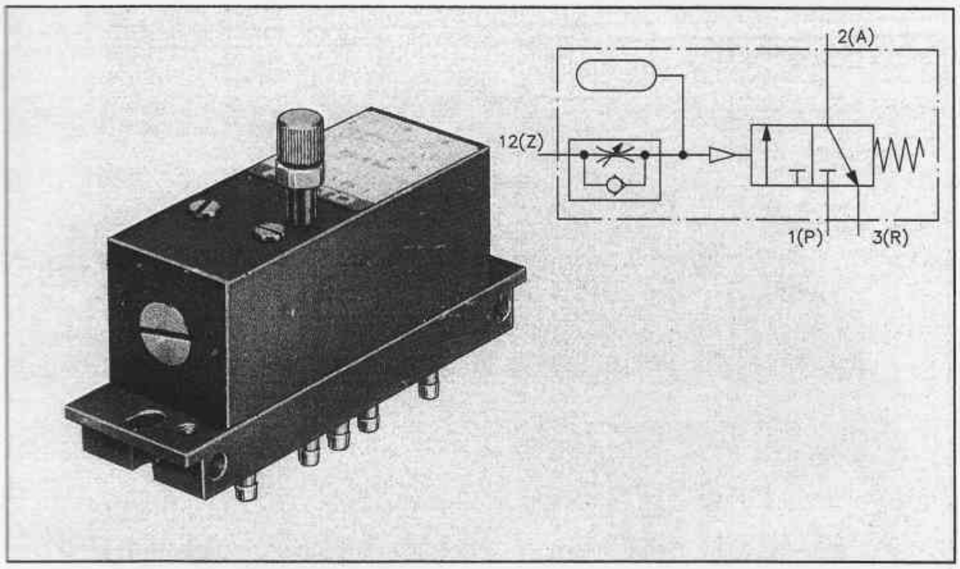


Combinational valves

B 4.4

The combined functions of various elements can produce a new function. The new component can be constructed by the combination of individual elements or manufactured in a combined configuration to reduce size and complexity. An example is the timer which is the combination of a one way flow control valve, a reservoir and a 3/2 way directional control valve.

Time delay valve



Other combinational valves include the one way flow control and the two hand start valve.

2.4 Processors: valves and logic elements

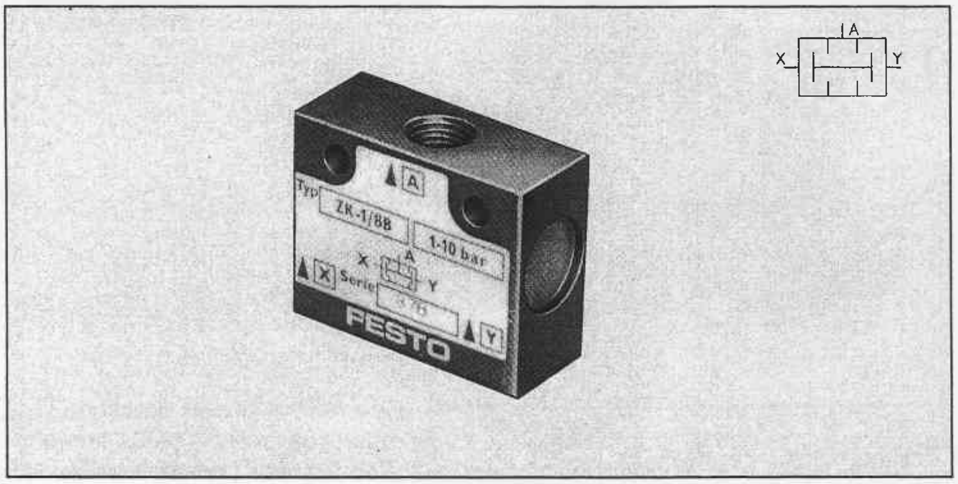
To support the directional control valves at the processing level, there are various elements which condition the control signals for a task. The elements are:

- Two pressure valve (AND function)
- Shuttle valve (OR function)

B 4.1

These elements derive their construction from the non-return valve and have logic based roles. A special feature is that they are fitted at a junction of three lines, therefore they have three connections, two in and one out.

Two pressure valve (AND function)



The further development of processing elements in pneumatics has brought about the modular systems, which incorporate directional control valve functions and logic elements to perform a combined processing task. This reduces size, cost and complexity of the system.

Modular processing unit

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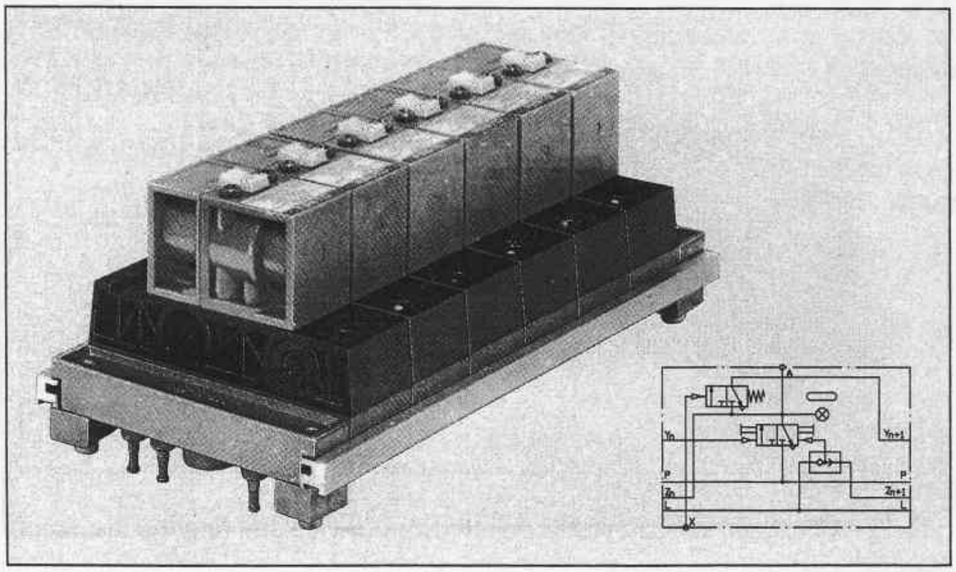

2.5 Actuators: working elements and directional control valves

The actuator group includes various types of linear and rotary actuators of varying size and construction. The actuators are complemented by the final control element, which transfers the required quantity of air to drive the actuator. Normally this valve will be directly connected to the main air supply and fitted close to the actuator to minimise losses due to resistance.

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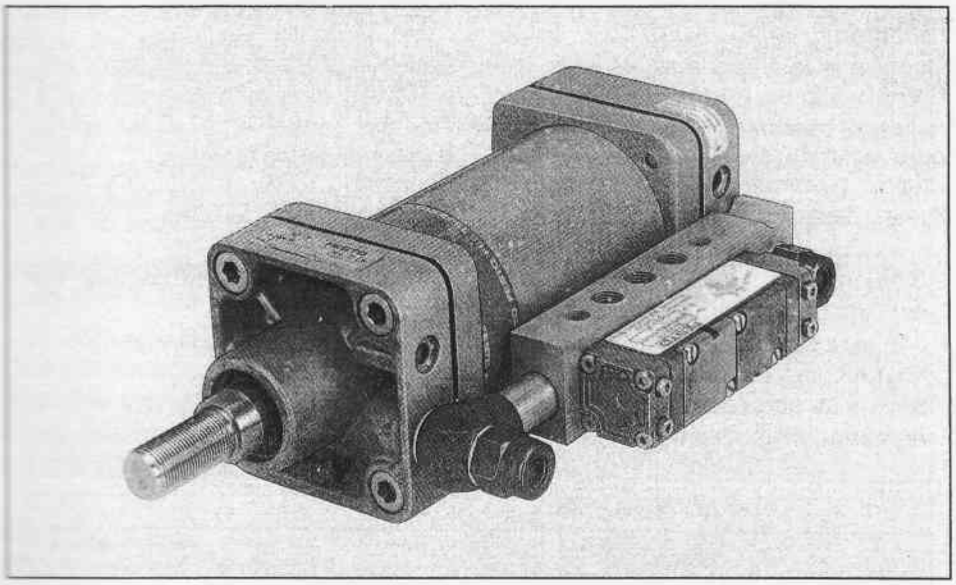
Actuator with final control element



Actuators can be further broken down into groups:

- Linear actuators
  - Single acting cylinder
  - Double acting cylinder
- Rotary actuators
  - Vane type
  - Air motors

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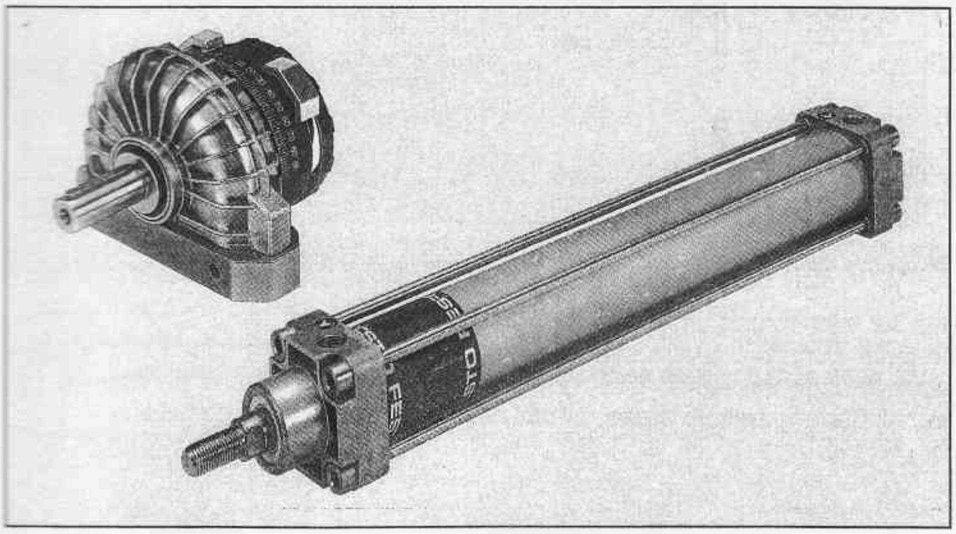
Actuators, linear and rotary



2.6 Systems : control circuits

The control of the cylinder is an important consideration in the development of control solutions. The pneumatic energy is to be transferred to the cylinder via a final control element or directional control valve. The direction of motion of the cylinder is controlled by the valve pushbutton. A circuit is developed.

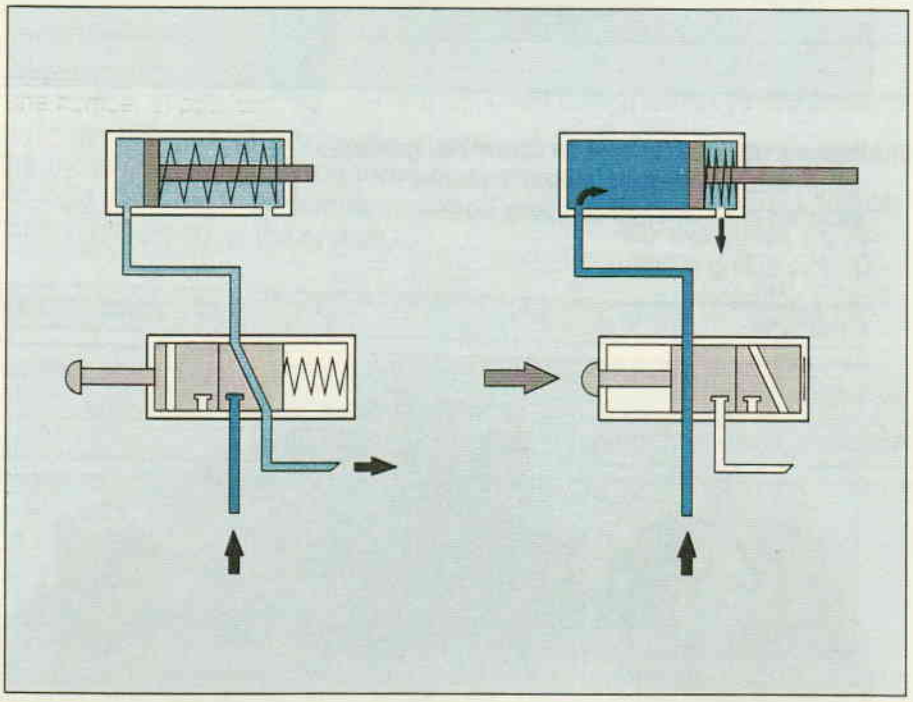
Control circuit for the single acting cylinder

The Problem
The piston rod of a single acting cylinder is to advance when air is applied. When the air is removed, the piston is to automatically return to the initial position.

Solution
A valve is to create a signal when a pushbutton is pressed and to cancel this signal when the pushbutton is released. The 3/2 way directional control valve is a signal generating valve. It is suitable for the control of a single acting cylinder. The circuit therefore includes the following primary features:

- Single acting cylinder with one supply connection and one exhaust or vent port and the spring for return force
- 3/2 way directional control valve: 3 ports and 2 positions, pushbutton for operation and spring for return force
- Supply air source connected to the 3/2 way valve
- Air connection between valve and cylinder

Control of a single acting cylinder



The 3/2 way control valve has 3 ports. The supply port, the exhaust port and the outlet port. The relationship between these ports is determined by the passages through the valve. The number of variations possible is determined by the number of positions drawn. In this case two positions are possible.

Initial position: The initial position (left-hand circuit) is defined as the 'rest' position of the system. All connections are made and there is no manual intervention by the operator. The air supply is shut off and the cylinder piston rod retracted (by spring return). The cylinder port is connected to the exhaust port via the body of the valve. The supply pressure is shut off internally by the valve.

Pushbutton operation: Pressing the pushbutton moves the 3/2 way valve against the valve return spring. The diagram (right-hand circuit) shows the valve in the actuated or working position. The air supply is now connected via the valve passage to the single acting cylinder port. The build-up of pressure causes the piston rod of the cylinder to extend against the force of the cylinder return spring. As soon as the piston rod arrives at the forward end position, the air pressure in the cylinder body reaches a maximum level.

Pushbutton release: As soon as the pushbutton is released, the valve return spring returns the valve to its initial position and the cylinder piston rod retracts.

If the pushbutton is operated and then released before the cylinder fully extends, the cylinder piston rod immediately retracts. Therefore there is a direct control relationship between pushbutton operation and cylinder piston rod position. It is possible that the cylinder may not fully extend in such cases.

Note: The speed of extension and the speed of retraction are different. As the piston rod moves forward it is under control of the air supply. During retraction the speed is mainly controlled by the size of the cylinder return spring. Therefore forward motion is faster than return motion.

Control circuit for the double acting cylinder

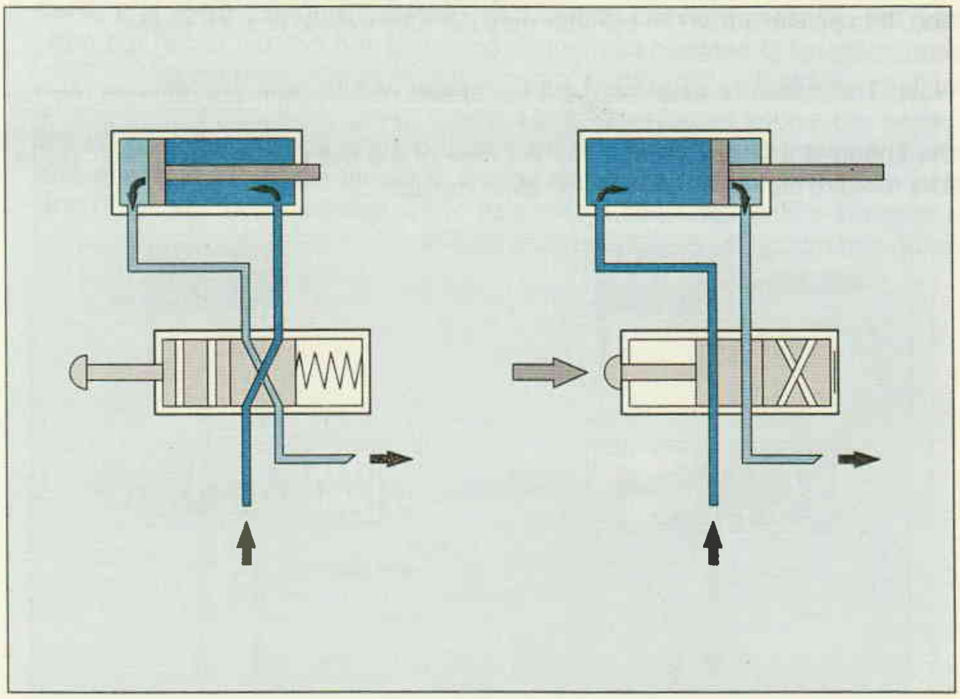
The Problem
The piston rod of a double acting cylinder is to advance when a pushbutton is operated and to return to the initial position when the pushbutton is released. The double acting cylinder can carry out work in both directions of motion, due to the full air supply pressure being available for extension and retraction.

Solution
A valve is to create one signal and cancel another signal when a pushbutton is pressed and to change over the signals when the pushbutton is released. The 4/2 way directional control valve is a signal generating valve with two signal output ports. It is suitable for the control of a double acting cylinder. The circuit therefore includes the following features:

- Double acting cylinder with two supply connections
- 4/2 way directional control valve: 4 ports and two positions, pushbutton for operation and spring for return force
- Supply air source connected to the 4/2 way valve
- Two air connections between valve and cylinder

Control of a double acting cylinder

B 3.4
B 5.2



Initial position: In the initial position (left-hand circuit) all the connections are made and there is no manual intervention by the operator. In this unactuated position, air is applied to the cylinder piston rod side, while the pressure on the piston side of the cylinder is exhausted.

Pushbutton operation: Pressing the pushbutton operates the 4/2 way valve against the valve return spring. The diagram (right-hand circuit) shows the valve in the operated or actuated position. In this position, the supply pressure is connected to the piston side of the cylinder, while the piston rod side is exhausted. The pressure on the piston side advances the piston rod. Once full extension is reached, the air pressure on the piston side reaches a maximum.

Pushbutton release: Once the pushbutton is released, the valve return spring pushes the valve into the initial position. The supply pressure is now connected to the piston rod side, while the piston side is exhausted via the exhaust port of the valve. The piston rod retracts.

If the pushbutton is released before the cylinder is fully extended, then the cylinder piston rod immediately returns. Therefore, there is a direct relationship between pushbutton operation and cylinder piston rod position.

Chapter 3

Symbols and standards in pneumatics

3.1 Symbols and descriptions of components

The development of pneumatic systems is assisted by a uniform approach to the representation of the elements and the circuits. The symbols used for the individual elements must display the following characteristics:

- Function
- Actuation and return actuation methods
- Number of connections (all labelled for identification)
- Number of switching positions
- General operating principle
- Simplified representation of the flow path

A symbol does not represent the following characteristics:

- Size or dimensions of the component
- Particular manufacturer, methods of construction or costs
- Orientation of the ports
- Any physical details of the element
- Any unions or connections other than junctions

The symbols used in pneumatics are detailed in the standard DIN ISO 1219, "Circuit symbols for fluidic equipment and systems". A summary listing of the relevant symbols are shown and a more complete listing is detailed in the TP102 book.

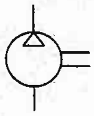
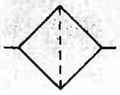
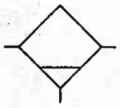
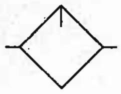
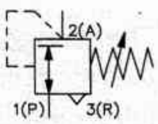
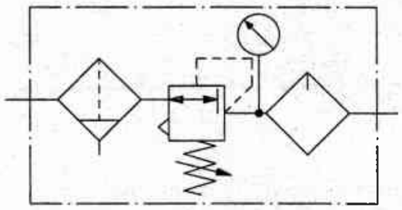
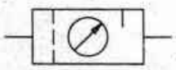
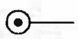
The relevant standards for the construction, testing and design of pneumatic control systems are listed in the reference section of this book.

Air supply and generation

The symbols for the energy supply system can be represented as individual elements or as combined elements. The choice between using simplified or detailed symbols is dependent upon the purpose of the circuit and its complexity. In general where specific technical details are to be given such as requirements for non-lubricated air or micro-filtering, then the complete detailed symbol should be used. If a standard and common air supply is used for all components, then the simplified symbols can be used. For trouble-shooting the detailed symbols are more suitable. But the detail should not add to the complexity of the circuit for reading.

B 2

Symbols used in energy conversion and preparation

Supply			
	Compressor	With fixed capacity	
	Air receiver and 'T' junction		
Service equipment			
	Filter	Separation and filtration of particles	
	Water separator	Partial water removal	
	Lubricator	Metered quantities of oil passed to the air stream	
	Pressure regulator	Relieving type – vent hole for excess upstream pressure – adjustable	
Combined symbols			
	Air service unit	Filter, Regulator, Gauge, Lubricator	
		Simplified air service unit	
	Pressure source		

Valve symbol description

In general the symbols are similar for pneumatics and hydraulics but each control medium has specific characteristics that are unique.

B 3

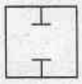
Directional control valves: symbol development

Valve switching positions are represented as squares

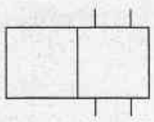
The number of squares shows how many switching positions the valve has

Lines indicate flow paths, arrows show the direction of flow

Shut off positions are identified in the boxes by lines drawn at right angles



The connections (inlet and outlet ports) are shown by lines on the outside of the box and are drawn in the initial position



Directional control valves: way valves

The directional control valve is represented by the number of controlled connections and the number of positions. Each position is shown as a separate square. The designation of the ports is important when interpreting the circuit symbols and the valve as fitted to the physical system. To ensure that the correct lines, connections and valves are physically in place, there must be a relationship between the circuit and the components used.

Therefore all symbols on the circuit must be designated and the components used should be labelled with the correct symbol and designations.

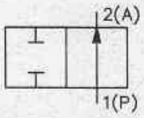
B 3

Directional control valves: ports and positions (ways)

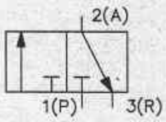
Number of ports

Number of positions

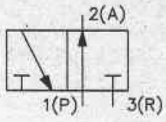
2/2 – Way directional control valve



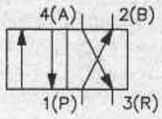
3/2 – Way directional control valve Normally closed



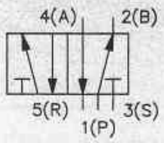
3/2 – Way directional control valve Normally open



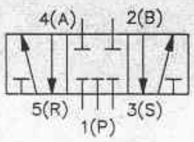
4/2 – Way directional control valve



5/2 – Way directional control valve



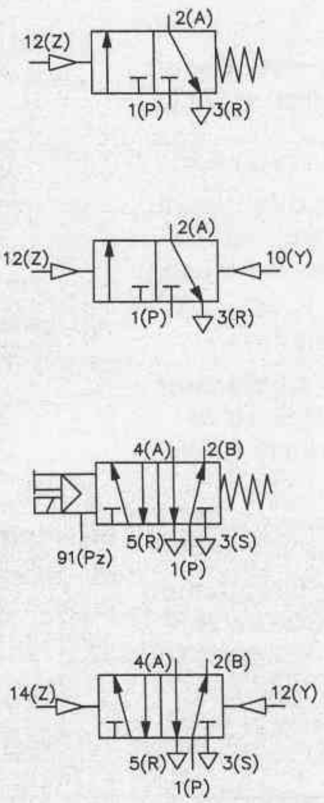
5/3 – Way directional control valve Mid position closed



A numbering system is used to designate directional control valves and is in accordance with ISO 5599 (Draft). Prior to this a lettering system was utilised and both systems of designation are presented here:

Port or Connection	ISO 5599	Lettering System
Pressure port	1	P
Exhaust port	3	R (3/2 way valve)
Exhaust ports	5,3	R,S (5/2 way valve)
Signal outputs	2,4	B,A
Pilot line opens flow 1 to 2	12	Z (single pilot 3/2 way)
Pilot line opens flow 1 to 2	12	Y (5/2 way valve)
Pilot line opens flow 1 to 4	14	Z (5/2 way valve)
Pilot line flow closed	10	Z,Y
Auxiliary pilot air	81, 91	Pz

Examples of designations



Methods of actuation

The methods of actuation of pneumatic directional control valves is dependent upon the requirements of the task. The types of actuation vary, i.e. mechanical, pneumatic, electrical and combined actuation. The symbols for the methods of actuation are detailed in ISO 1219.

B 3

When applied to a directional control valve, consideration must be given to the method of initial actuation of the valve and also the method of return actuation. Normally these are two separate methods. They are both shown on the symbol either side of the position boxes. There may also be additional methods of actuation such as manual overrides, which are separately indicated.

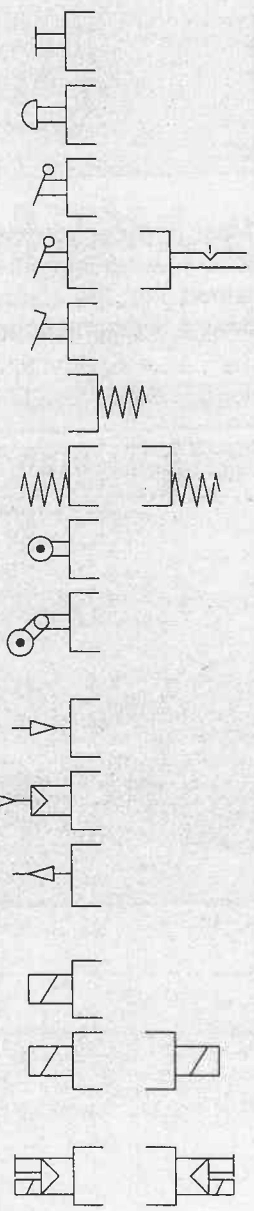
Methods of actuation

Mechanical
- General manual operation
- Pushbutton
- Lever operated
- Detent lever operated
- Foot pedal
- Spring return
- Spring centred
- Roller operated
- Idle return, roller

Pneumatic
- Direct pneumatic actuation
- Indirect pneumatic actuation (piloted)
- Pressure release

Electrical
- Single solenoid operation
- Double solenoid operation

Combined
- Double solenoid and pilot operation with manual override

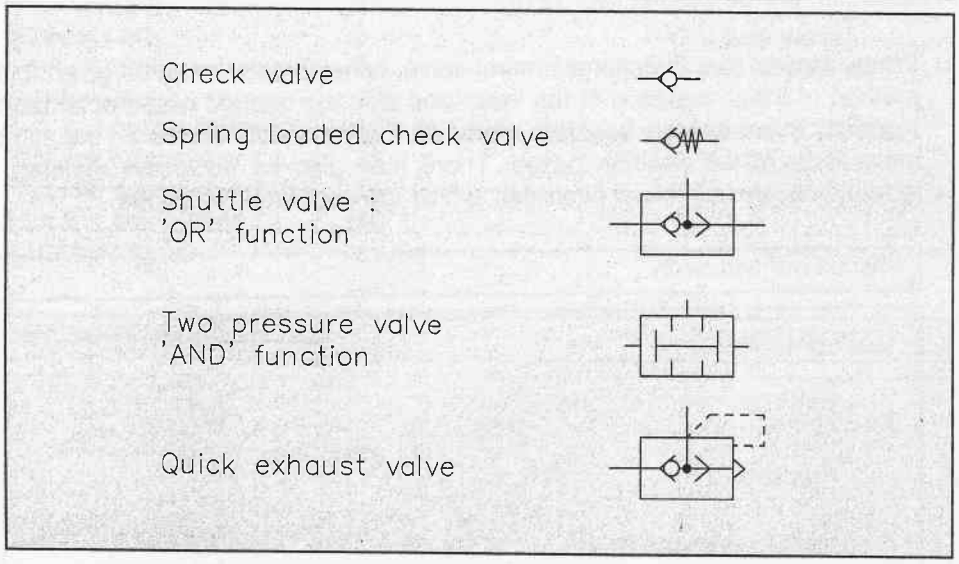


Non-return valves and derivatives

B 4.1

The non-return valve (check valve) is the basis for the development of many combined components. There are two main configurations for non-return valves, with and without the spring return.

Non-return valves and derivatives

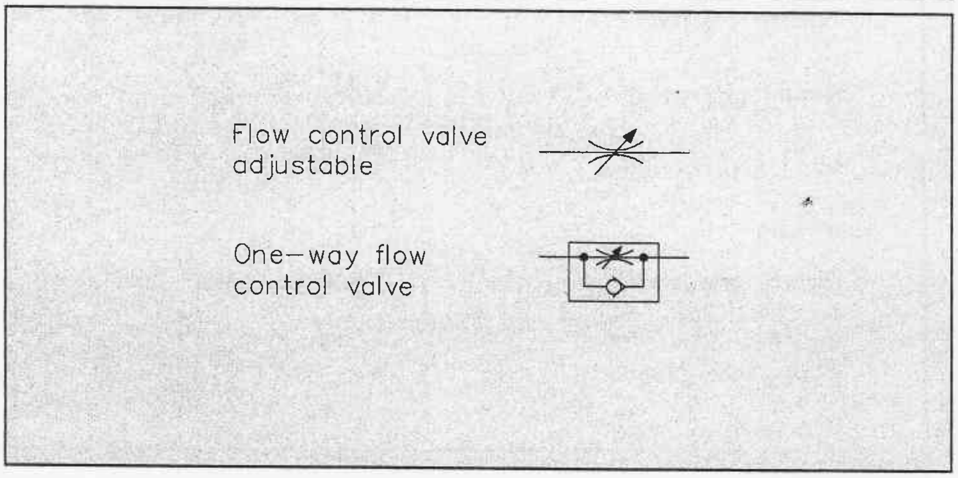


Flow control valves

B 4.2

Most flow control valves are adjustable. The one way flow control valve permits flow adjustment in one direction only with the non-return fitted. The arrow shows that the component is adjustable but does not refer to the direction of flow; it is diagrammatic only.

Flow control valves



Pressure regulating valves

B 4.3

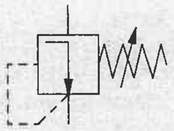
Pressure regulating valves are generally adjustable against spring compression. The symbols are distinguished according to the following types:

- Pressure sensing: downstream, upstream or external
- Relieving or non-relieving and fluctuating pressure
- Adjustable or fixed settings

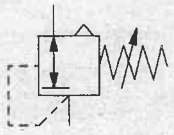
The symbols represent the pressure valve as a single position valve with a flow path that is either open or closed initially. In the case of the pressure regulator the flow is always open, whereas the pressure sequence valve is closed until the pressure reaches the limit value as set on the adjustable spring.

Pressure valves

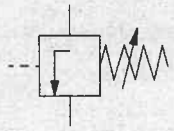
Adjustable pressure regulating valve, non-relieving type



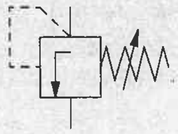
Adjustable pressure regulating valve, relieving type (overloads are vented)



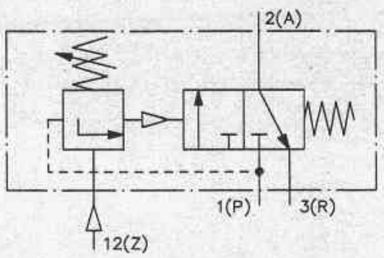
Sequence valve external source



Sequence valve in-line



Sequence valve combination



Linear actuators

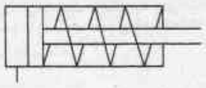
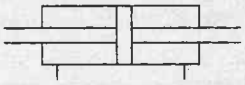
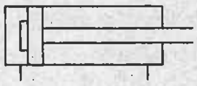
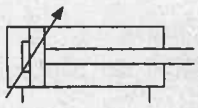
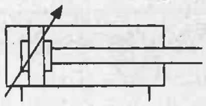
The linear actuators or cylinders are described by their type of construction and method of operation.

B 5.1

B 5.2

The single acting cylinder and the double acting cylinder form the basis for design variations. The use of cushioning to reduce loads on the end caps and mountings during deceleration of the piston is important for long-life and smooth operation. The cushioning can be either fixed or adjustable. The cushioning piston is shown on the exhaust air side of the piston. The arrow indicates adjustable cushioning and not the direction of cushioned motion.

Linear actuators

Single acting cylinder	
Double acting cylinder	
Double acting cylinder with double ended piston rod	
Double acting cylinder with non–adjustable cushioning in one direction	
Double acting cylinder with single adjustable cushioning	
Double acting cylinder with adjustable cushioning at both ends	

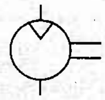
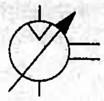
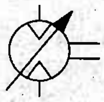
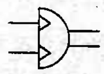
Rotary actuators

Rotary actuators are divided into continuous motion and limited angle of rotation. The air motor is normally a high speed device with either fixed or adjustable speed control.
Units with limited angle of rotation are fixed or adjustable in angular displacement. The rotary actuator may be cushioned depending upon the load and speed of operation.

B 5.5

B 5.6

Rotary motion

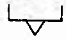
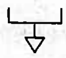
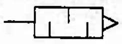
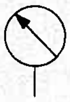
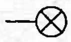
Air motor, rotation in one direction fixed capacity	
Air motor, rotation in one direction variable capacity	
Air motor, rotation in both directions variable capacity	
Rotary actuator limited travel rotation in both directions	

Auxiliary symbols

There are a number of important symbols for accessories which are utilised in conjunction with pneumatics. These include the exhaust air symbols, visual indicators and the methods of connection of components.

B 5.7

Auxiliary symbols

Exhaust port	
Exhaust port with threaded connection	
Silencer	
Line connection (fixed)	
Crossing lines (not connected)	
Pressure gauge	
Visual indicator	

3.2. Safety requirements for pneumatic systems

There are a limited number of standards and regulations for pneumatic systems. Therefore for all factors affecting safety, reference must be made to existing general guidelines and regulations from a number of different engineering fields.

Safety requirements for pneumatic clamping devices

Consideration should be given to the following guidelines when operating pneumatic cylinders under clamping conditions.

The control system for the pneumatic clamping devices should be designed or arranged in such a way as to avoid accidental operation. This can be achieved by means of:

- Manually-operated switching devices with protective covers, or
- Control interlocks

Precautions must be taken to prevent hand injuries caused by the clamping device. Machines with pneumatic clamping devices must be equipped in such a way that the drive of the working spindle or feed cannot be switched on until the clamping is confirmed complete. This can be achieved by checking the clamping conditions by means of:

- Pressure transducers, or
- Pressure sequence valves

A failure of the air supply must not cause the clamping device to open during the machining of a clamped workpiece. This can be achieved by means of:

- Pressure reservoirs
- Control interlocks (memory valves)

Environmental pollution

Two forms of environmental pollution may occur in pneumatic systems :

- Noise: caused by the escape of compressed air
- Oil mist: caused by lubricants which have been introduced at the compressor or via a service unit and which are discharged into the atmosphere during the exhaust cycles

Exhaust noise

Measures must be taken against excessive exhaust noise. This can be achieved by means of:

- Exhaust silencers

Silencers are used to reduce the noise at the exhaust ports of valves. They operate on the principle of exhaust air flow control by creating a greater or lesser flow resistance. Normal silencers have only limited influence on the speed of the piston rod. In the case of throttle silencers, however, the flow resistance is adjustable. These silencers are used to control the speed of the cylinder piston rod and the valve response times.

Another method of noise reduction is to fit manifolds with connections to the exhaust ports of the power valves and thus to discharge the air via a large common silencer or to return it to a reservoir.

Oil mist

The exhaust air of mechanically driven tools or mechanically controlled machines contains atomised oil which often remains in a room for some considerable time in the form of a vapour, which can be breathed in.

Pollution of the environment is particularly acute in cases where a large number of air motors or large-diameter cylinders are fitted in an installation.

B 2.4

Effective countermeasures must be taken to reduce the amount of oil mist that escapes to the atmosphere.

Operational safety

When maintaining or working with pneumatic systems, care must be taken in the removal and the reconnection of air lines. The energy stored in the tube or pipe will be expelled in a very short time with enough force to cause severe whiplash of the line which can endanger personnel. Where possible the air should be isolated at two different points, removing the air pressure before the disconnection is made. An additional danger is in the disturbance of particles due to the air blast which causes eye hazards.

On most control systems safety devices and guards will be fitted for the protection of personnel. These should never be manipulated as the safety of personnel may be at risk.

Chapter 4

Systematic approach to pneumatic solutions

The solution to a control problem is worked out according to a system with documentation playing an important role in communicating the final result. The circuit diagram should be drawn using standard symbols and labelling. Comprehensive documentation is required including most of the following:

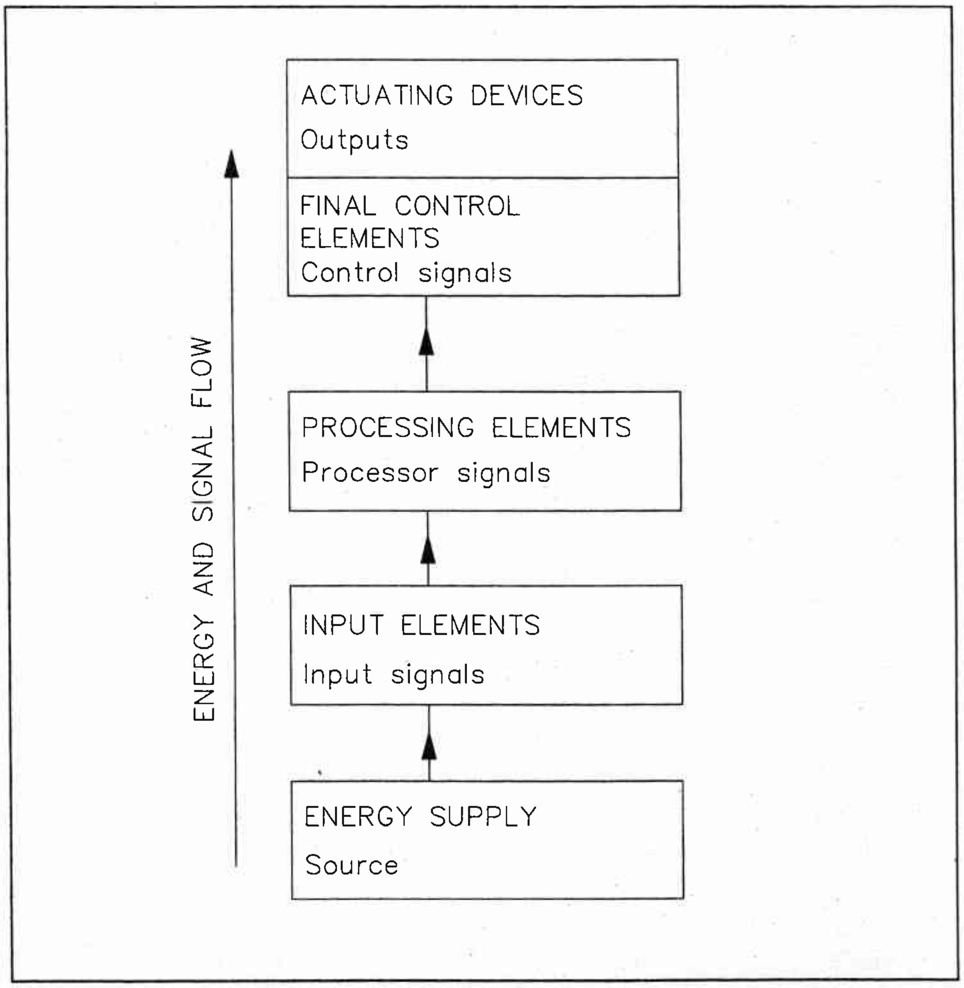
- Displacement-step or motion diagram
- Flow chart of the process
- Circuit diagram
- Parts list of all components in the system
- Description of the operation of the system
- Maintenance and fault-finding information
- Spare parts list
- Technical data on the components

B 6.2

4.1 Design of the circuit diagram

The layout of the circuit diagram should correspond to the control chain flowchart, i.e. there should be a signal flow from the bottom of the circuit to the top. The energy supply is important and must be included in the circuit. The elements required for the energy supply should be drawn at the bottom. Simplified or full component symbols can be utilised. In larger circuits, the energy supply section (service unit, shut-off valve, various distribution connections etc.) can be drawn separately.

Control chain flowchart

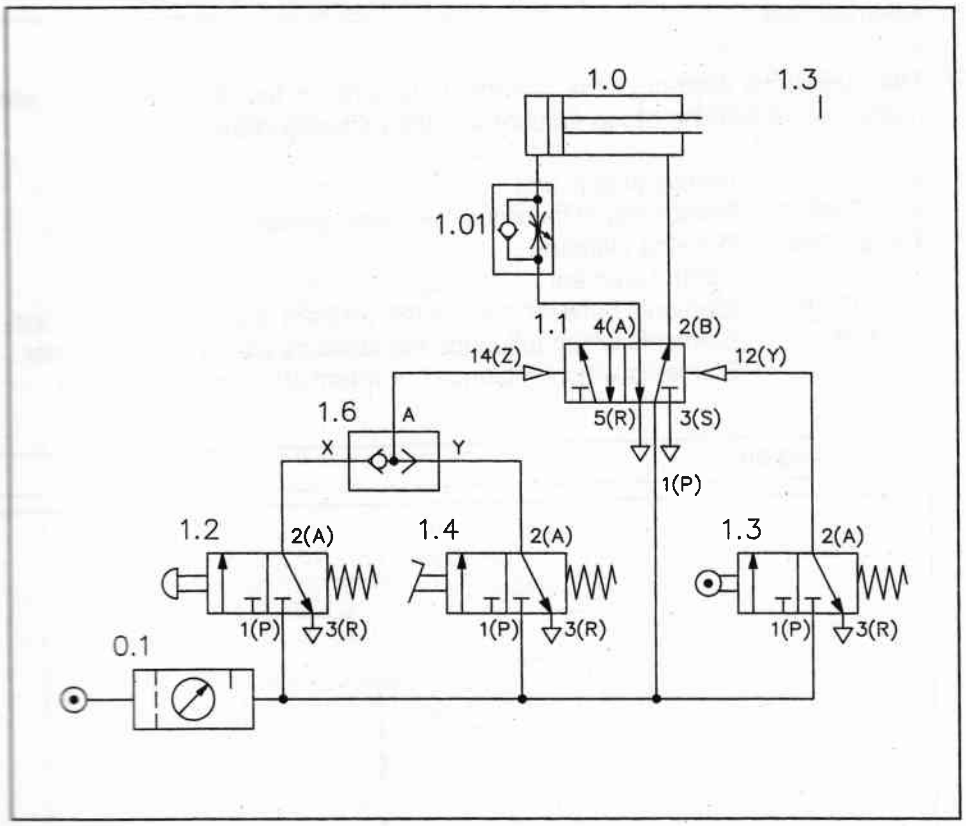


This layout means that the circuit diagram must be drawn without considering the actual physical locations of each of the elements. It is recommended that all cylinders and directional control valves be drawn horizontally with the cylinders operating from left to right, so that the circuit can be more easily understood.

4.2 Circuit layout

The Problem
The piston rod of a double-acting pneumatic cylinder travels out if either a manual pushbutton or a foot pedal is operated. The cylinder returns to its starting position after fully extending. The piston rod will return provided the manual actuators have been released.

Circuit diagram



Solution
The valve 1.3 is mounted at the full extension position of the cylinder. The circuit diagram shows this element situated at the signal input level and does not directly reflect the orientation of the valve. The mark on the circuit at the extended cylinder position indicates the physical position of the valve 1.3 for circuit operation.

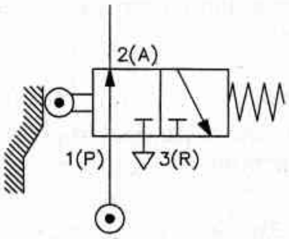
If the control is complex and contains several working elements, the control should be broken down into separate control chains. A chain can be formed for each functional group.

Wherever possible, these chains should be drawn next to each other in the same order as the operating sequence. This is not always possible.

4.3 Designation of individual elements

All elements should be shown in the circuit diagram in the initial position: here the valve is initially actuated. This must be indicated (for example, by an arrow, or in the case of a limit switch by drawing a cam). The valve is shown in the operated state with the left hand position in line with the supply port. The signal at 2(A) is initially active due to operation of the roller element.

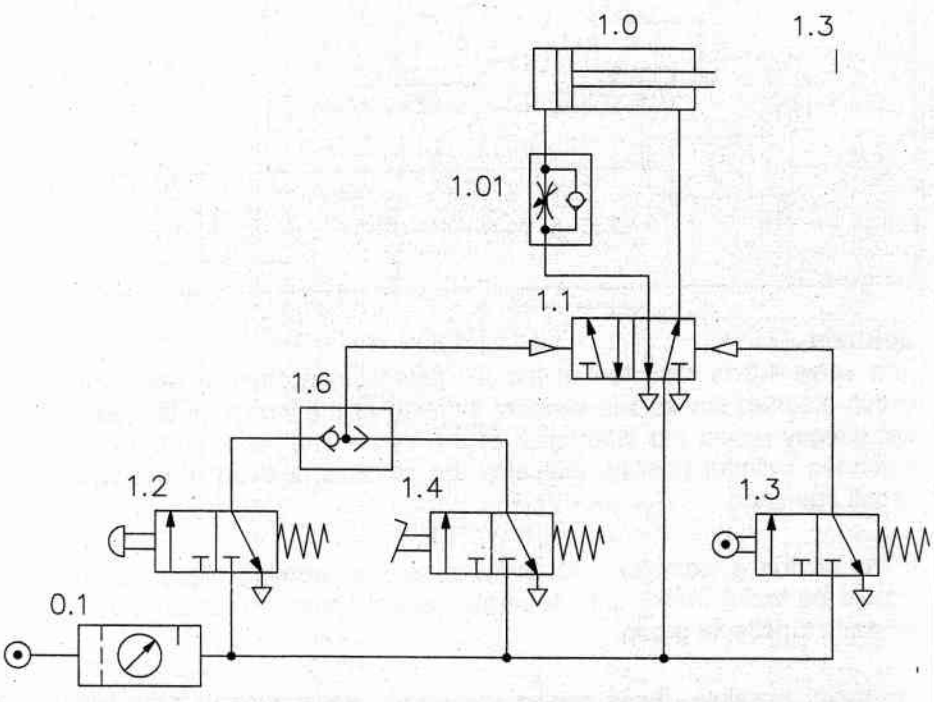
Actuated initial position



The numbering system of the individual elements in the circuit diagram below relates to the working group number and the following criteria:

0.	Energy supply unit
1, 2, 3 etc.	Numbering of individual working groups or control chains
1.0, 2.0 etc.	Working element
.1	Control element
.01, .02 etc.	Elements between the control element and working element
.2, .4 etc.	Elements which influence the advance stroke of the cylinder
.3, .5 etc.	Elements which influence the return stroke of the cylinder

Circuit diagram



Summary

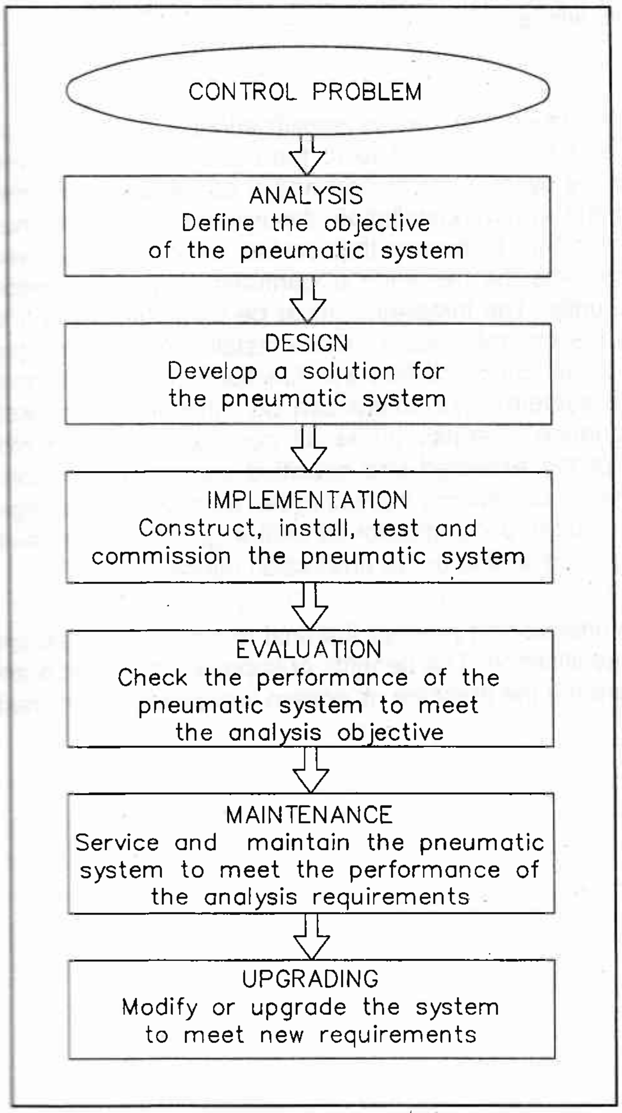
- Signal flow from bottom of circuit to the top.
- Energy source can be shown in simplified form.
- Physical arrangement of the elements is ignored.
- Draw the cylinders and directional control valves horizontally wherever possible, cylinders extending from left to right.
- Designate all elements in the completed installation the same as in the circuit diagram.
- Identify position of the input signals by a mark (limit valve). If signals are issued in one direction only, show an arrow on the mark.
- Show elements in the initial position of the control. Identify actuated elements by a cam or arrow.
- Draw pipelines straight without cross-over wherever possible. Junctions are indicated by a dot.

4.4 The life cycle of a pneumatic system

The development of solutions for pneumatic control systems is dependent upon methodical planning.

The various phases involved in the life cycle of such systems are shown here.

Pneumatic system development



Analysis of a pneumatic control problem

The first step is the definition of objectives for the project with a clear definition of the problem(s). Design or development of the solution is not involved at the analysis stage. A flow chart of the total project plan can be developed to define the step-orientated processes.

Design

There are two stages of design development.

The first is the overall system design where general systems hardware and control medium decisions are made. At this stage alternative solutions may be addressed for consideration.

The next stage of the design process involves the following :

- Development of hardware systems
- Documentation development - preliminary documentation
- Definition of further requirements
- Time schedules for project implementation
- Product lists and specifications
- Costing data

Implementation

The project is implemented using the design specifications. The hardware components are ordered and then constructed to form a system. A delivery date can be estimated for the system completion and a schedule for commissioning drawn up. Prior to the system installation, the system's functions must be fully tested. This is important to ensure that on-site work is not delayed. The installation process involves the mounting of controls, actuators, sensors and connection of service units. The installation must be fully completed prior to any attempt to operate the control system. Once installation is completed, the commissioning stage is reached. When the functional test of all components is completed, the system as a whole can be functionally checked. Finally to ensure the sequence operates under all conditions, the machine must be cycled under all of the expected and specified operating conditions, e.g. product failure, emergency conditions, manual cycle, auto cycle, blockages etc. The machine is not considered commissioned until a quantity of products have been passed through the machine under production conditions.

Evaluation

Upon completion of the commissioning process the final result is evaluated and compared to the original specification. The benefits of improved production and reduced costs will be apparent if the machine or system is properly maintained.

Maintenance

Maintenance is essential to minimise the system downtimes.

Regular and careful maintenance helps to increase the reliability of a system and to reduce the operating costs.

After a certain number of cycles, some components may show signs of early deterioration which might be due to incorrect product selection or a change in operating conditions. Basic preventive maintenance carried out at regular intervals helps to diagnose failures of this kind and thus avoids system downtimes.

A 7

System upgrade

After the system has been in service for some time, the reliability of the system can be improved through component replacement or upgrade.

Chapter 5

Development of single actuator circuits

There are two primary methods for constructing circuit diagrams:

- The so-called intuitive methods, also frequently termed conventional or trial-and-error methods
- The methodical design of a circuit diagram in accordance with prescribed rules and instructions

Whereas much experience and intuition is required in the first case and above all, a great deal of time where complicated circuits are concerned; designing circuit diagrams of the second category requires methodical working and a certain amount of basic theoretical knowledge.

B 6.2

Regardless of which method is used in developing the circuit diagram, the aim is to end up with a properly functioning and reliable operating control. Whereas previously emphasis was placed on the least expensive hardware solution, more importance is now attached to operational reliability and ease of maintenance by a clear layout and documentation.

This inevitably leads to increased usage of methodical design processes. In such cases, the control is always constructed in accordance with the given procedure and is less dependent upon personal influences from the designer. In many cases, however, more components will be required for the methodical solution than in a circuit devised by the intuitive method.

This additional material requirement will usually be rapidly compensated for by time-saving at the project stage and also later in terms of maintenance. Generally, it must be ensured that the time spent in project design and particularly in simplifying the circuit, is in reasonable proportion to the overall effort.

Regardless of which method and which technique is used to produce a circuit diagram, the basic requirements are sound fundamental knowledge of the devices concerned and knowledge of the switching characteristics of the components used.

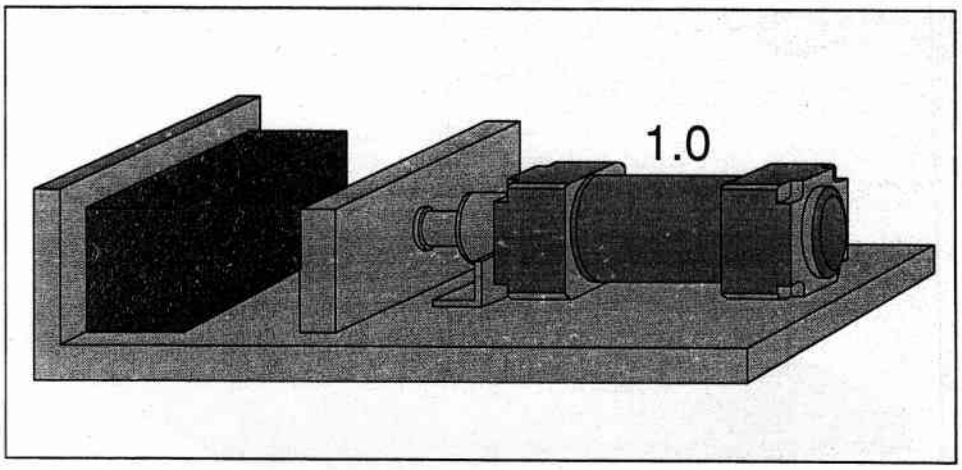
5.1 Direct control of a pneumatic cylinder

The simplest level of control for the single or double acting cylinder involves direct control signals. Direct control is used where the flow rate required to operate the cylinder is relatively small, and the size of the control valve is also small with low actuating forces. If the valve is too large, the operating forces required may be too great for direct manual operation.

5.2 Example 1: Direct control of a single acting cylinder

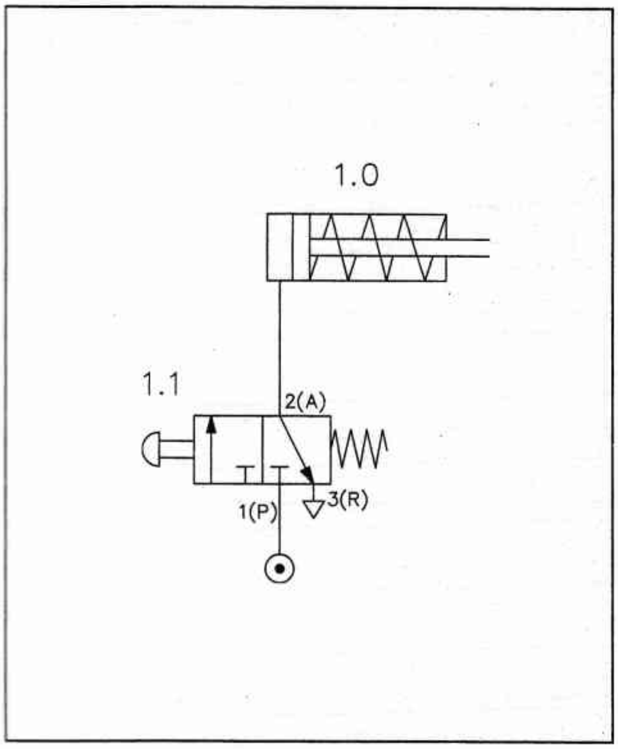
The Problem
A single acting cylinder of 25mm diameter is to clamp a component when a pushbutton is pressed. As long as the pushbutton is activated, the cylinder is to remain in the clamped position. If the pushbutton is released, the clamp is to retract.

Clamping device



Solution
The control valve used for the single acting cylinder is the 3/2 way valve. In this case, since the cylinder is of small capacity, the air consumption is low and the operation can be directly controlled by a pushbutton 3/2 way directional control valve with spring return.

Circuit diagram



On operating the pushbutton the air passes through the valve from 1(P) to the 2(A) port and extends the piston rod against the force of the cylinder return spring. On release of the button, the valve spring returns the 3/2 way valve to its initial position and the cylinder retracts. The air returns from the cylinder via the exhaust 3(R) port.

B 3.3

Since the cylinder is the only working element or actuator in the circuit, it is designated 1.0. The final control element that extends the cylinder is designated 1.1.

B 5.1

5.3 Exercise 1: Direct control of a double acting cylinder

Exercise

Draw the circuit diagram for the problem.

Designate the valves and indicate the numbering system for the connections (ports).

Describe the operation of the circuit.

B 3.4

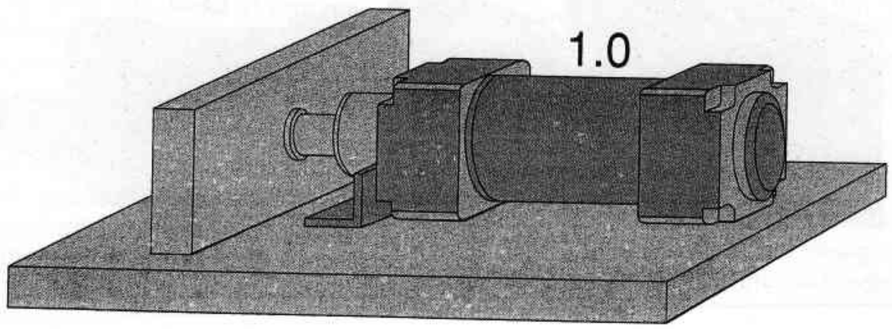
B 3.6

B 5.2

The Problem

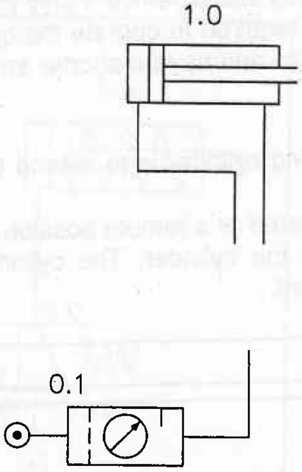
A double acting cylinder is to extend when a pushbutton is operated. Upon release of the pushbutton the cylinder is to retract. The cylinder is of small bore (25mm diameter) requiring a small flow rate to operate at the correct speed.

Positional sketch



Notes:

Circuit diagram



Question

What happens to the cylinder, if the pushbutton is pressed for a very short period, and is then immediately released?

Notes:

5.4 Indirect control of a pneumatic cylinder

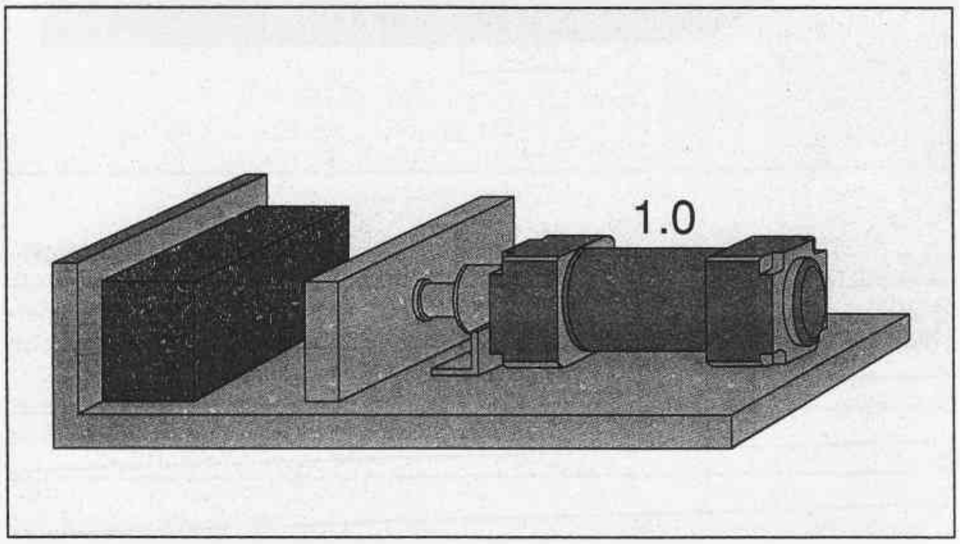
For controlling cylinders at high speed or of large diameter, the air flow required determines whether a larger size control valve should be used. The operating force to actuate the valve may be relatively large and in this case indirect control is preferable. A similar situation exists when a cylinder operates at high speed, and requires a large valve that cannot be directly operated. The control element will have a large orifice size and flow rate and be operated by pilot air to assist opening against the switching force. This is indirect control. The supply line can also be short, since the control valve can be mounted close to the cylinder. The other advantage is that the signal element (i.e. pushbutton 3/2 valve) can be small in size, since it only provides a signal to operate the control valve and is not required to operate the cylinder directly. This signal element will be of smaller size and have a shorter switching time.

B 3.3

5.5 Example 2: Indirect control of a single acting cylinder

The Problem
A large diameter single acting cylinder is to extend upon operation of a pushbutton valve.
The pushbutton valve is situated at a remote position. Therefore indirect control should be used to operate the cylinder. The cylinder is to retract once the remote pushbutton is released.

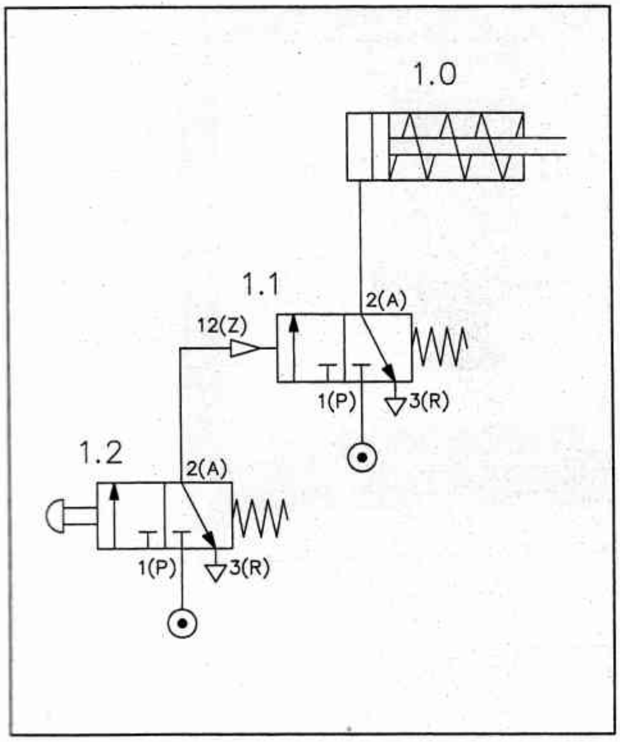
Clamping device



Solution
In the initial position, the single acting cylinder is retracted and the control valve 1.1 is in the unactuated position, due to the spring return. The pushbutton valve is in the spring return position with the connection at 2(A) exhausted to atmosphere. Therefore the only active lines are the 1(P) lines of the two 3/2 way valves.

B 3.3

Circuit diagram



The 3/2 way pushbutton valve (1.2) opens the 1(P) air supply to the 2(A) port and generates a signal at the 12(Z) pilot port of the control valve. The control valve 1.1 is actuated against spring force and the 1(P) line is opened to the 2(A) port, causing the single acting cylinder to extend. The signal at the 12(Z) line remains as long as the pushbutton is held down, and therefore the cylinder remains extended until the pushbutton is released. This is an indirect pushbutton control of the cylinder.

If the pushbutton is released, the spring return closes the 1(P) port of the 3/2 way valve and exhausts the 2(A) line to atmosphere. This removes the actuating pilot signal at the control valve. The control valve is returned to the initial position by the return spring and the single acting cylinder line is exhausted to atmosphere. The spring in the cylinder retracts the cylinder to the initial position.

The control valve can be fitted close to the cylinder and be large in size to control the large bore cylinder. The pushbutton can be small in size and fitted remotely.

5.6 Exercise 2: Indirect control of a double acting cylinder

The Problem

A double acting cylinder is to extend when a pushbutton is operated. Upon release of the pushbutton the cylinder is to retract.

The cylinder is 250mm diameter and consumes a large volume of air.

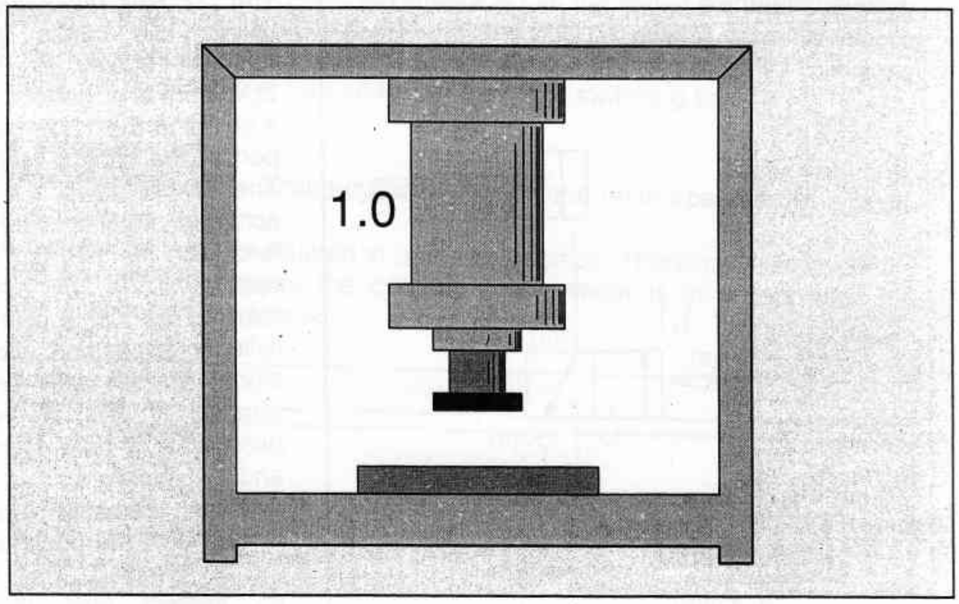
Exercise

Draw the circuit diagram for the problem.

Designate the valves and indicate the numbering system for the connections.

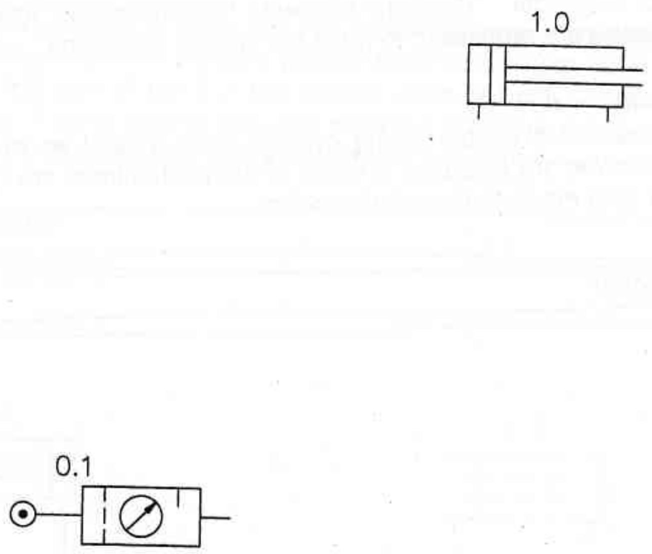
B 3.3

Positional sketch



Notes:

Circuit diagram



Question

What happens to the cylinder, if the pushbutton is pressed for a very short period and is then immediately released?

Describe the operation of the circuit.

Notes:

5.7 Logic functions: AND, OR

B 4.1

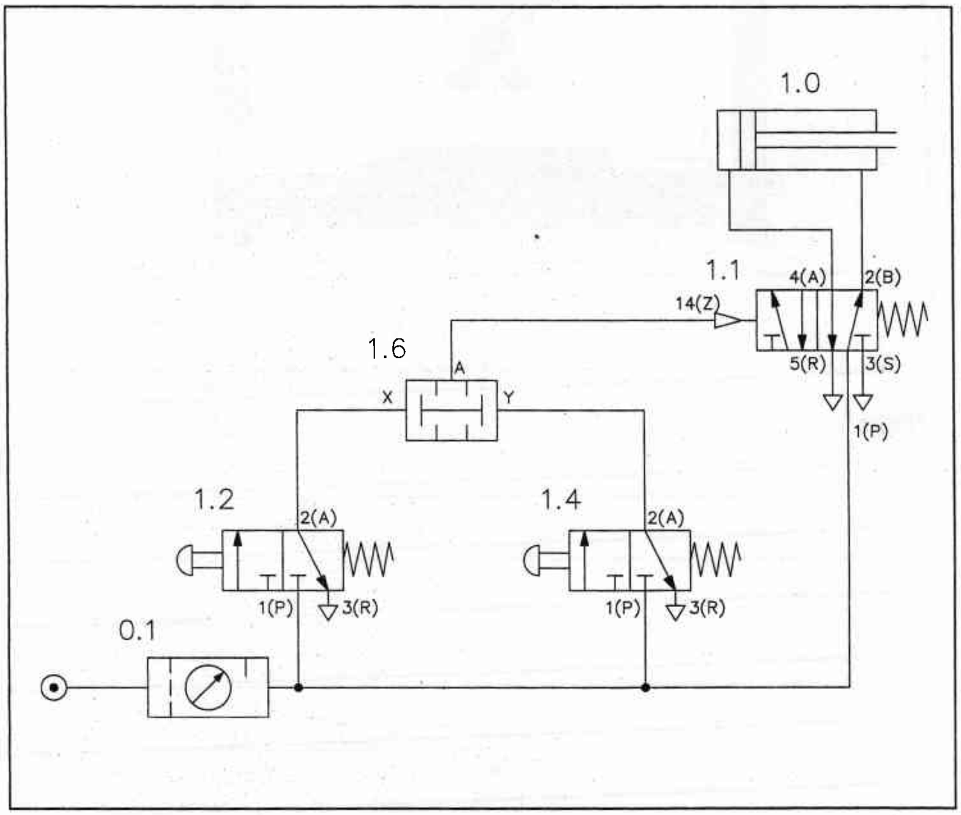
The pneumatic shuttle valve and the two pressure valve have logic functions. The shuttle valve has the characteristic of an OR function, whereby at least either of two inputs X or Y are required to generate an output at port A of the valve. In the case of the two pressure valve, the characteristic is that of the AND function, whereby both inputs X and Y are required to initiate an output A. The two pressure valve and the shuttle valve normally control the input signals' passage to ensure special conditions are met in a circuit. For example, interlocks, safety measures and operating conditions which are required prior to the actuation of a cylinder. The logic elements have processor roles in a circuit, whereby signals are processed to meet the special conditions.

5.8 Example 3: The logic AND function; the two pressure valve

The Problem

The piston rod of a double acting cylinder is to extend when two 3/2 way pushbutton valves are actuated. If either of the pushbuttons are released, then the cylinder is to return to the initial position.

Circuit diagram



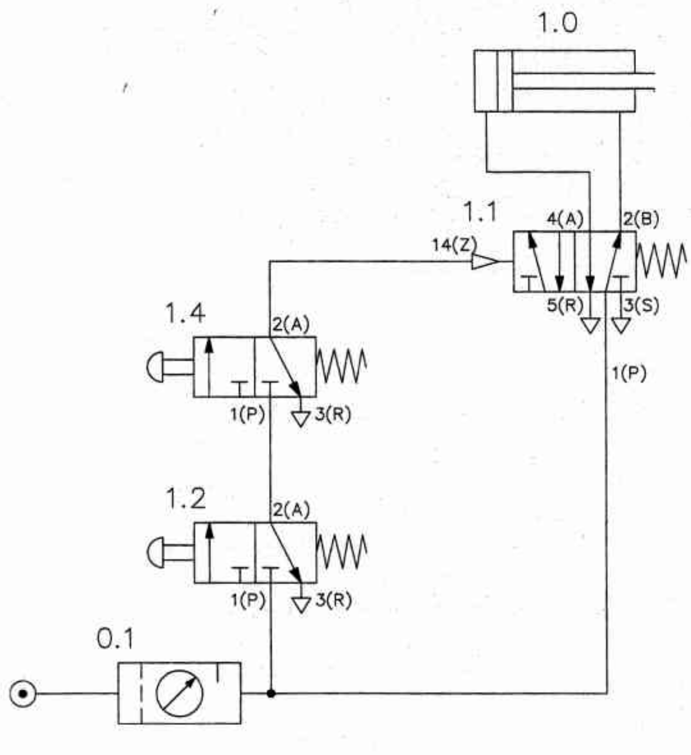
Solution

The two pressure valve is connected to the junction between the two 3/2 way pushbutton valves. Upon operation of one of the pushbuttons, a signal is generated at the X or Y side of the two pressure valve. This signal is blocked by the two pressure valve. If the second pushbutton is also operated, then the two pressure valve will produce a signal at port A which operates the control valve 14(Z) pilot signal against the spring return and the cylinder extends.

The control valve can be a 4/2 way or a 5/2 way valve and can be of a size which suits the flow rate required for the cylinder speed. If either of the two signals produced via the pushbutton valves is removed, then the two pressure valve will relieve the 14(Z) signal back through the exhaust port of the non-operated 3/2 way valve. The spring in the control valve switches the 5/2 way valve to the initial position. The outlet 2(B) is active with the outlet 4(A) exhausted to atmosphere and the cylinder retracts.

An alternative solution to using the two pressure valve is to use two 3/2 way valves in series. Here the signal is passed from valve 1.2 to valve 1.4 and then on to the 14(Z) port of the 5/2 way control valve but only if both pushbuttons are operated. If either pushbuttons are released, then the signal at 14(Z) of the control valve is exhausted at the non-operated pushbutton valve.

Circuit diagram



5.9 Exercise 3: The logic AND function; the two pressure valve

The Problem

A transfer station removes a product from a conveyor belt. If the product is detected as present and if the operator presses the pushbutton, the pick-up cylinder 1.0 extends. The product is sensed by a 3/2 way roller lever valve. Upon the release of the pushbutton the cylinder 1.0 is to retract to the initial position.

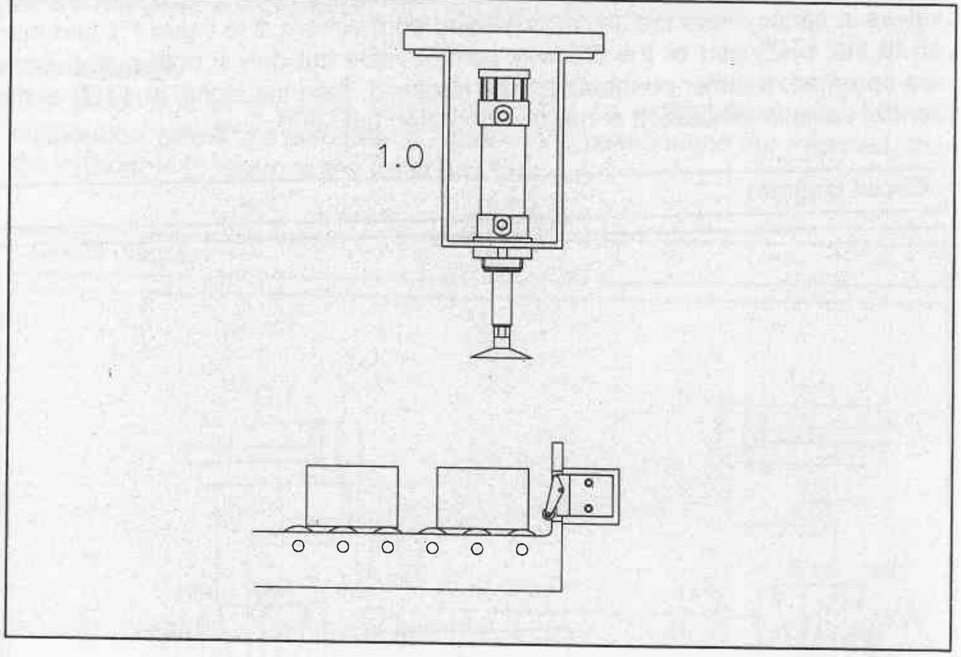
Exercise

Draw the circuit diagram for the problem.

Designate the valves and indicate the numbering system for the connections (ports).

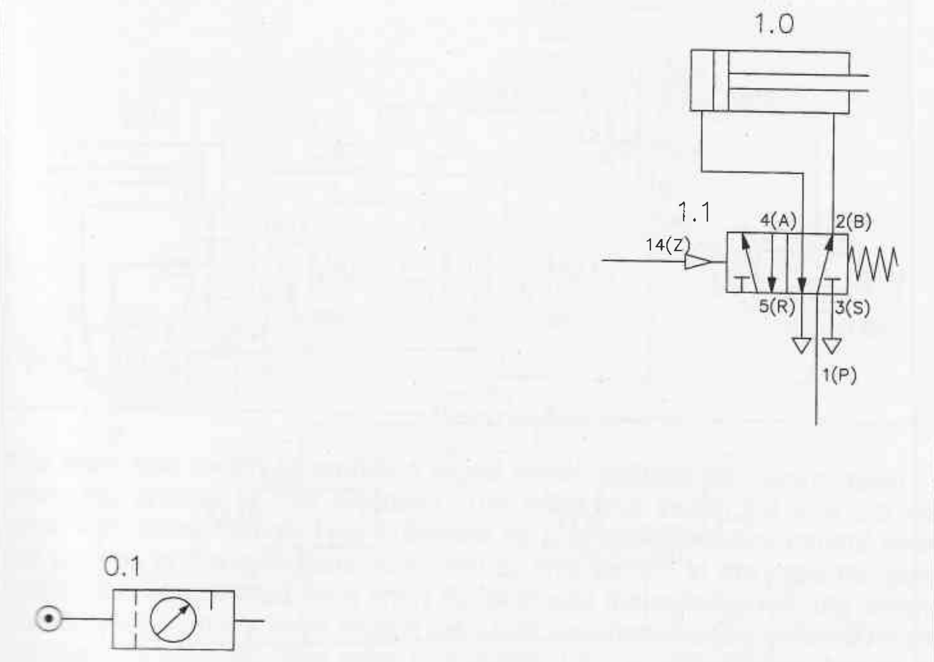
B 4.1

Positional sketch



Notes:

Circuit diagram



Describe the operation of the circuit.

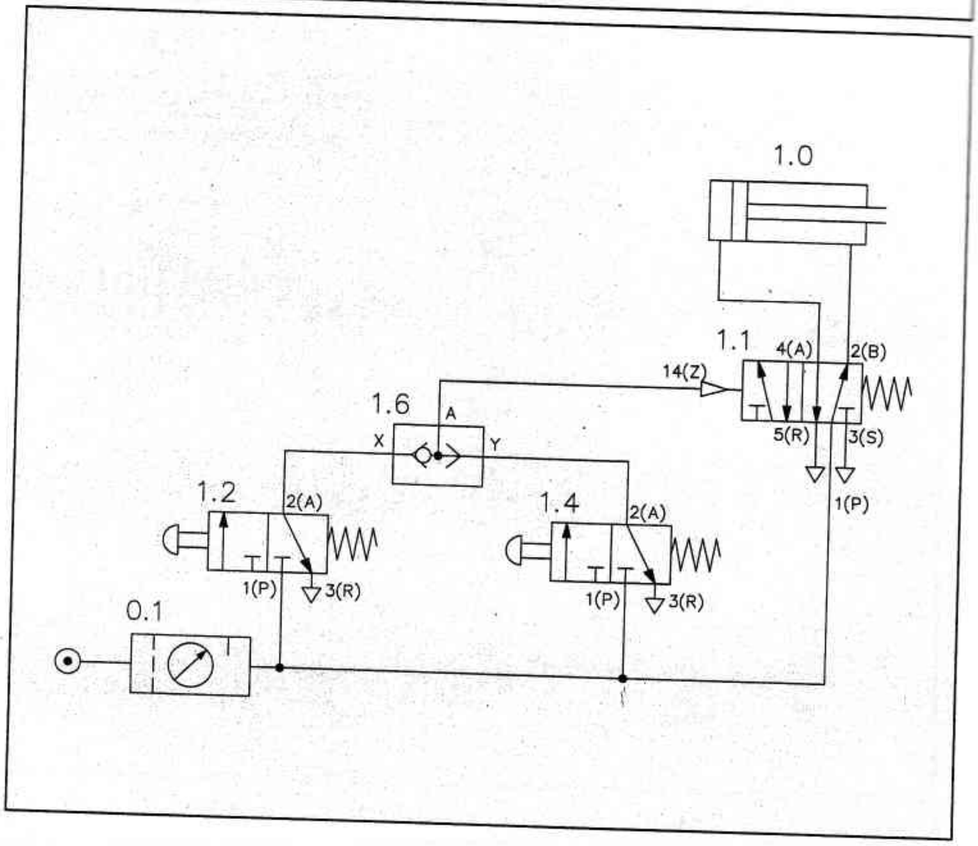
Notes:

5.10 Example 4: The logic OR function; the shuttle valve

B 4.1

The Problem
A double acting cylinder is to extend if one or both of two pushbuttons are operated. If both pushbuttons are then released, the cylinder is to retract.

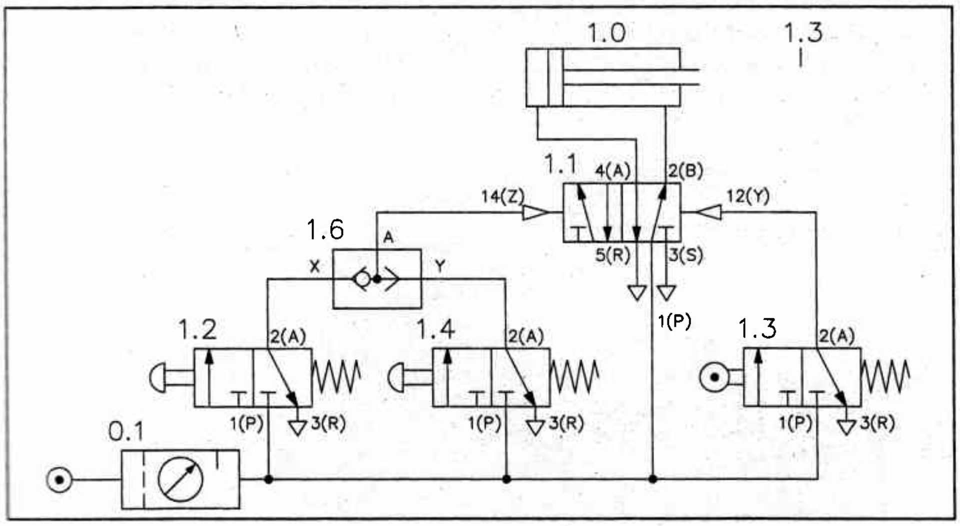
Circuit diagram



Solution
The shuttle valve is connected to the junction between the two 3/2 way pushbutton valves. Upon operation of one of the pushbuttons, a signal is generated at the X or Y side of the shuttle valve. This signal passes through the shuttle valve and is emitted at port A. This reverses the control valve via pilot port 14(Z), and the cylinder extends. The control valve can be a 4/2 way or a 5/2 way valve and can be sized to suit the flow rate required for the cylinder speed. If both of the signals produced via the pushbutton valves are removed, then the shuttle valve will release the 14(Z) pilot signal back through the exhaust port of one of the 3/2 way valves. The return spring in the control valve switches the 5/2 way valve to the initial position. The outlet 2(B) is active with the outlet 4(A) exhausted to atmosphere, and the cylinder retracts.

Conclusion
If the cylinder is to retract on reaching its fully extended position, roller limit valves should be used to confirm that this position has been reached. In addition, a memory valve should be fitted for the control of the cylinder.

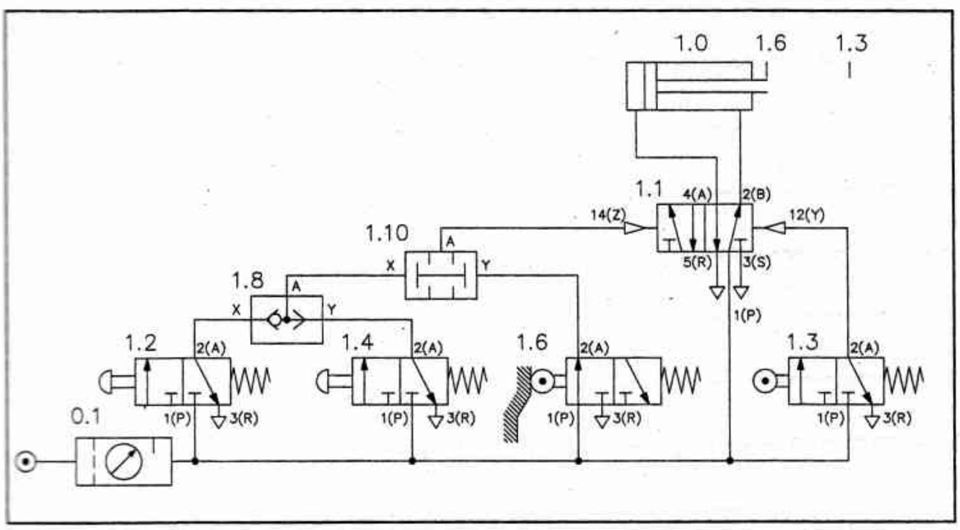
Circuit diagram



The roller limit switch generates a signal which reverses the control valve 1.1 when the cylinder is fully extended. The roller limit switch 1.3 is a 3/2 way valve with spring return. This is defined as a stroke-dependent control where the position of the cylinder is confirmed by limit switch. In this case the push-button can be operated for a short duration and the cylinder will fully extend. The 5/2 way memory valve retains the 14(Z) switched position until the reversing signal is received from roller limit switch 1.3. A further refinement to the operation of this cycle is to ensure that the cylinder is fully retracted before the pushbutton can extend the cylinder. This requires an additional limit switch 1.6.

B 3.3

Circuit diagram



The addition of the two pressure valve 1.10 and the roller limit switch 1.6 ensures that the cylinder is fully retracted before the cylinder can be extended. The conditions required to initiate extension are either of the pushbuttons in addition to the cylinder in the retracted position (1.6). When the cylinder is extended at position 1.3, the cylinder retracts even if the pushbuttons are still operated since the limit 1.6 is inactive.

5.11 Exercise 4: The logic OR function; the shuttle valve

Exercise

Draw the circuit diagram for the problem.

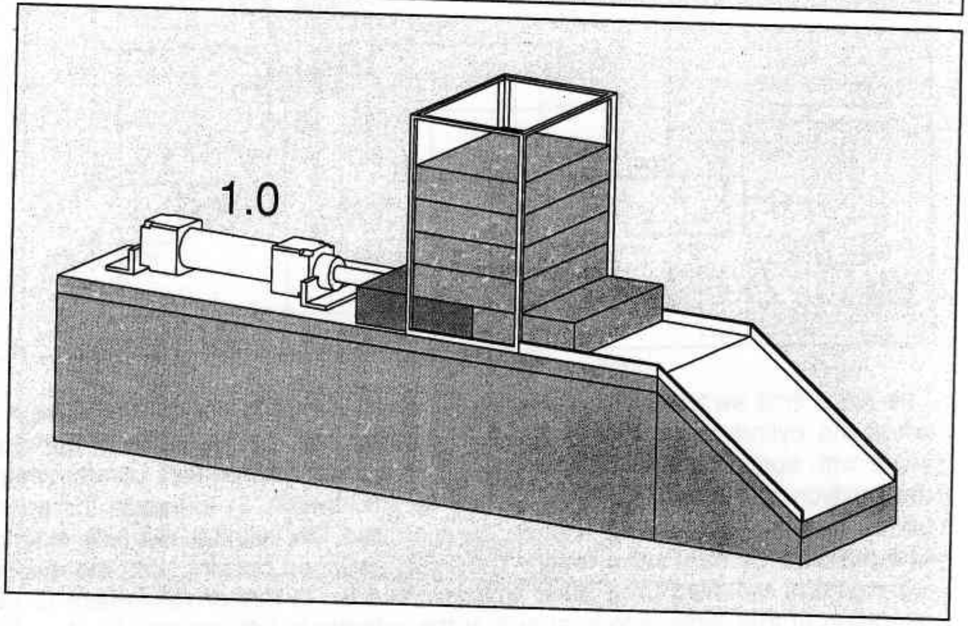
Designate the valves and indicate the numbering system for the connections (ports).

B 4.1

The Problem

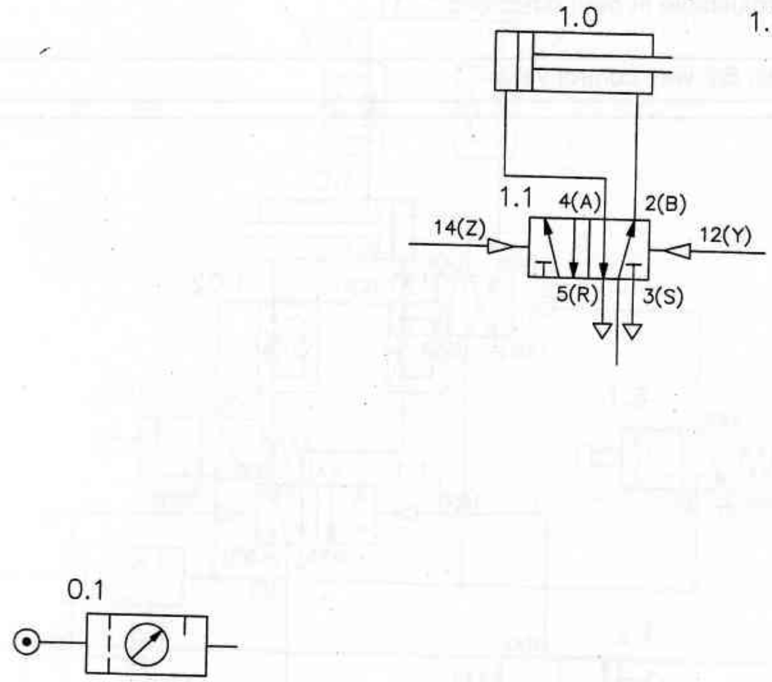
A cylinder is used to transfer parts from a magazine. If either a pushbutton or a foot pedal is operated, then the cylinder is to extend. Once the cylinder is fully extended, it is to retract to the initial position. A 3/2 way roller lever valve is to be used to detect the full extension of the cylinder.

Positional sketch



Notes:

Circuit diagram



Describe the operation of the circuit.

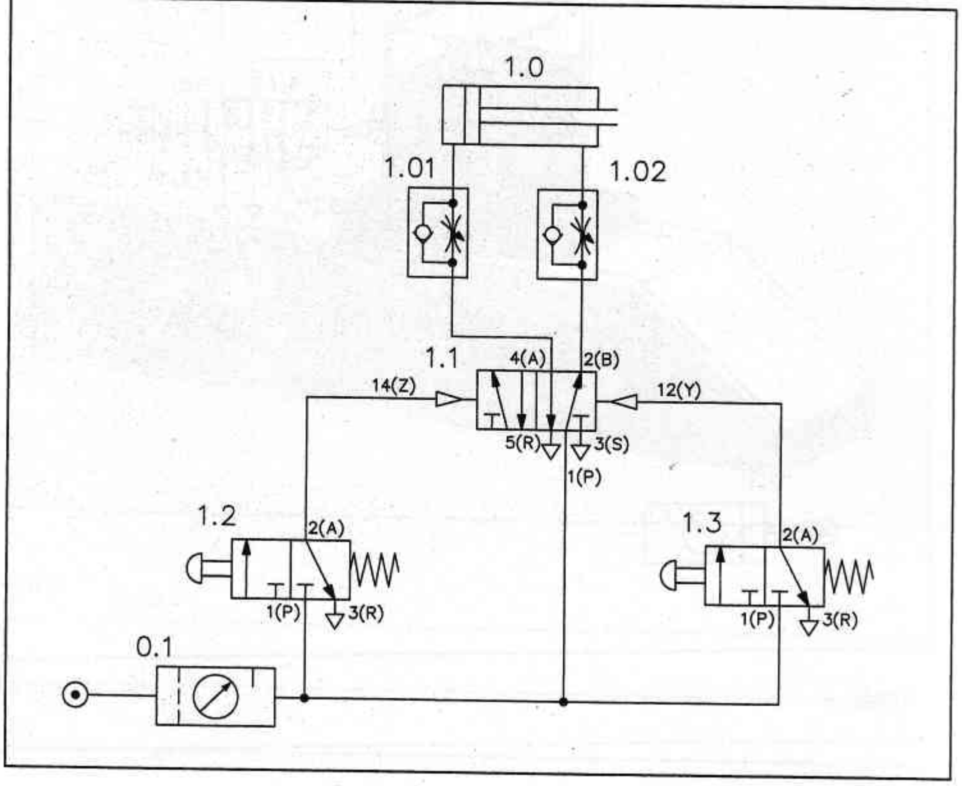
Notes:

5.12 Example 5: Memory circuit and speed control of a cylinder

The Problem

The piston rod of a double acting cylinder is to extend when a 3/2 way pushbutton valve is actuated.
The cylinder is to remain extended until a second pushbutton is actuated and only if the first pushbutton has been released.
The cylinder is to then return to the initial position. The cylinder is to remain in the initial position until a new start signal is given. The speed of the cylinder is to be adjustable in both directions.

Circuit: 5/2 way control valve



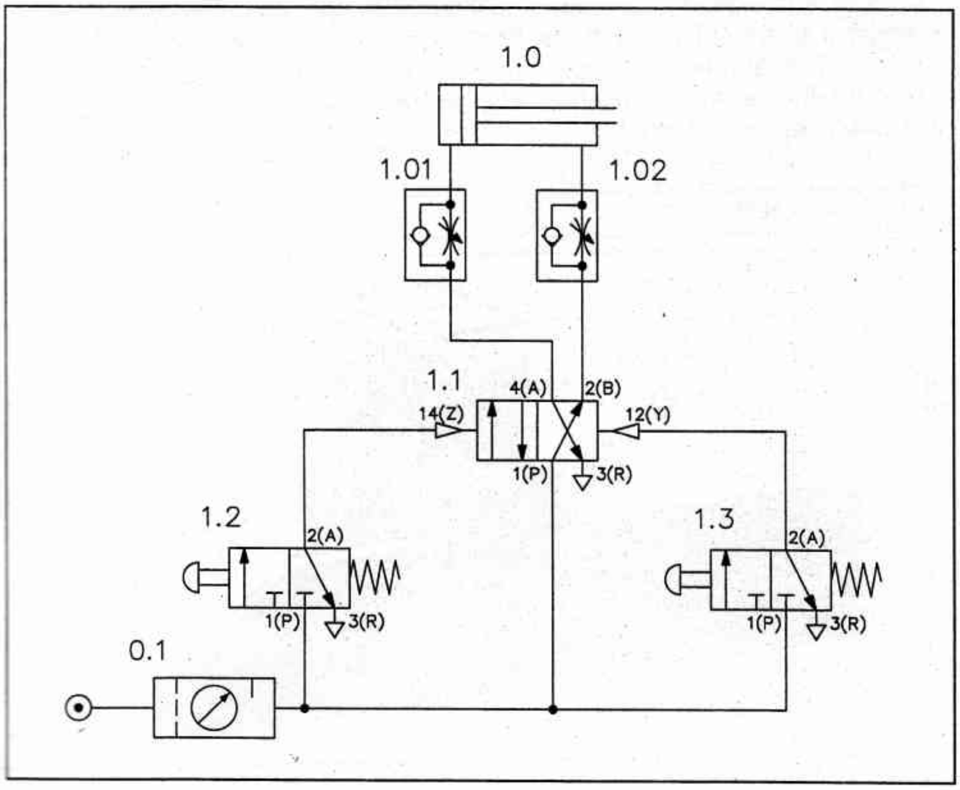
Solution

B 3.4
B 3.6
B 4.2

4/2 way or 5/2 way double pilot valves possess the required memory function. The valve retains its last switched position until an opposing signal is received. For this reason signals created by the pushbutton signalling devices can be of short duration.

The flow control valves control the cylinder speed in both directions and are independently adjustable.

Circuit: 4/2 way control valve



Upon operation of pushbutton 1.2, a signal is generated at the 2(A) port and the pilot port 14(Z) of valve 1.1. The 5/2 way memory valve switches and the signal from port 4(A) fully extends the cylinder 1.0. If the pushbutton valve 1.2 is released, the signal at 14(Z) is exhausted at the 3(R) port of the pushbutton valve 1.2. The valve 1.1 remains in the switched position until the pushbutton valve 1.3 is operated. If the pushbutton valve 1.2 is released and therefore there is no signal at 14(Z) then the signal generated by 1.3 will return the memory valve to its initial position and the cylinder retracts. The cylinder remains retracted until a new signal is generated at 14(Z) by the valve 1.2. The cylinder piston rod will extend and retract if there are no obstructions, but there is no confirmation that the cylinder is in its fully extended position. If both the 14(Z) signal and the 12(Y) signal are active due to both pushbuttons being operated, then the memory valve will remain in the last position attained.

The flow control valves have been fitted to throttle the exhausting air in both directions of piston motion. The supply air is transferred through the by-pass check valve of the flow control valves, giving unrestricted supply to the cylinder.

5.13 Exercise 5: Memory circuit and speed control of a cylinder

The Problem

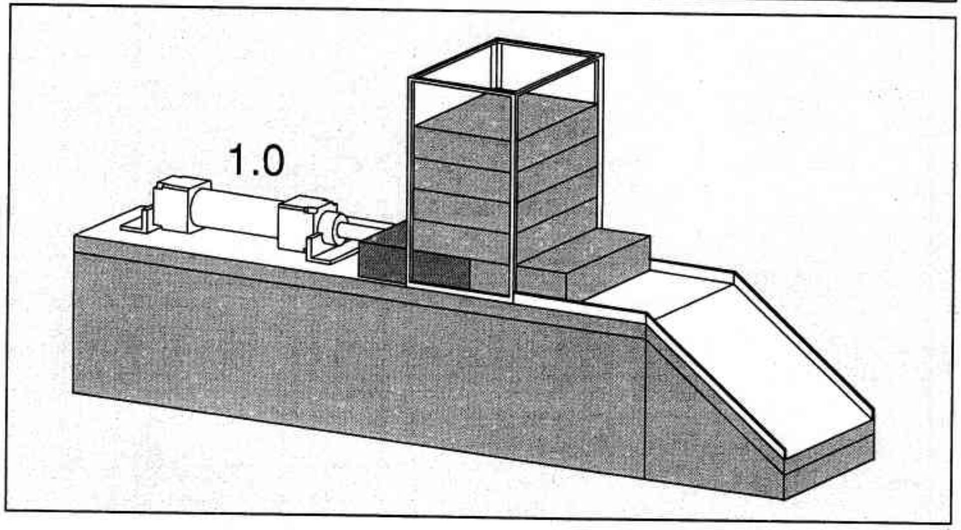
A double acting cylinder pushes products from a magazine onto a chute. The cylinder is to extend fully when a pushbutton is operated. The cylinder is not to retract until full extension is reached. Extension is confirmed by a roller lever valve. The cylinder is to continue forward even if the pushbutton is released before full extension is reached. The speed of the cylinder is to be adjustable in both directions of motion.

Exercise

Draw the circuit diagram for the problem.

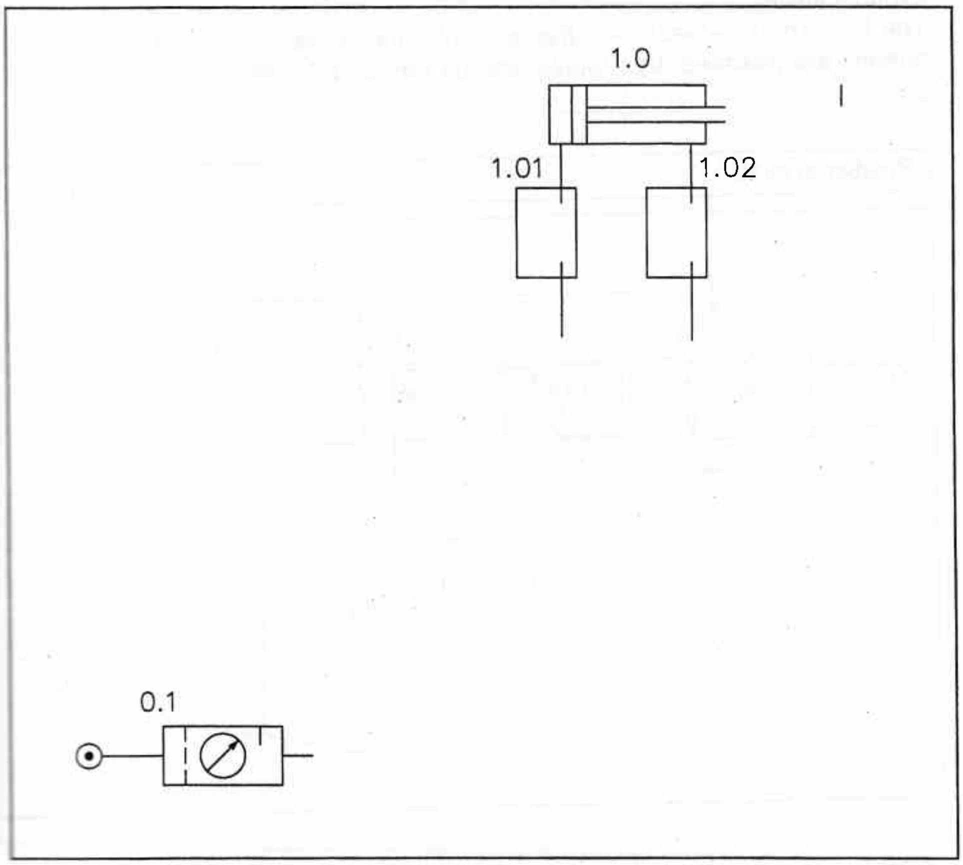
Designate the valves and indicate the numbering system for the connections (ports).

Positional sketch



Notes:

Circuit diagram



Notes:

Questions

1. What is the switching status of the memory valve when first fitted to the system and therefore what position will the cylinder be in?

2. Describe the operation of the circuit.

3. If the pushbutton is held operated even after full extension is reached, what effect will this have on the cylinder retraction?

4. What is the effect on the operation of fitting the roller lever valve at the mid-stroke position of the cylinder, i.e. not at the full extension position?

5.14 Exercise 6: The quick exhaust valve

The Problem

The operation of two identical pushbutton valves advances a forming tool on an edge folding device. For rapid forward travel, the circuit utilises a quick exhaust valve.

The forward movement folds the edge of a flat sheet. If either of the two push-buttons are released, the double acting cylinder is to return slowly to the initial position.

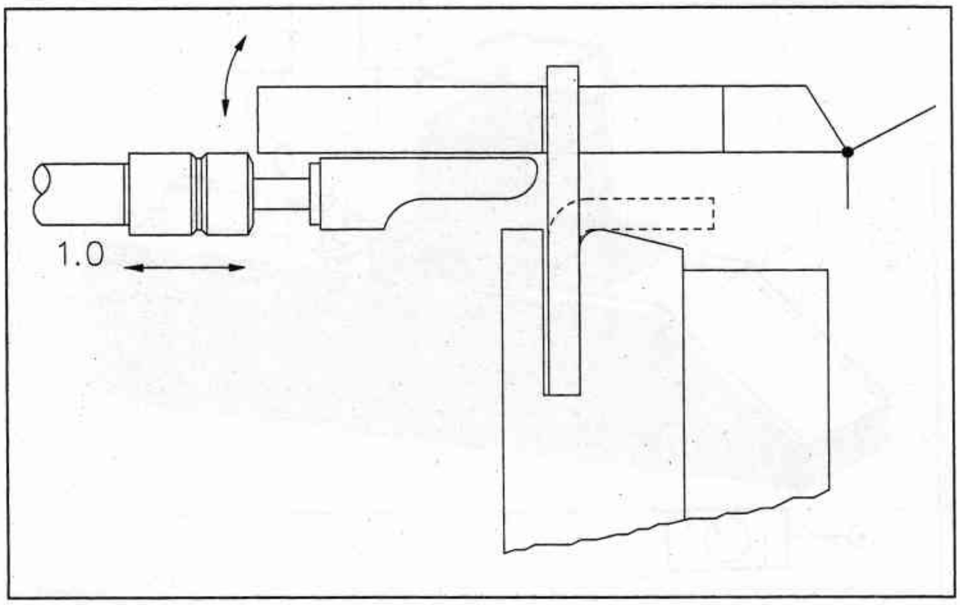
Exercise

Draw the circuit diagram for the problem.

Designate the valves and indicate the numbering system for the connections (ports).

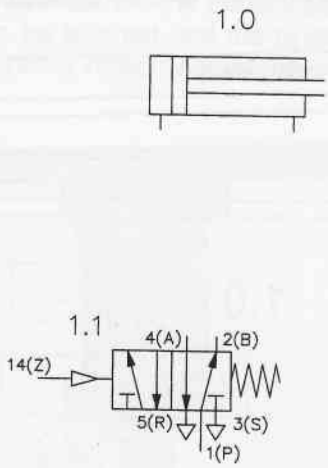
B 4.1

Positional sketch



Notes:

Circuit diagram



Describe the operation of the circuit

Notes:

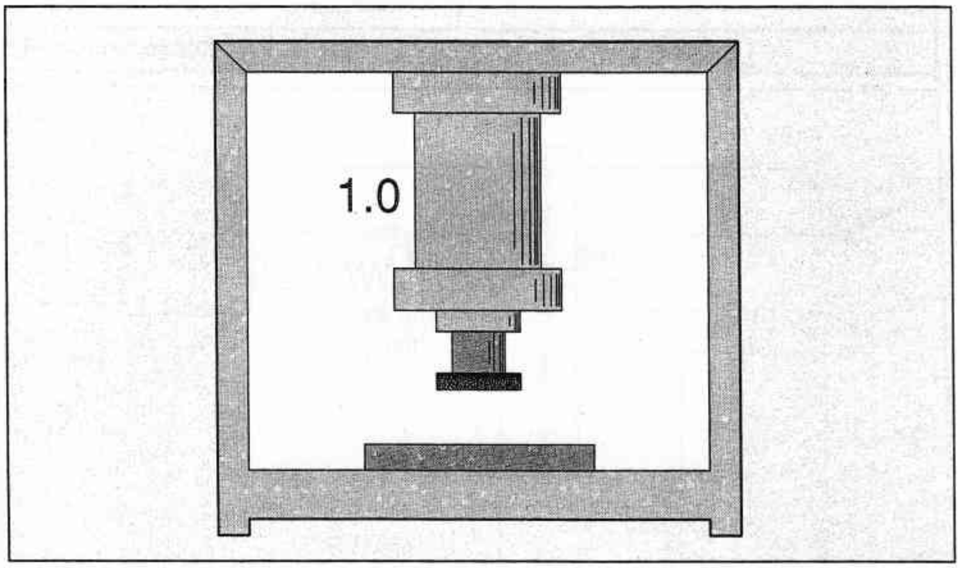
5.15 Example 7: Pressure dependent control; embossing of plastic components

The Problem

A plastic component is embossed using a die driven by a double acting cylinder. The die is to advance and emboss the plastic when a pushbutton is operated. The return of the die is to be effected when a preset pressure is reached. The embossing pressure is to be adjustable.

B 4.3

Embossing of plastic components



Solution

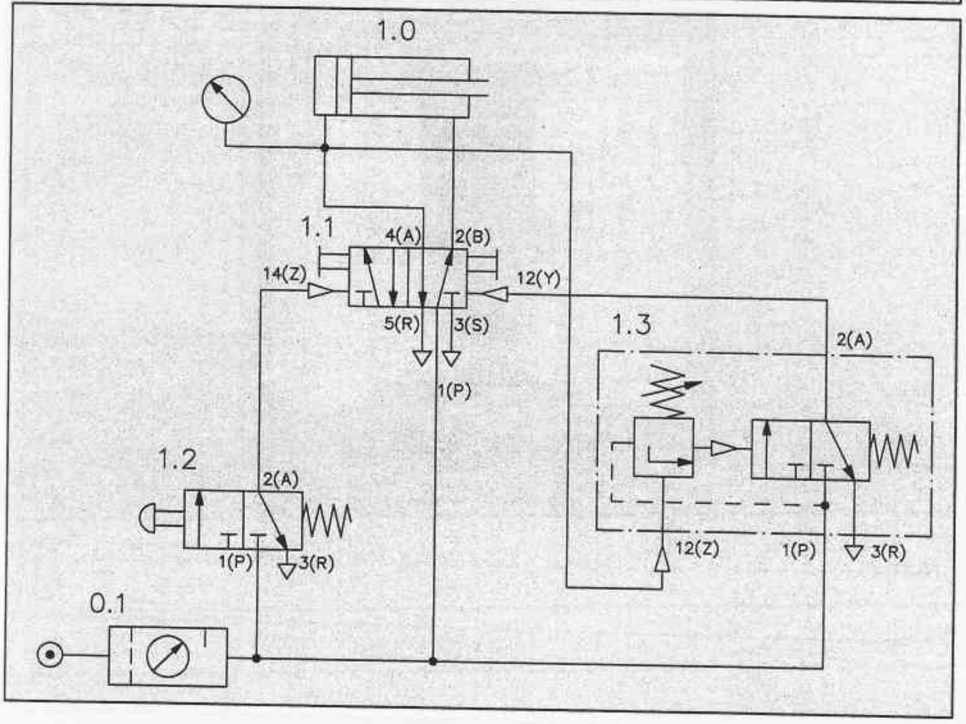
The 5/2 way memory valve as fitted may not be in the correct position. If the cylinder extends when the air supply is turned on, it is incorrect to reverse the connections on the 5/2 way valve. Instead, the circuit should be placed in the correct initial position by operating the manual overrides on the 5/2 way valve.

The 5/2 way directional control valve is switched at the 14(Z) port by the operation of the pushbutton valve 1.2 and the cylinder extends. The plastic component is embossed by the die under pressure, until the preset pressure set on the sequence valve is reached. The pressure on the inlet side of the cylinder is connected to the sequence valve pilot line 12(Z) and this acts against the preset compression of the adjustable spring. If the preset value is reached, then the sequence valve opens from 1(P) to 2(A) and sends a pilot signal to port 12(Y) of the control valve. If there is no signal at 14(Z) then the memory valve switches and air is supplied from the 2(B) port to retract the cylinder. At the same time the air in the 4(A) port is exhausted and the pilot signal at the sequence valve is relieved. Therefore the sequence valve cancels the signal at 2(A) and the pilot signal to the control valve at 12(Y). The cylinder retracts to the initial position. The pilot signals at 14(Z) and 12(Y) need only to be very short pulses to effect the position of the 5/2 way valve.

If the pressure at the sequence valve pilot line fails to reach the preset limit of the spring adjustment, then the cylinder will remain extended. If the cylinder encounters an obstacle or obstruction to the die movement during extension to the forward position, then even before the die embosses the part, it is possible for the preset pressure to be attained and the cylinder will retract. Therefore confirmation of the full forward motion should be checked in addition to the embossing pressure.

B 4.3

Circuit diagram



If the pressure sensing line from the junction of the pressure gauge to the sequence valve is too long, it is possible that the sequence valve may not switch correctly. If the cylinder encounters any resistance to motion during the forward travel, the sequence valve may be prematurely triggered. Therefore it is advisable to include a roller limit switch at the extension position to confirm the full travel. The roller valve should be placed in series with the pressure sensing signal to prevent early triggering of the sequence valve. The next exercise incorporates this additional condition.

5.16 Exercise 7: Pressure dependent control; embossing of plastic components

The Problem

A plastic component is embossed using a die powered by a double acting cylinder. The die is to advance and emboss the plastic when a pushbutton is operated. The return of the die is to be effected when the cylinder rod has fully extended to the embossing position and the preset pressure is reached. A roller limit valve is to be used to confirm full extension. The cylinder is then to retract. The pressure in the piston chamber is indicated on a pressure gauge.

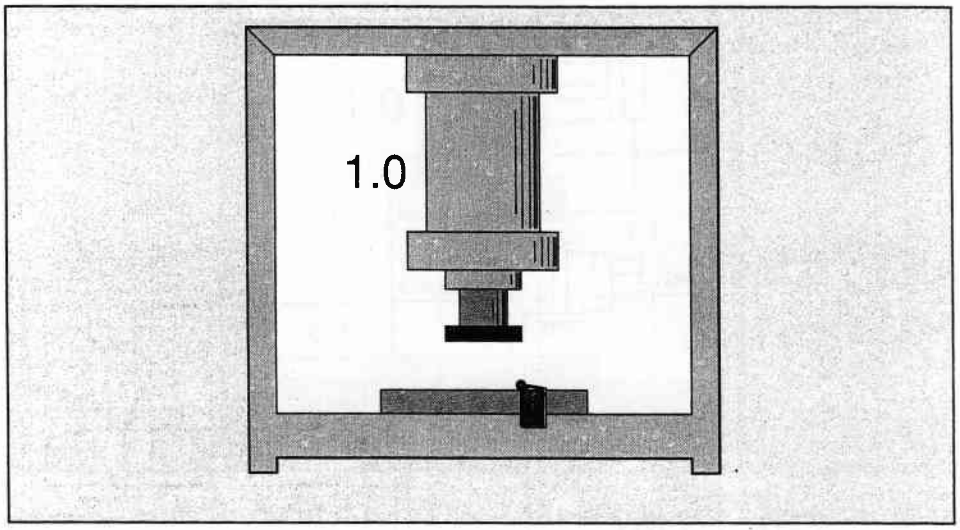
Exercise

Draw the circuit diagram for the problem.

Designate the valves and indicate the numbering system for the connections (ports).

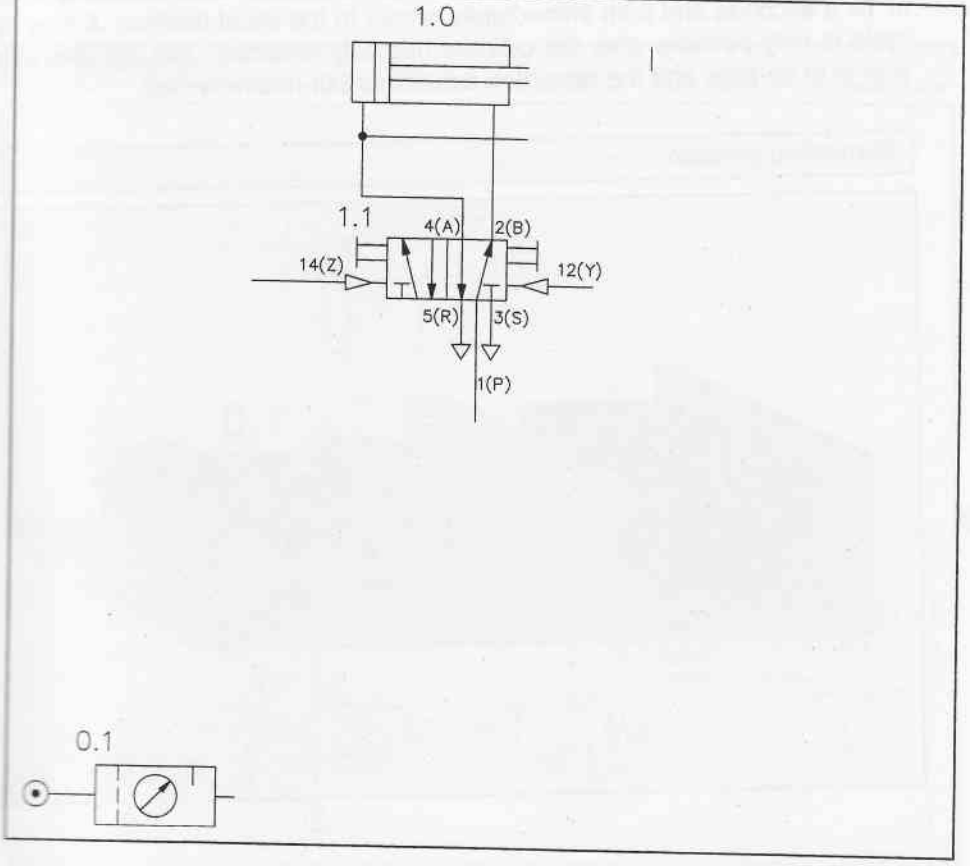
B 4.3

Positional sketch



Notes:

Circuit diagram



Describe the operation of the circuit.

Notes:

5.17 Example 8: The time delay valve

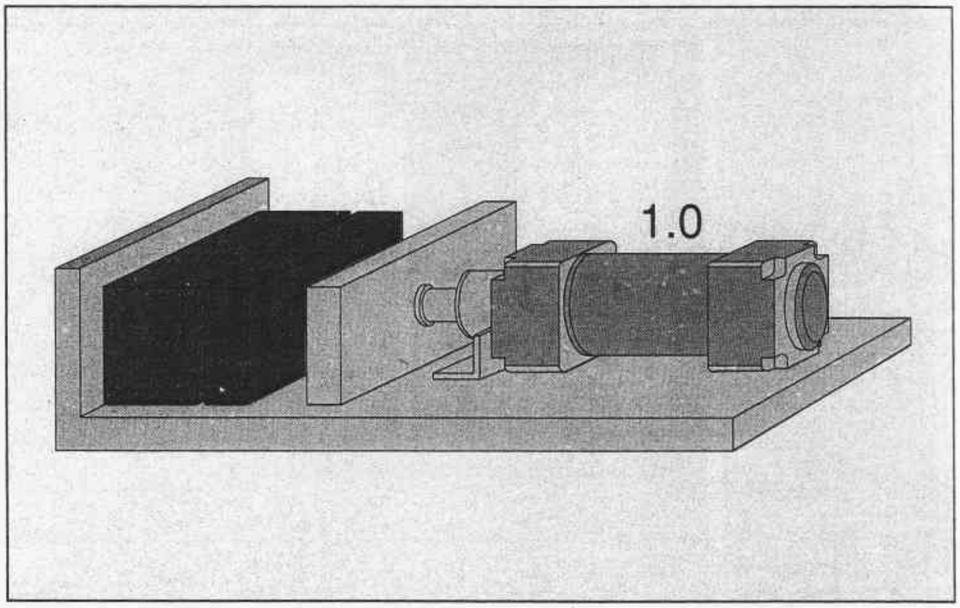
The Problem

A double acting cylinder is used to press together glued components. Upon operation of a pushbutton, the clamping cylinder extends and trips a roller lever valve.

Once the fully extended position is reached, the cylinder is to remain for a time of T= 6 seconds and then immediately retract to the initial position. A new start cycle is only possible after the cylinder has fully retracted. The cylinder extension is to be slow and the retraction adjustable but relatively fast.

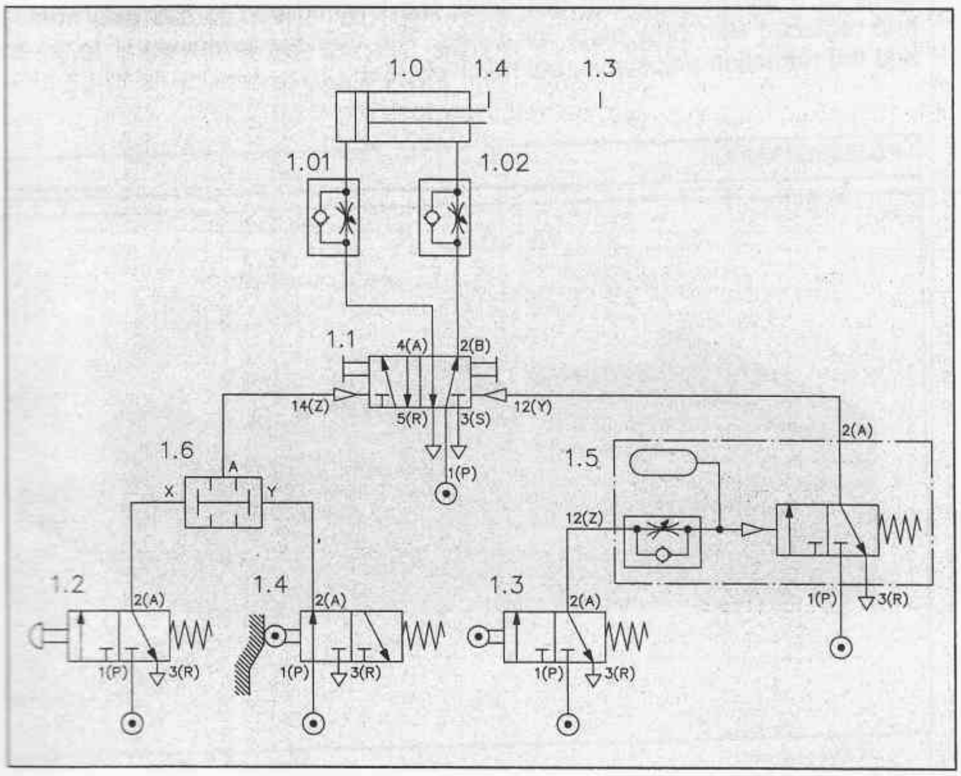
B 4.4

Cementing process



Solution
Initially the cylinder should be at the rest position but this is dependent on the position of the 5/2 way valve 1.1. This memory valve must be positioned manually to ensure that the cylinder will be retracted initially.

Circuit diagram



The start conditions for the extension of the double acting cylinder 1.0 are the acknowledgement of the retracted position (roller limit 1.4) and the operation of the start button 1.2. The output signal A at the two pressure valve 1.6 pilots the 5/2 way memory valve. The signal 4(A) extends the cylinder with the flow control valve 1.02 (exhaust throttling) setting the speed. The limit switch 1.4 is de-activated and therefore, even if the start button is still held on, the signal at 14(Z) is exhausted by the removal of the limit switch signal.

The cylinder reaches the limit switch 1.3 and produces a pilot signal for the time delay valve 1.5. The time delay valve is normally closed and only opens port 2(A) when the preset time, as determined by the adjustable throttle, is reached. The air reservoir in the time delay valve fills, and a pressure is reached that is sufficient to operate the valve against the spring return. A signal is produced 6 seconds after the limit switch 1.3 is operated, and a pilot signal is sent to the 5/2 way valve port 12(Y). The 5/2 way valve switches to the initial position with 2(B) now active and 4(A) exhausted. The air to the cylinder is supplied to the return side and the return speed is adjustable via the valve 1.01. The roller limit valve 1.3 is de-activated and the pilot signal to the timer is cut-off, thereby removing the 12(Y) signal from the 5/2 way valve. The cylinder retracts to the limit valve 1.4. A new start signal can now occur when the start button is pressed, since the roller valve 1.4 is actuated.

B 4.4

5.18 Exercise 8: The time delay valve

The Problem

A double acting cylinder is used to press together glued components. Upon operation of a pushbutton, the clamping cylinder extends and trips a roller lever valve.

Once the fully extended position is reached, the cylinder is to remain for a time of T= 6 seconds and then immediately retract to the initial position. A new start cycle is only possible after the cylinder has fully retracted and after a delay of 5 seconds. During this delay the finished part is manually removed and replaced with new parts for gluing. The cylinder extension is to be slow and the retraction adjustable, but relatively fast.

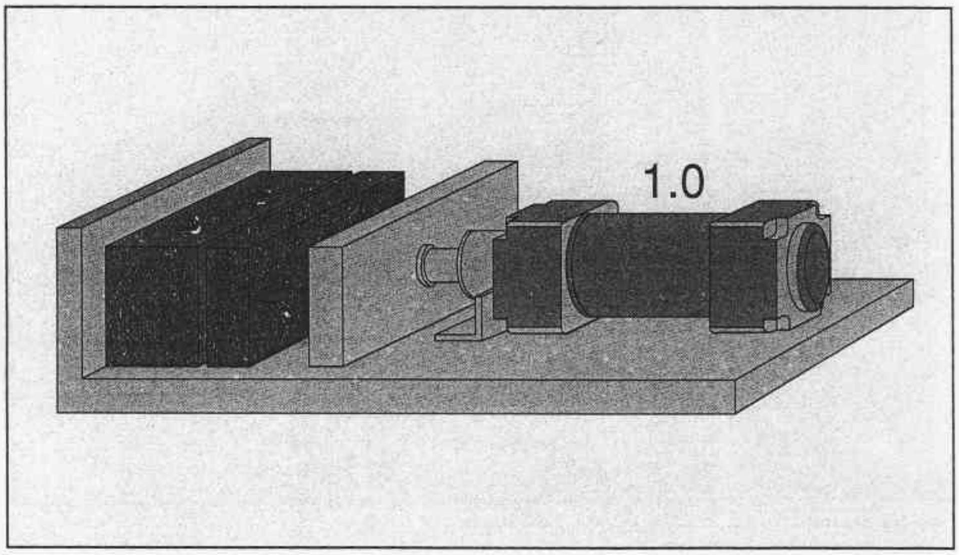
Exercise

Draw the circuit diagram for the problem.

Designate the valves and indicate the numbering system for the connections (ports).

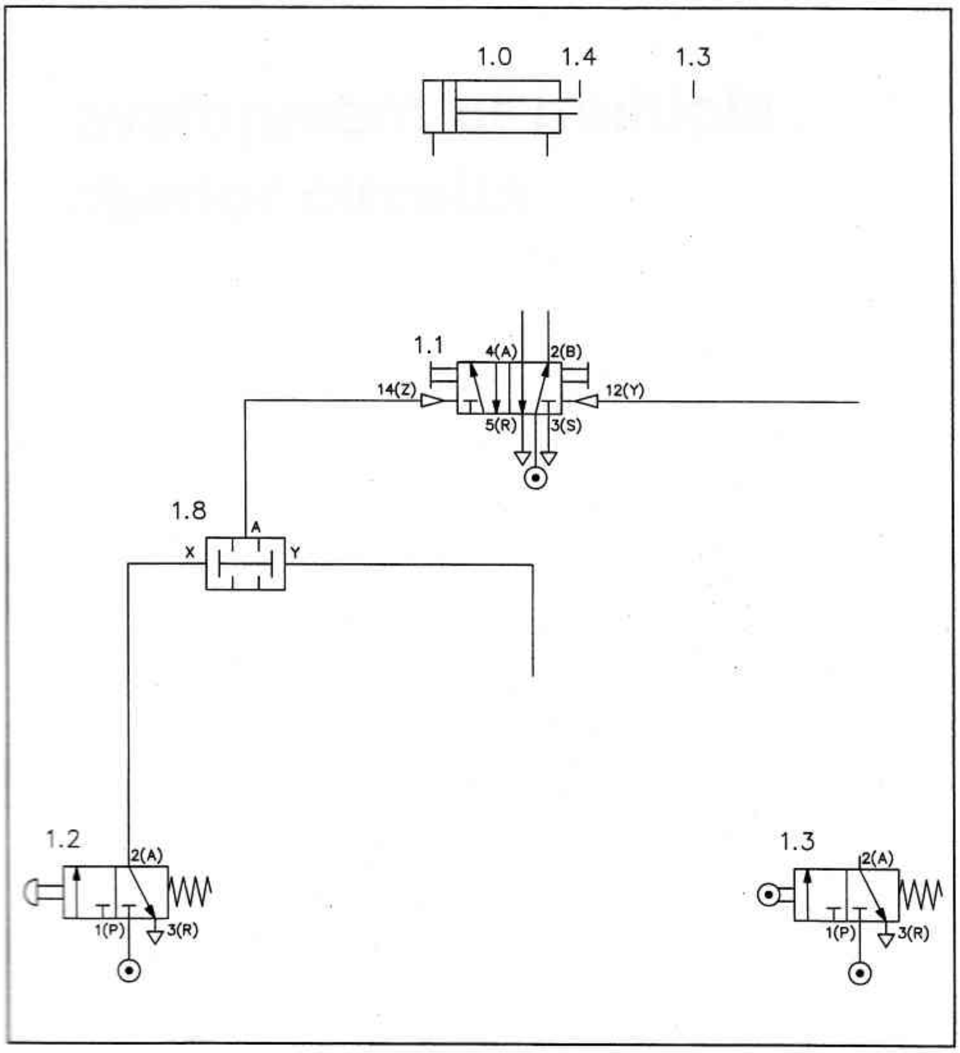
B 4.4

Positional sketch



Notes:

Circuit diagram



Describe the operation of the circuit.

Notes:

Chapter 6

Development of multiple actuator circuits

6.1 Control of multiple actuators

B 6.2

In the case of multiple cylinder circuits, a clear definition of the problem is important. The representation of the desired motion of all actuators is described using the displacement-step diagram. The special conditions for the start of the sequence must also be defined.

If the motion diagram and auxiliary conditions have been clearly defined, drawing of the circuit diagram can commence. Using the standard representation and drawing layout, the circuit is now developed in accordance with the requirements.

B 3.3

The design process and the basic development of the circuit diagram depend upon the type of signal processing selected. Where simpler types of controls are concerned, the less favoured method of signal cut-out using idle return rollers is possible.

In most cases, signal cut-out by means of reversing valves should be incorporated.

Another methodical approach towards producing a circuit diagram is also called the "Cascade Method".

This method for constructing a circuit diagram is certainly the easiest to learn for controls where signal cut-out is effected by means of reversing valves. The same basic thinking is also behind the design of a stepper circuit.

Another point to be observed is the inclusion of auxiliary conditions in a control. It is expedient to consider and include these conditions only after the basic circuit functions have been completed. These auxiliary conditions should then be incorporated in a step-wise manner, i.e., the circuit diagram should be expanded step by step. This is a way to ensure that the circuit retains its overall clarity, even where elaborate controls are concerned.

Examples follow which should ensure an understanding of the methods used.

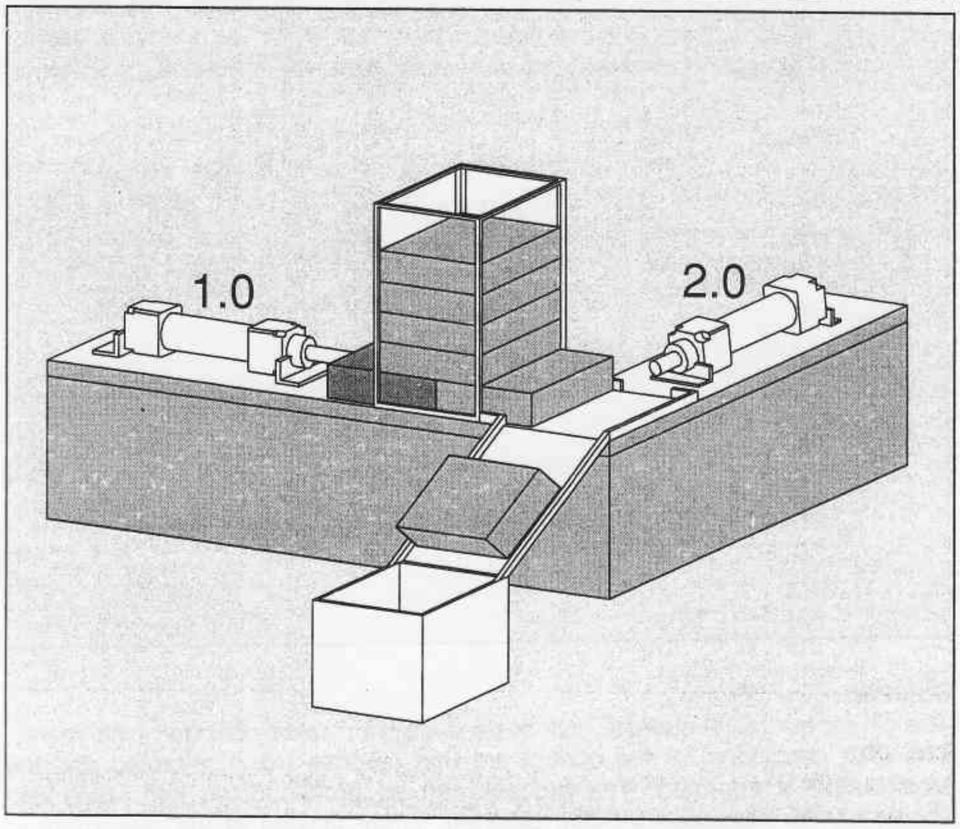
6.2 Example 9: Co-ordinated motion

The Problem

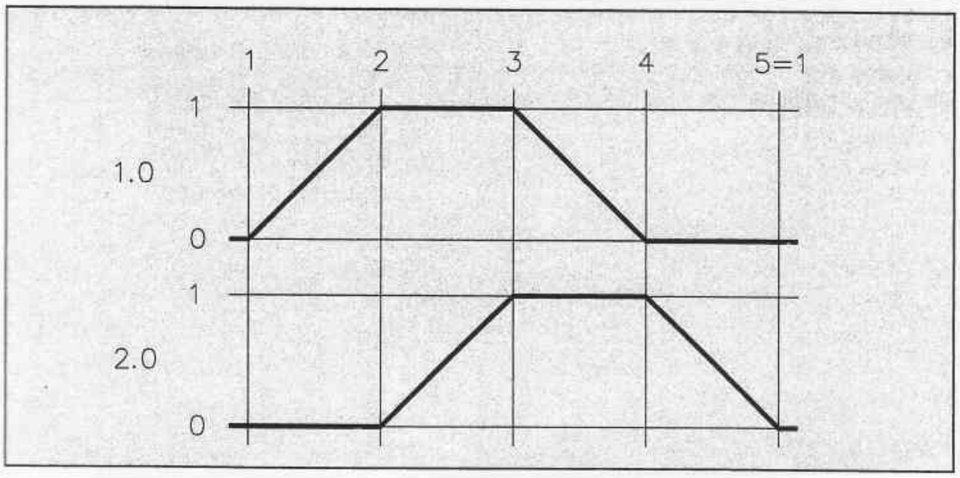
Two cylinders are used to transfer parts from a magazine onto a chute. When a pushbutton is pressed, cylinder 1.0 extends, pushing the part from the magazine and positions it in preparation for transfer by cylinder 2.0 onto the outfeed chute. Once the part is transferred, the first cylinder retracts, followed by the second.

The speed of both cylinders are to be adjustable. Confirmation of all extended and retracted positions are required.

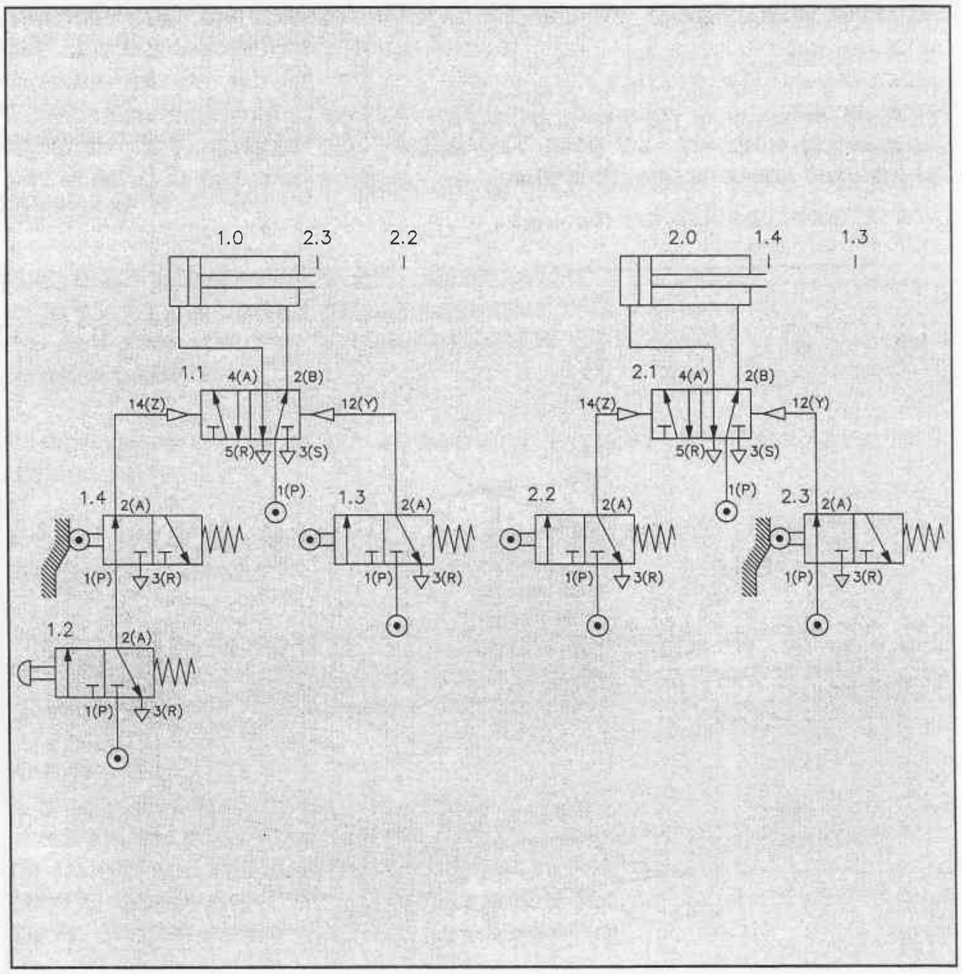
Transfer of parts



Displacement-step diagram



Circuit diagram



Solution
The circuit for this sequential task is dependent on roller operated limit valves. The start conditions for the control are that cylinder 1.0 is retracted and the start button is operated. The process can be broken down into steps and shown on the displacement-step diagram. When looking at the placement of the roller valves, the current action and then reaction must be analysed. These will determine the valve positioning. The sequence of the actuators can be described by:

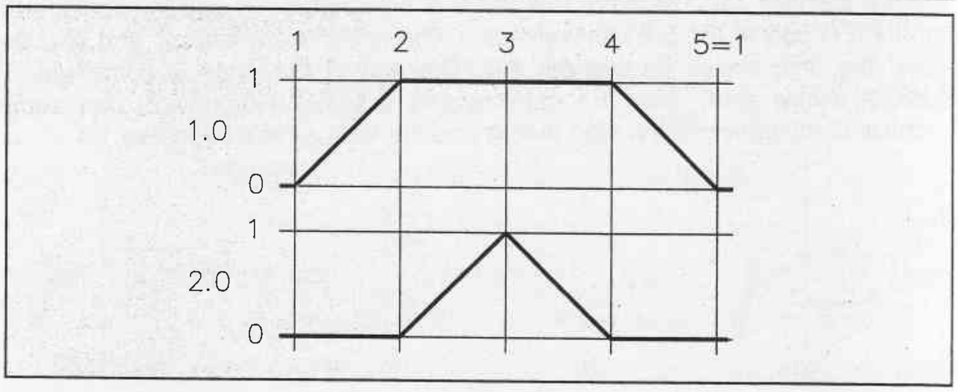
• Valves 1.2 and 1.4	⇒ Cylinder 1.0 extend
• Valve 2.2	⇒ Cylinder 2.0 extend
• Valve 1.3	⇒ Cylinder 1.0 retract
• Valve 2.3	⇒ Cylinder 2.0 retract

When cylinder 1.0 extends a limit switch is operated. This must have the effect of advancing cylinder 2.0, therefore it is designated as valve 2.2 (even number 2 for forward motion on cylinder 2) and is connected to the 14(Z) port of the 5/2 way valve 2.1. Next, cylinder 2.0 extends, and the reaction is the operation of the forward limit valve which causes cylinder 1.0 to retract and hence the valve is designated 1.3 (odd number 3 for return motion on cylinder 1) and connects to the 12(Y) port of valve 1.1. The next reaction is that the limit switch at the retracted position of cylinder 1.0 operates and this must return cylinder 2.0. Therefore this valve is designated 2.3 and is connected to the 12(Y) port of the 5/2 way valve 2.1. The cylinder 2.0 retracts and operates the rear limit switch on cylinder 2.0. The end of the cycle is confirmed. To obtain a new start, valve 1.1 must receive a signal at the 14(Z) port from a logical combination of the start button and the limit valve designated 1.4.

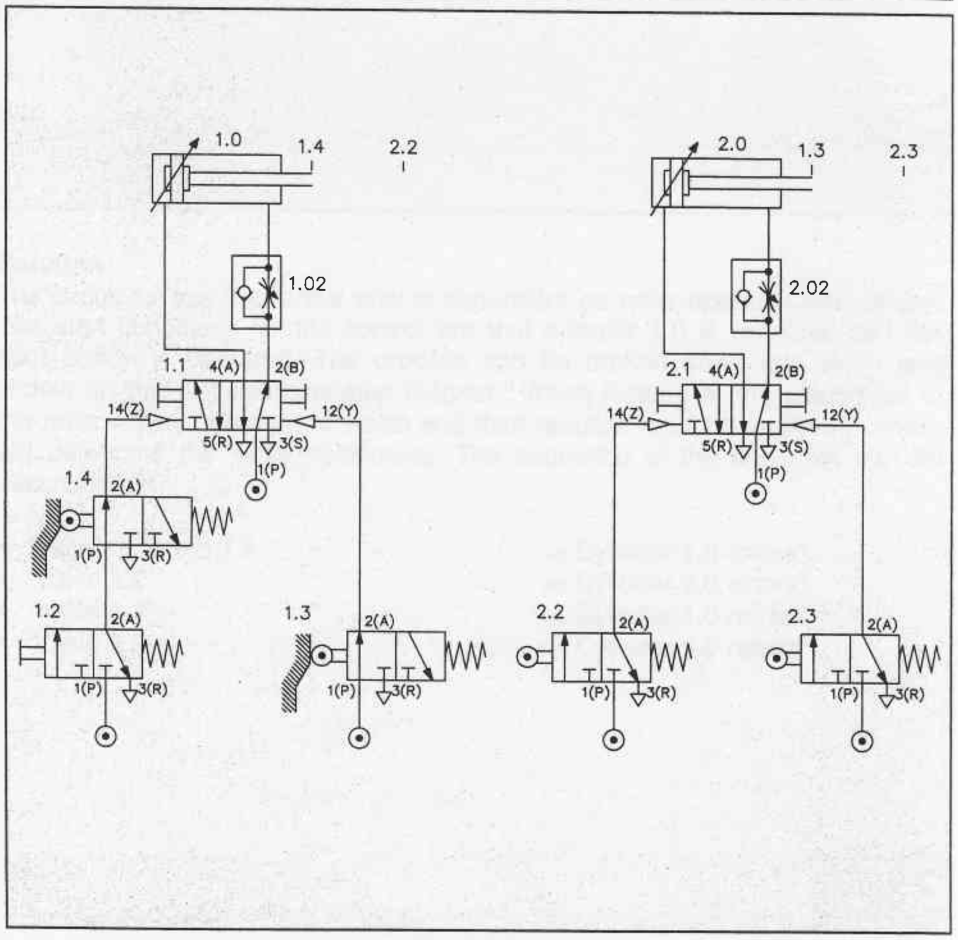
6.3 Example 10: Signal overlap

The Problem
In co-ordinated motion control, the 5/2 way memory valve can only switch positions when a single pilot signal is present. If two signals are operated simultaneously, i.e. both pilot signals on the 5/2 way valve are active, a signal overlap problem occurs.
There are various methods of solving the problem, but firstly the overlap must be identified.

Displacement-step diagram



Circuit diagram: signal overlap circuit



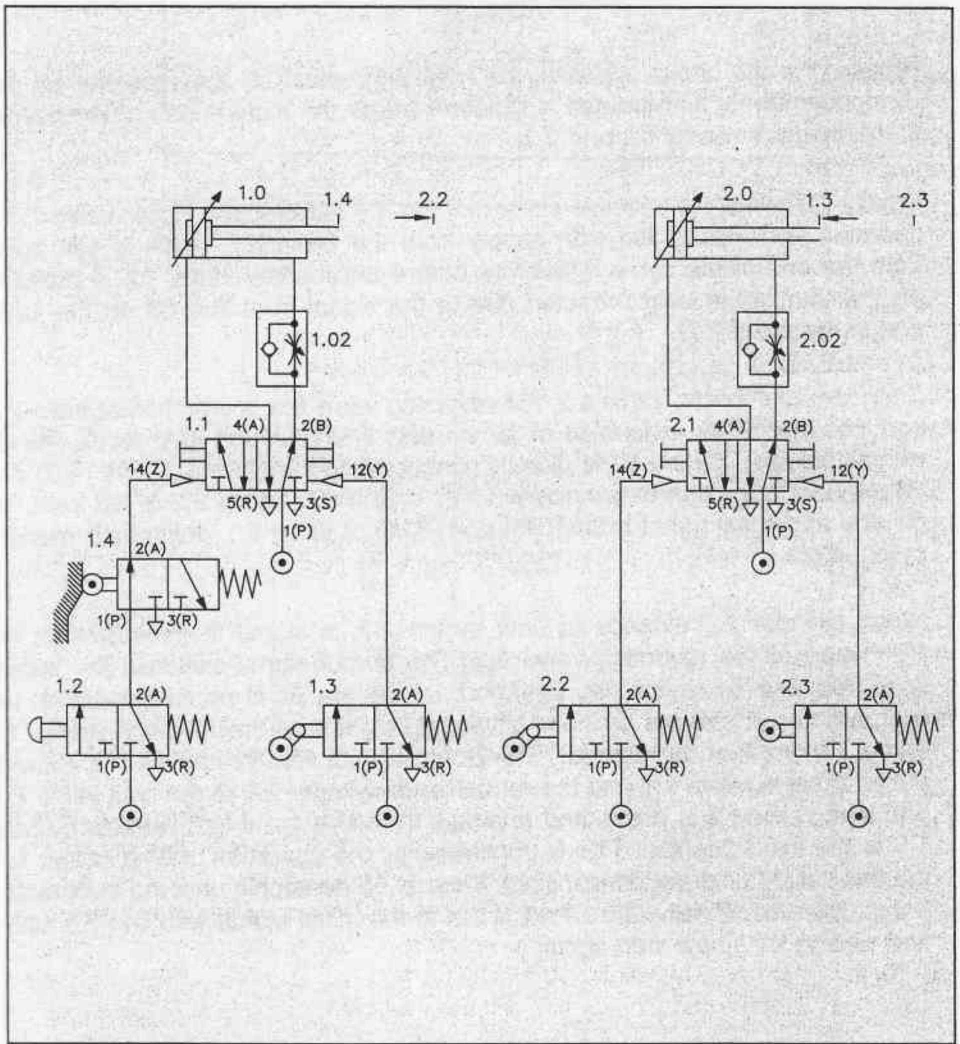
B 3.3

Solution
For the control diagram, the signal overlap can be identified by looking at the pilot signals on both the final control valves 1.1 and 2.1.

The first control valve 1.1 has an overlap problem in the first step, since the valve 1.2 and 1.3 can be active at the same time. Therefore the first of these signals must be cut short so that it is not active past the usage in step 4. The valve 1.3 should be an idle roller lever valve that only operates when the retraction of the cylinder occurs. When the start of the cycle is initiated, the valve 1.3 is deactivated since the idle roller is overrun.

The second overlap problem is with valve 2.1, where the signals 2.2 and 2.3 coincide. The two signals are active in step 3, when the cylinder 2.0 is fully extended. Therefore the first of the two signals is required to be cut short to allow the second to operate alone. The valve 2.2 must be an idle roller valve which is only active in step 2 for a short duration when the cylinder 1.0 is moving forward to the extended position. Therefore the circuit utilising idle roller valves 1.3 and 2.2 is correct, if this method of signal cut-out is utilised.

Circuit diagram



6.4 Signal elimination by reversing valves

Signal elimination by means of a reversing valve is a frequently used solution. Using this method, savings can be made in cutting off several signals from individual reversing valves. The method is relatively reliable in operation. This basic idea is to allow the signal to be active only for as long as is required to switch the memory valves. This is achieved by blocking the signal downstream of the signal element by means of a reversing valve, i.e. by supplying energy to the signal element only when the signal is required. An impulse valve is used to effect the reversal. The main difficulty lies in the selection of the correct signals for the reversing valve.

6.5 Example 11: Signal overlap; reversing valve solution

The Problem

If idle return rollers are not to be used to provide the signal cut-out, then an additional reversing valve is introduced. The circuit in section 6.3 shows the solution utilising idle return valves to eliminate the overlap of signals. The problem areas for the two memory valves 1.1 and 2.1 are the signals generated by the valves 1.3 and 2.2, which in this case have been eliminated in one direction of motion. Another way to shorten the time the signals, is to remove the air supply to these two valves except at the step required. The signal generated by 1.3 is only required during the start of the sequence and the signal generated by the valve 2.2 is only required during steps 2 and 3 and can be very short in duration if there are no opposing signals at the memory valve 1.1 and 2.1.

Solution

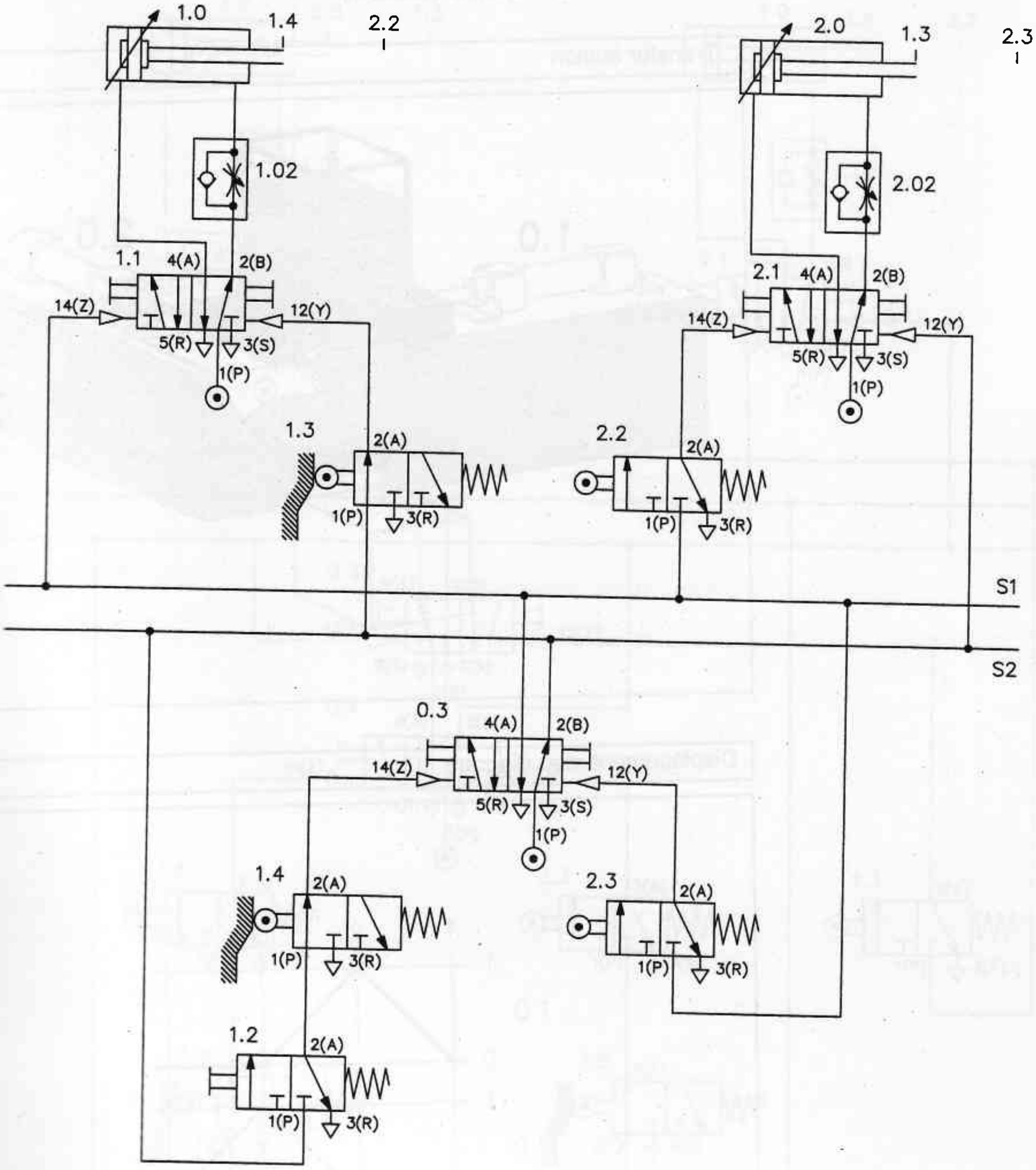
Referring to the circuit opposite, the reversing valve 0.3 activates line S1 and S2 consecutively and creates a situation where the signals can never overlap at the memory valves 1.1 and 2.1.

Initially the valve 1.4 is active since cylinder 1.0 is retracted. Roller valve 1.3 is operated and initially fed with supply from the line (S2), which is still active from the end of the cycle. Therefore before the manual valve 1.2 is pressed, the cylinder 1.0 is held retracted due to the signal from line S2 on the 12(Y) port of the valve 2.1.

After operation of the valve 1.2, the reversing valve 0.3 is switched at the 14(Z) port: the line S2 is exhausted of air via port 3(S) and port 4(A) feeds line S1 with signal air. The line S1 is directly connected to the valve 1.1 port 14(Z) and the cylinder 1.0 extends towards the limit switch 2.2. Valve 2.2 is fed from line S1 and applies a signal to the pilot port Z(14) of valve 2.1 which then extends cylinder 2.0.

When cylinder 2.0 extends to limit switch 2.3, a signal is generated at the 12(Y) port of the reversing valve 0.3. The output signal switches the supply lines from line S1 to line S2. Therefore, since line S1 is no longer active, the limit switch 2.2 and the cylinder advancing signals of the memory valves 1.1 and 2.1 have been eliminated. The energising of line S2 causes the immediate reversal of valve 2.1 and the retraction of cylinder 2.0 to the limit valve 1.3. The limit valve 1.3 is active and reverses the valve 1.1 which retracts cylinder 1.0 to the initial position. This is confirmed by the operation of limit switch 1.4, but this valve is not yet active, since there is no air supply until the start button 1.2 is operated. Finally, the circuit is set in the initial status with line S2 active and waiting for a new start signal.

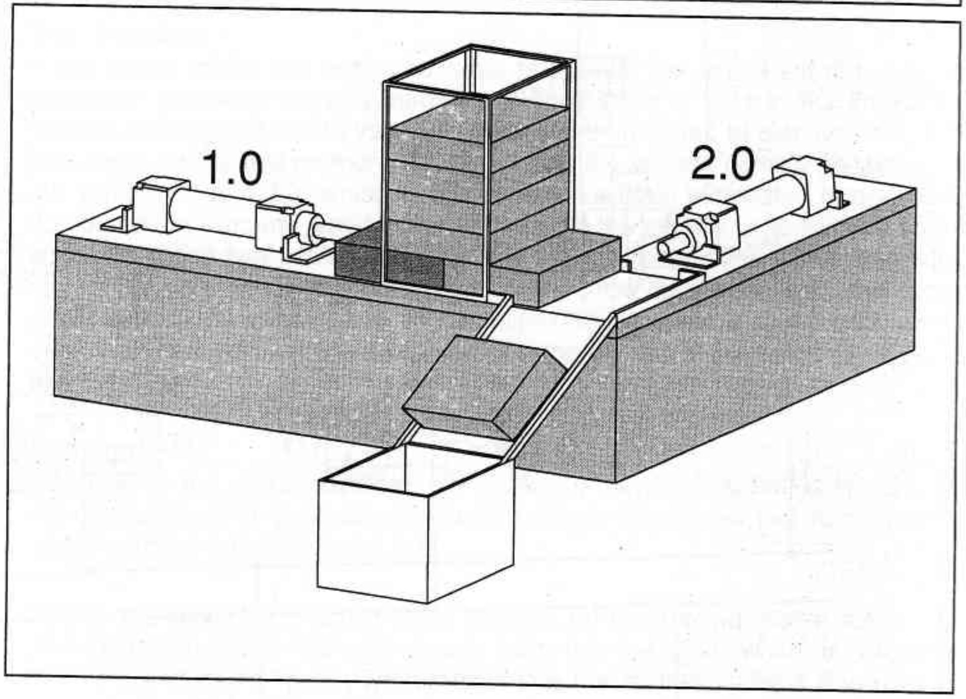
Circuit diagram



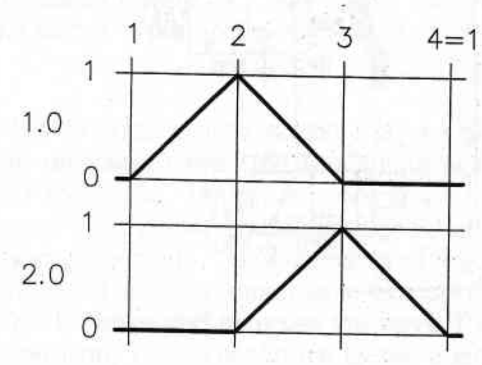
6.6 Example 12: Transfer station; using reversing valves

The Problem
Using a transfer station, parts are to be transferred from a vertical magazine to a processing station. The parts are pushed by cylinder 1.0 and then transferred onto a chute by cylinder 2.0 for transfer to the processing station. The piston rod of cylinder 2.0 is only to retract after confirmation that cylinder 1.0 has fully retracted. The cycle is to start when a start button is pressed. Limit switches are used to confirm cylinder positions.

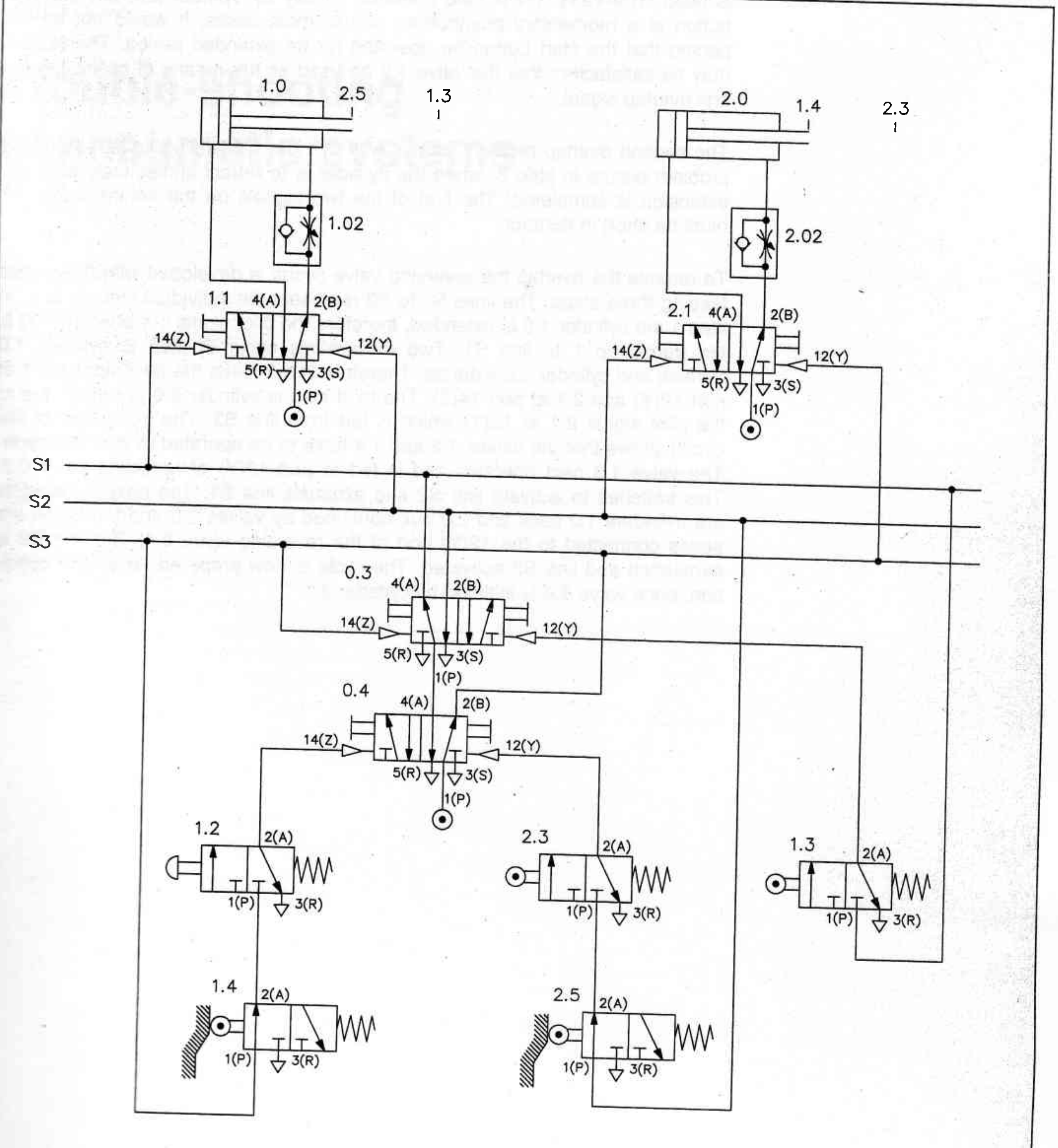
Transfer station



Displacement-step diagram



Circuit diagram



The sequence has three steps and overlap is potentially a problem at two positions. The first step is the extension of cylinder 1.0, followed by step 2, the immediate retraction of cylinder 1.0. Therefore it is possible that overlap occurs on the valve 1.1 at ports 14(Z) and 12(Y), unless the reversing valve technique is used. The valve 1.4 is held operated initially by cylinder 2.0, but the start button is a momentary pushbutton, and in most cases, it would not be expected that the start button be operated for an extended period. Therefore it may be satisfactory that the valve 1.2 be used as the means of cancelling the first overlap signal.

The second overlap problem occurs with cylinder 2.0 and valve 2.1. Here the problem occurs in step 3, when the cylinder is to retract immediately after the extension is completed. The first of the two signals on the control valve 2.1 must be short in duration.

To remove the overlap the reversing valve circuit is developed with three lines feeding three steps. The lines S1 to S3 represent the individual steps 1 to 3. In step 1 the cylinder 1.0 is extended, therefore the pilot signal 1.1 at port 14(Z) is fed from step 1 to line S1. Two movements occur in step 2: cylinder 1.0 retracts and cylinder 2.0 extends. Therefore line 2 feeds the pilot signals 1.1 at port 12(Y) and 2.1 at port 14(Z). The third step is cylinder 2.0 to retract due to the pilot signal 2.1 at 12(Y) which is fed from line S3. The input side of the circuit shows that the valves 1.2 and 1.4 have to be operated to start the cycle. The valve 1.3 next operates and is fed to port 12(Y) of reversing valve 0.3. This switches to activate line S2 and exhausts line S1. The next movements are cylinders 1.0 back and 2.0 out, confirmed by valves 2.3 and 2.5 which are series connected to the 12(Y) port of the reversing valve 0.4. The line S2 is exhausted and line S3 activated. The cycle is now prepared for a start condition, once valve 1.4 is initiated by cylinder 2.0.

Chapter 7

Trouble-shooting of pneumatic systems

Fault diagnosis

From the time that energy is supplied to the control system, fault diagnosis becomes an important part of the process to reduce commissioning time and downtime in the operation of a system.

Fault diagnosis involves a number of distinct stages of identification prior to solving the problem. Faults generally occur either :

- Due to external failure of the machine components or due to stoppages
- Internal failures within the control system.

Experience has shown that the occurrence of control system failure is rare compared with external sensor or machine failure.

Trouble-shooting : what can we expect to achieve?

In the case of system failure, action must be taken by the end-user of the system. The action to be taken is dependent on the complexity of the required repair work. If the problem is relatively simple, the work will be carried out immediately. Where more complex repairs are required, service personnel will be called in.

External faults and most internal faults, such as external sensor or machine failures, can be identified and often solved by the experienced user or the maintenance engineer. If the problem cannot be quickly solved, the characteristics of the machine at the point of failure and the status of the control system should be recorded. Using this information, the maintenance engineer can make a decision as to the kind of failure that has occurred and the necessary actions to be taken.

Fault diagnosis should be carried out at the time of failure, without delay. The processes of recording results and potentially identifying the simpler faults should take only minutes. Therefore, machine downtime will be minimal, if the trained personnel and diagnostic tools are available.

7.1 Documentation

The documentation of a pneumatic system comprises the following:

- Clear system layout diagram with labelled valves and lines
- Circuit diagram
- List of components
- Component data sheets
- Displacement-step diagram
- Operating instructions
- Installation and maintenance manuals
- List of spare parts for critical items

The documentation should be supplied when the pneumatic system is installed or delivered. When the system is modified, the documentation and the machine history should be updated to reflect any changes. This is to ensure that the potential users and maintenance engineers have available the current status of the machine.

7.2 The causes and effects of malfunctions

In general, malfunctions of a system fall into the following categories:

- Wear and tear on components and lines which can be accelerated by environmental influences:
  - Quality of compressed air
  - Relative motion of components
  - Incorrect loading of components
  - Incorrect maintenance
  - Incorrect mounting and connection (i.e. signal lines are too long)

These environmental influences can lead to the following malfunctions or failures of the system:

- Seizure of units
- Breakages
- Leakages
- Pressure drop
- Incorrect switching

Preventive maintenance

Even the most intensive maintenance is of little use when the system incorporates a design or planning error or is incorrectly installed. This leads to damage which is characterised in the course of time by premature wear and failure of components. Careful planning, even if this costs a little more in some cases, can considerably reduce the frequency of malfunctions and thus failure and downtime. Important preventive measures include :

- Selection of the appropriate components and signal generators. They should be adjusted to suit the environmental and operational conditions of the system (e.g. switching frequency, heavy loads)
- Protection of components against contamination
- Mechanical absorption of the actuating forces through additional shock absorbers
- Short line lengths, fitted with amplifiers where necessary

Fault finding of pneumatic systems

As a rule, a newly-designed and installed pneumatic system will run trouble-free for some time after initial adjustments have been carried out. Any instances of premature wear may not become noticeable until weeks or months later. Normal wear may not become noticeable for years. Even then, faults or the effects of wear frequently do not show directly apparent, with the result that it is not easy to identify the defective component. It is obviously not possible to cover all the faults which may occur. The malfunctions described here are therefore those which frequently occur and which are difficult to localise in pneumatic systems. Even more complex controls can be divided into smaller units and checked. In many cases the operator can eliminate the fault immediately, or at least identify the cause.

Malfunctions caused by under-sized air supply

It frequently occurs that sections of pneumatic systems are extended without enlarging the necessary air supply. Depending on the sequence and design of the plant section, malfunctions then occur not continuously but sporadically, with the result that fault-finding is made increasingly difficult.

Possible effects :

- The piston rod speed is not always correct, since the actuation of additional components can cause sudden pressure drops.
- The force at the power cylinder drops for a short time during a pressure drop.

The same symptoms may occur as the result of changes in orifice cross-sections caused by contamination or by leaks at connectors which have worked loose (a reduction in diameter of 20% means a doubling of the pressure drop).

Malfunctions caused by condensate

The necessity to ensure that the compressed air fed into the network is free of condensate is emphasised. What effects can occur in practical terms when the proportion of condensate in the compressed air is too high?

B 2.4

Apart from the corrosive damage caused to surfaces by the condensate which is, in many cases extremely aggressive, there is the considerable danger of seizure of valve components if they need to be reset by spring force after being held in one switching position for a considerable time. Lubricants without additives have a tendency to emulsify and create resin or gumming. All close-tolerance sliding fits in valves are particularly susceptible to these resistances to movement.

Malfunctions caused by contamination

Filters are generally fitted upstream in pneumatic systems. If, however, the supply lines for valves are not blown clear before they are connected, all the dirt particles produced by the connecting or welding process (sealing tape, welding beads, pipe scale, thread swarf and many other contaminants) can pass onto the valves.

In the case of systems which have been in service for some time, an excessive proportion of condensate in the compressed air may produce rust particles in cases where lines are fitted without corrosion protection. This contamination of the lines may produce the following effects :

- Sticking or seizure of slide-valve seats
- Leaks in poppet valves
- Blockage of flow control valve nozzles.

7.3 Maintenance

For pneumatic systems the following regular maintenance routines are recommended:

- Check the filter and service units - drain water regularly from traps and replenish and adjust lubricators where used
- Discuss with the operators of the system any noted differences in performance or unusual events
- Check for air leaks, crimped air lines or physical damage
- Check signal generators for wear or dirt
- Check cylinder bearings and mountings

Planned maintenance routines

B 2.4

Daily :
Drain condensate from the filters if the air has a high water content and if no automatic condensate drainage has been provided. With large reservoirs, a water separator with automatic drain should be fitted as a general principle. Check the oil level in the compressed-air lubricator and check the setting of the oil metering.

Weekly :
Check signal generators for possible deposits of dirt or swarf. Check the pressure gauge of the pressure regulators. Check that the lubricator is functioning correctly.

Every 3 months :
Check the seals of the connectors for leaks. If necessary, re-tighten the connectors. Replace lines connected to moving parts. Check the exhaust ports of the valves for leaks. Clean filter cartridges with soapy water (do not use solvents) and blow them out with compressed air in the reverse of the normal flow direction.

B 5.2

Every 6 months :
Check the rod bearings in the cylinders for wear and replace if necessary. Also replace the scraper and sealing rings.

Section B

Theory

Chapter 1

Fundamentals of pneumatics

1.1 Physical properties of air

The surface of the globe is entirely covered by a mantle of air. It is an abundant gas mixture with the following composition :

- Nitrogen approx. 78 vol. %
- Oxygen approx. 21 vol. %

It also contains traces of carbon dioxide, argon, hydrogen, neon, helium, krypton and xenon.

To assist in the understanding of the natural laws as well as the behaviour of air, the physical dimensions which are employed and their classification in the systems of units are documented below.

The following terms and units are required for definitions in pneumatics :

Base Quantities

Unit	**Symbol**	**Units and unit symbols** Technical System	 System SI
Length	L	Metre (m)	Metre (m)
Mass	m	$Kp \cdot s^2/m$	Kilogram (kg)
Time	t	Second (s)	Second (s)
Temperature	T	Degrees Celsius (^oC)	Kelvin (K)

Derived Quantities

Unit	**Symbol**	**Derived units and unit symbols** Technical System	 System SI
Force	F	Kilopond (kp)	Newton (N) = 1 $kg \cdot m/s^2$
Area	A	Square metre (m^2)	Square metre (m^2)
Volume	V	Cubic metre (m^3)	Cubic metre (m^3)
Flowrate	Q	(m^3/s)	(m^3/s)
Pressure	p	Atmosphere (at)	Pascal (Pa) 1 Pa= $1 N/m^2$ 1 bar = 10^5Pa

The international and technical systems of units are linked by :

Newtons Law: Force = mass x acceleration
$F = m \cdot a$
where a is replaced by the acceleration due to gravity
$g = 9.81\ m/s^2$

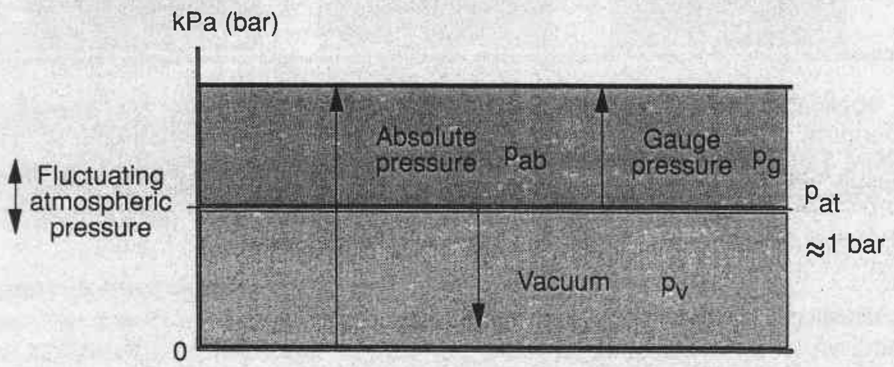
Pressure :
1 Pascal is equal to the constant pressure on a surface area of $1m^2$ with the vertical force of 1 N (Newton). 100kPa is equal to 14.5 psi (pounds per square inch).

Since everything on earth is subjected to the absolute atmospheric pressure (p_{at}), this pressure cannot be felt. The prevailing atmospheric pressure is therefore regarded as the base and any deviation is termed:

Gauge Pressure = p_g
or
Vacuum = p_v

This is illustrated by the following diagram :

Air pressure relationship



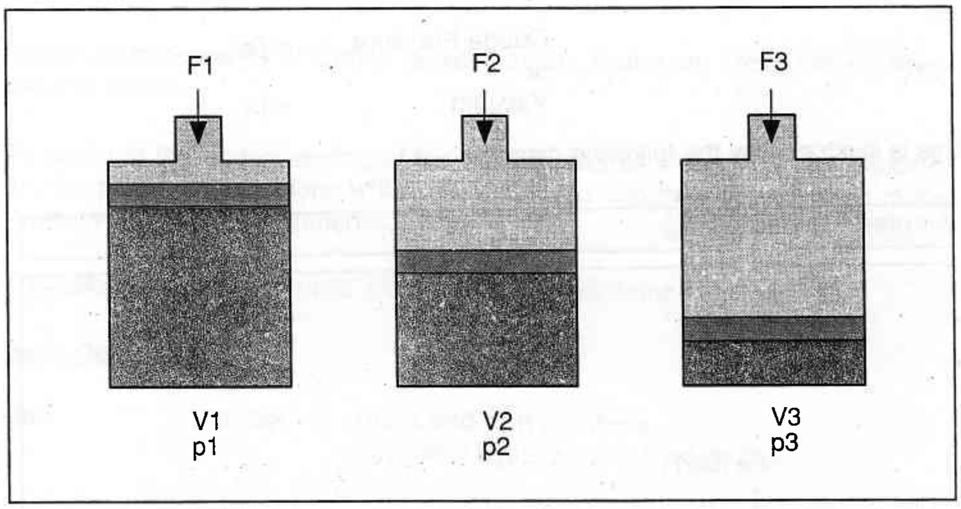
The atmospheric pressure does not have a constant value. It varies with the geographical location and the weather. The range from the absolute zero line to the variable atmospheric pressure line is called the vacuum range and above this, the pressure range.

The absolute pressure p_{ab} is composed of pressure p_{at} and pressure p_g. In practice, gauges are used which show only the excess pressure p_g. Pressure p_{ab} is approximately one bar (100 kPa) greater than the P_g value.

1.2 Characteristics of air

In common with all gases, air has no particular shape. Its shape changes with the slightest resistance, i.e. it assumes the shape of its surroundings. Air can be compressed and it endeavours to expand.

Boyle - Mariotte's law: pressure and volume relationship



The applicable relationship is given in Boyle-Mariottes Law. "At constant temperature, the volume of a given mass of gas is inversely proportional to the absolute pressure", i.e. the product of absolute pressure and volume is constant for a given mass of gas.

$$p_1 \cdot V_1 = p_2 \cdot V_2 = p_3 \cdot V_3 = \text{Constant}$$

The following example illustrates the above principles.

Example calculation

Air at atmospheric pressure is compressed by an air compressor to 1/7th the volume. What is the gauge pressure of the air assuming a constant temperature process :

$$p_1 \cdot V_1 = p_2 \cdot V_2$$

$$p_2 = p_1 \cdot \frac{V1}{V2}$$ Note : $V_2 / V_1 = 1/7$

$$p_1 = p_{at} = 1 \text{ bar} = 100 \text{ kPa}$$

$$p_2 = 1 \cdot 7 = 7 \text{ bar} = 700 \text{ kPa absolute}$$

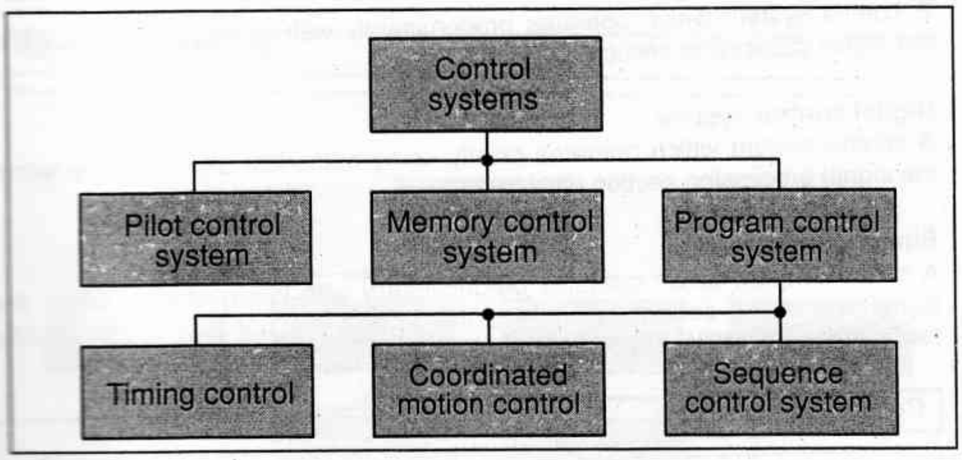
Therefore : $p_{gauge} = p_{ab} - p_{at} \approx (7\text{-}1) \text{ bar} = 6 \text{ bar} = 600 \text{ kPa}$.

A compressor that produces air at p_{gauge} = 600 kPa must have a compression ratio of 1:7. (This assumes that the atmospheric pressure is 1 bar or 100 kPa).

1.3 Control theory

The allocation of a control system to one of the three control types is dependent on the task involved. In the case of the program control system, the planner has the choice between the three sub-groups for program control.

Control system processing types



Pilot control system
There is always a clear relationship between the command or reference value and the output value provided disturbance variables do not cause any deviations (DIN 19226). Pilot controls do not have a memory function.

Memory control system
When the command or reference value is removed or cancelled, in particular after completion of the input signal, the output value achieved is retained (memorised). A different command value or an opposing input signal is required to return the output value to an initial value (DIN 19226).

Time (schedule) control
In a time (schedule) control system, the command values are supplied by a time-dependent program generator (DIN 19226). Characteristics of a timing control system are, thus, the existence of a program generator and a time-dependent program sequence. Program generators may be :

- Cam shafts
- Cams
- Punched cards
- Punched tape
- Programs in an electronic memory

Coordinated motion control system
In a coordinated motion control system, the reference values are supplied by a signal generator whose output values are dependent on the path covered or the position of a movable part within the system being controlled (DIN 19226).

Sequence control system
The sequence program is stored in a program generator which runs through the program step-by-step according to the status attained by the system being controlled. This program may either be permanently installed or else read from punched cards, magnetic tapes or other suitable memories .

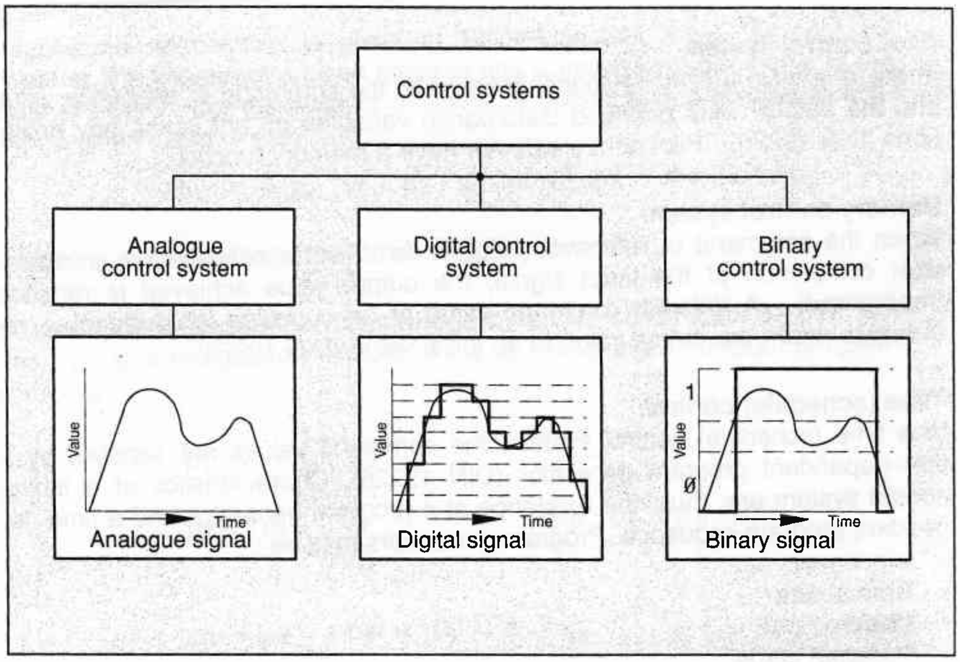
Classification in accordance with the signal type

Analogue control system
A control system which operates predominantly with analogue signals within the signal processing section (DIN 19237).

Digital control system
A control system which operates chiefly using numerical digital signals within the signal processing section (DIN 19237).

Binary control system
A control system which operates predominantly with binary signals within the signal processing section and where the signals are not part of numerically represented data (DIN 19237).

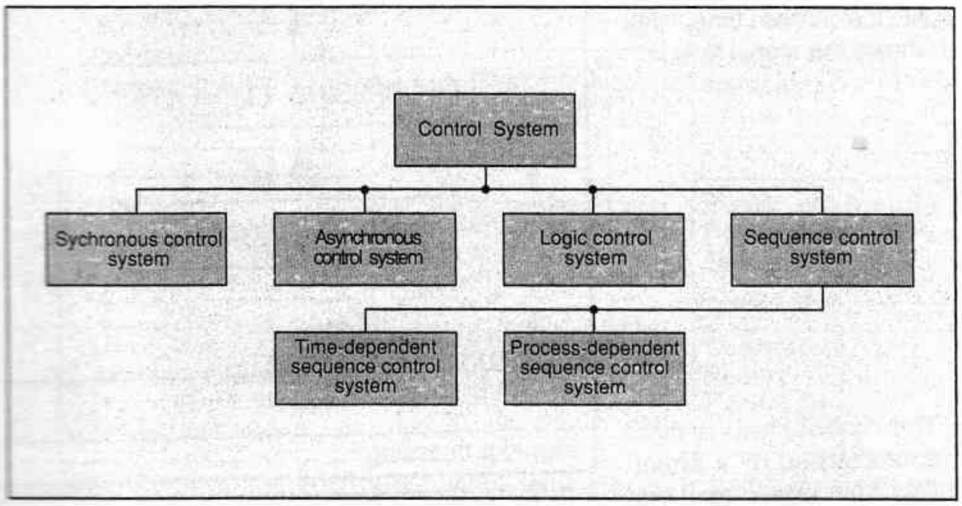
Control system signals



The classification of control systems according to the type of data representation is of a more theoretical nature and is independent of the method of solution. More suitable for practice is the classification according to the type of signal processing since it gives information about the method of solution to be chosen.

Classification according to the type of signal processing

Control system types



Synchronous control system
A control system where signal processing is synchronous to a clock pulse (DIN 19237).

Asynchronous control system
A control system operating without clock pulses where signal modifications are only triggered by a change in the input signals (DIN 19237).

Logic control system
A control system where specific signal status for the output signals are assigned to the signal status of the input signals by means of Boolean logic connections (DIN 19237).

Sequence control system
A control system with compulsory stepped operation where switching on from one step to the next in the program is dependent upon certain conditions being satisfied (DIN 19237).

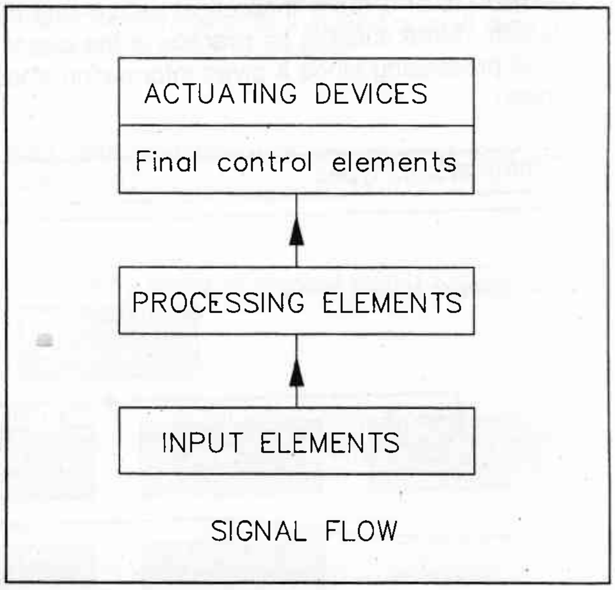
Time-dependent sequence control system
A sequence control whose switching conditions are dependent only on time (DIN 19237).

Process-dependent
A sequence control system whose switching conditions are dependent only on signals from the system being controlled (DIN 19237).

Signal flow and the control chain

The controller can be represented as a self-contained block, which can be broken down further. A control can always be broken down into the blocks to show the arrangement of the individual components. At the same time, this shows the signal flow.

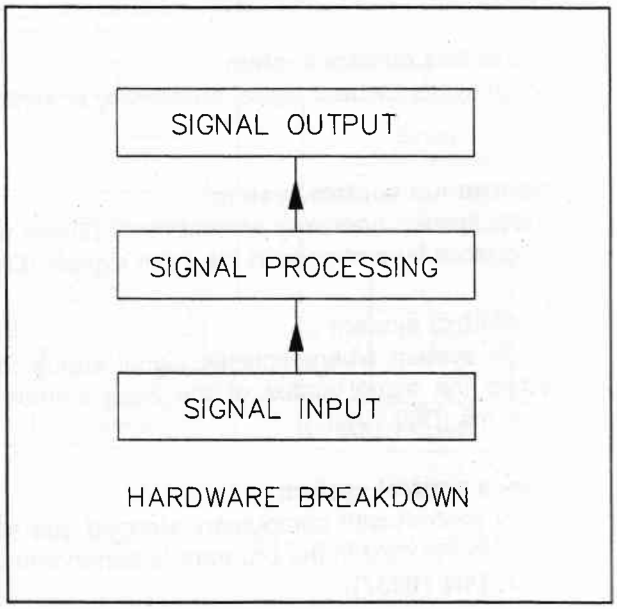
Control chain



The control chain is thus characterised by a signal flow from signal input via signal processing to signal output and execution of instructions.

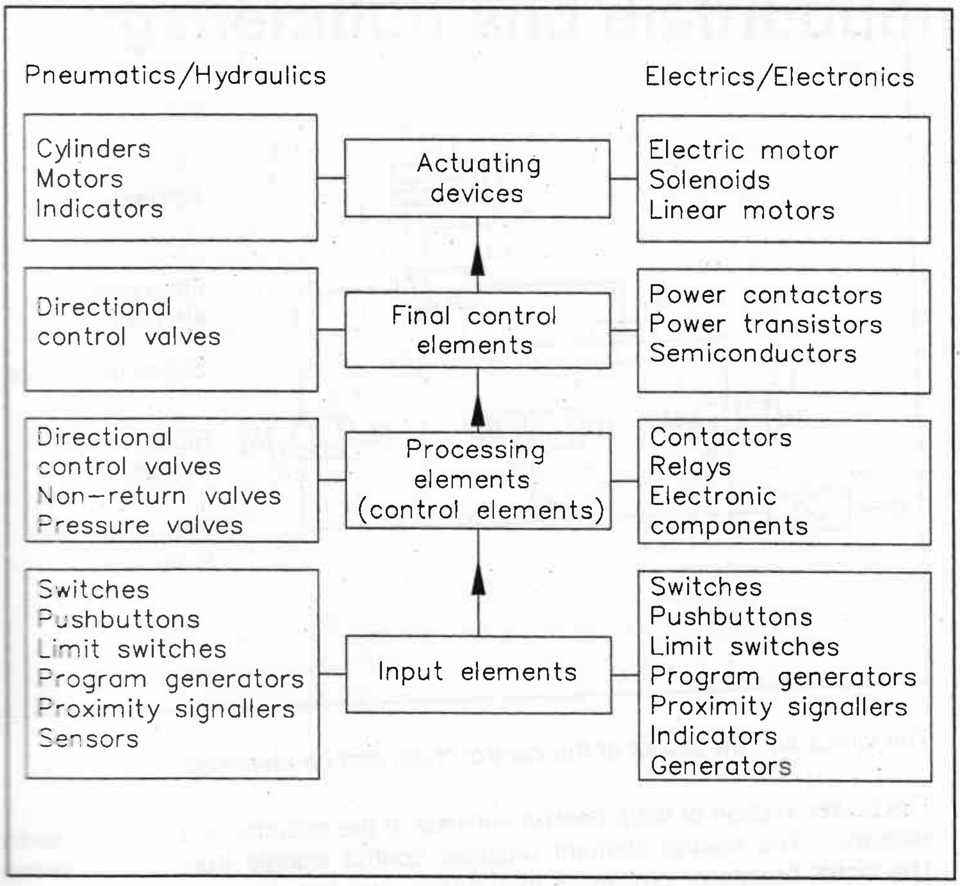
In hardware terms, this means that input devices processing devices and output devices must exist for these signals.

Signal processing



The following diagram shows some examples of the assignment of devices and signal flow:

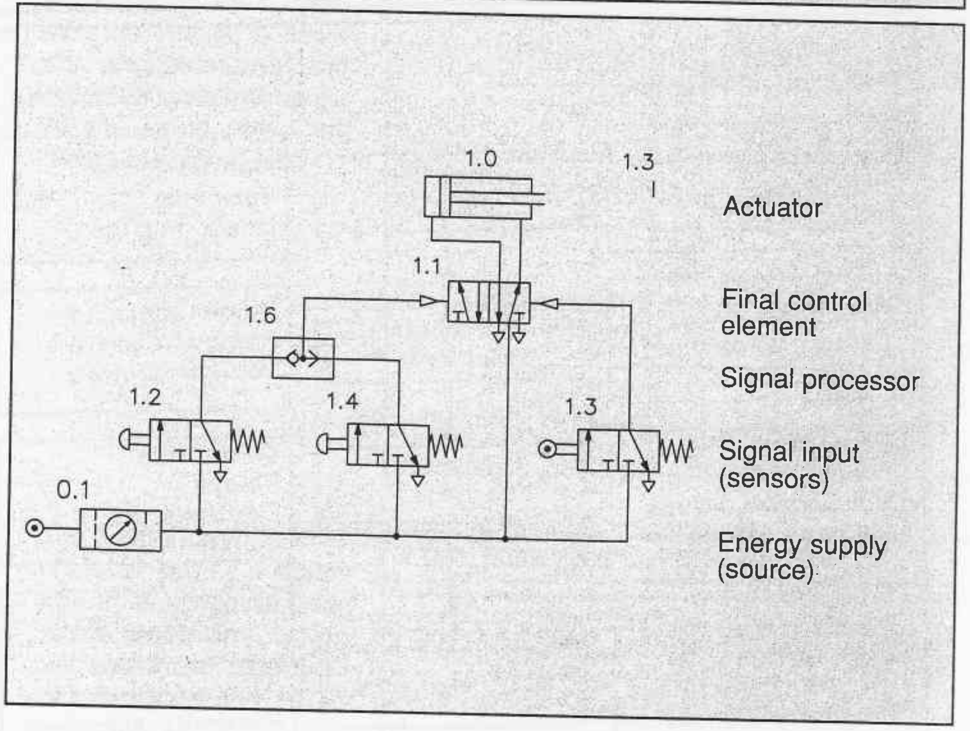
Signal flow



Example

This subdivision does mean however that additional devices must be introduced into the control chain for signal transformation. These devices consist of amplifiers or converters depending on whether or not the same form of energy is used for the operative part and the control part.

Circuit diagram



The circuit and the layout of the control chain can be identified.

The power section or work section consists of the actuator and the final control element. The control element receives control signals from the processor. The signal processor processes information sent from the signal input devices or sensors. The signal flow is from the energy source to the power section.

Chapter 2

Air generation and distribution

A 7

For the continuing performance of control systems and working elements it is necessary to guarantee that the air supply is clean, dry and at the required pressure. If these conditions are not fulfilled, then short to medium term degeneration of the system will be accelerated. The effect is downtime on the machinery in addition to increased costs for repair or replacement of parts. The preparation of the air starts from the point of generation and can be contaminated by many potential points in the system right up to the point of use. There is no use in preparing good quality air and then allowing incorrect component selection to reduce the quality. The equipment to be considered in the generation and preparation of air include:

- Air compressor
- Air receiver
- Air filter
- Air dryer
- Air lubricator
- Pressure regulator
- Drainage points
- Oil separators

The location and type of compressor influences to a greater or lesser degree the amount of particles, oil and water that is taken in or supplied to a system. The compressed air should therefore be properly prepared to prevent malfunctioning of the consuming devices which are connected to it.

Poorly-prepared compressed air will inevitably lead to malfunctions and may manifest itself in the system as follows :

- Rapid wear of seals and moving parts in the cylinders and valves
- Oiled-up valves
- Contaminated silencers

Preparation is achieved by means of pre-filters on the compressor intake, series-connected dryers, filters and separators for oil and condensate. Their selection must match the task requirements.

Pressure level

As a rule, pneumatic consuming devices such as cylinders and valves are designed for a maximum operating pressure of 8-10 bar. Practical experience has shown, however, that approximately 6 bar should be used for economic operation. The purchase price of the compressor system, the efficiency and wear of the cylinders and valves and the installation costs for the pipe system are at their most favourable in this range. Pressure losses of between 0.1 and 0.5 bar must be expected due to the restrictions, bends, leaks and pipe-runs, depending on the size of the piping system and the method of layout. The compressor's system should provide at least 6.5 to 7 bar for a desired operating pressure level of 6 bar.

If there is the danger of sudden and fluctuating consumption, a compressed air receiver can be installed to stabilise the pressure in the compressed air network. In normal operation, this receiver is filled by the compressor, with the result that a reserve is available at all times. This also makes it possible to reduce the switching frequency of the compressor.

Utilisation factor

Characteristic values of consumption should be determined for large-size compressors according to normal, medium and peak loads. Practice has shown that with a varying air consumption several individual compressors can be put to use more effectively than one large compressor. An approximate value of 75% should be taken as the utilisation factor to be aimed for with medium load operation. In order to make the correct selection, it is vital to have a list of all the consuming devices connected to the compressed air network together with their average and maximum air consumption, duty cycle and frequency of operation.

Why dry compressed air?

The atmospheric air taken in by the compressor always contains a proportion of moisture in the form of water vapour. The higher the air temperature, the greater the quantity of water vapour which it can take up, expressed in % of relative humidity. If the saturation point of 100% is reached, the water is precipitated in the form of droplets. The effects of this process can be explained by means of an example:

A compressor with a delivery of 10m^3/h (20°C and 50% humidity) compresses air at an absolute pressure of 7 bar (1.43 m^3/h). Before compression, the amount of water in the air is 8.5 g/m^3 (50% of the saturated content for 20°C i.e. 0.5 x 17 g/m^3), which means that the compressor takes up 85 g/h of water. At the compressor outlet the air is saturated and contains 51 g/m^3 of water. After compression, the temperature rises to 40°C.

For 1.43 m^3/h of compressed air the condensate will then amount to:

$$1.43\ m^3/h \cdot 51\ g/m^3 = 72.93\ g/h.$$

The precipitated condensate after compression thus amounts to:

$$85\ g/h - 72.93\ g/h = 12.07\ g/h$$

If this moisture is allowed to enter the pneumatic system, the consequences are as follows:

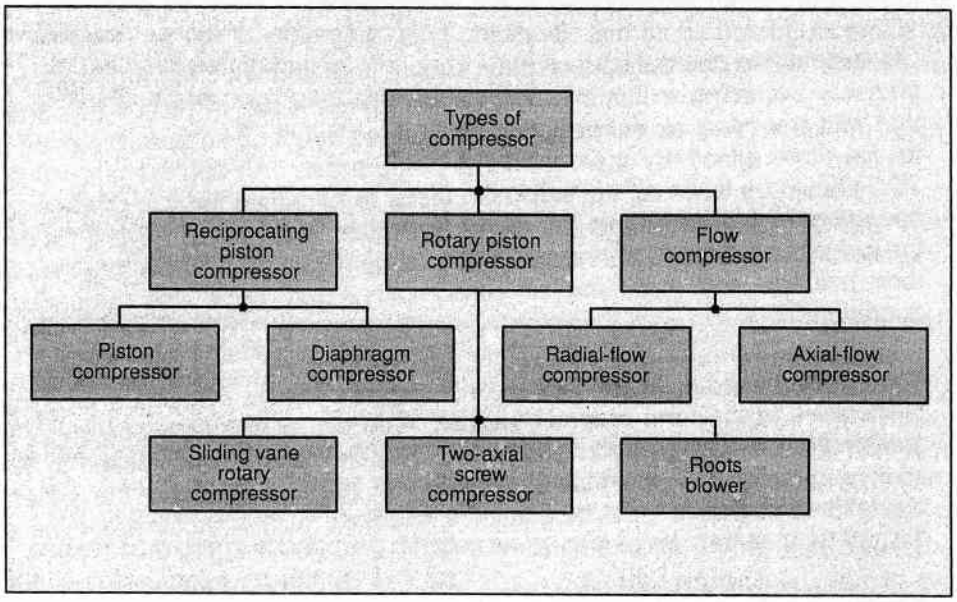
- Corrosion in pipes, cylinders and other components. This increases wear and maintenance costs.
- The basic lubrication in the cylinders is washed away.
- The switching function of valves is impaired, i.e. more malfunctions during the operating sequence.
- Contamination and damage at points where the compressed air comes directly into contact with sensitive materials (paint shops, food industry).

It therefore follows that the water must in all cases be removed from the compressed air before it can cause damage; the air must be adequately dried.

2.1 Air compressor

The selection from the various types of compressors available is dependent upon quantity of air, pressure, quality and cleanliness and how dry the air should be. There are varying levels of these criteria depending on the type of compressor.

Compressor types



Reciprocating piston compressor

Reciprocating compressors are very common and provide a wide range of pressures and delivery rates. For higher pressures multistage compression is used with intercooling between each stage of compression.

The optimum range of pressures for reciprocating compressors are approximately:

up to 400kPa	(4bar/58psi)	Single stage
up to 1500kPa	(15bar/217.5psi)	Double stage
over 1500kPa	(15bar/217.5psi)	Treble or multi stage

Also, it is possible but not necessarily economic to operate in the following ranges:

up to 1200kPa	(12bar/174psi)	Single stage
up to 3000kPa	(30bar/435psi)	Double stage
up to 22000kPa	(220bar/3190psi)	Treble or multi stage

Diaphragm compressor

The diaphragm compressor is used where oil is to be excluded from the air supply, for example in the food, pharmaceutical and chemical industries. Here there is no need for lubrication in the compression area.

Rotary piston compressor

The rotary group of compressors use rotating members to compress and increase the pressure of the air. They are smooth in operation but the compression is not as high as with multistage reciprocating compressors.

Flow (turbine) compressors

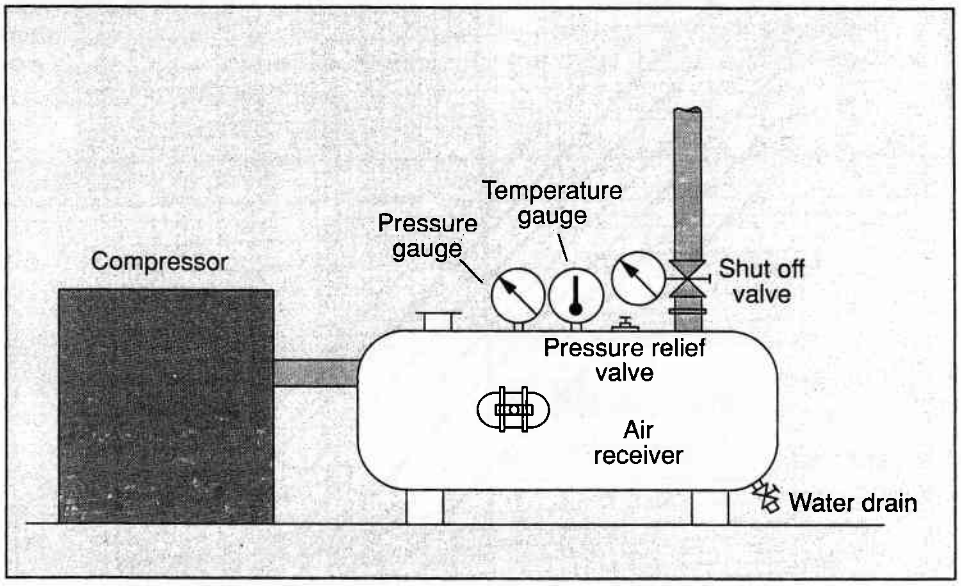
Flow compressors produce large volumes of air at small increases in stage pressure. The air is accelerated by the blades of the compressor but there is only a small increase in pressure of about 1.2 times the inlet pressure per stage.

2.2 Air receiver

Receivers provide constant air pressure in a pneumatic system, regardless of varying or fluctuating consumption. This enables briefly-occurring consumption peaks to be balanced out, which cannot be made up by the compressor.

A further function of receivers is the emergency supply to the system in cases of power failure. The reservoir can be fitted either downstream of the compressor, to act as an air chamber, or selectively at points where consumption is high.

Air receiver



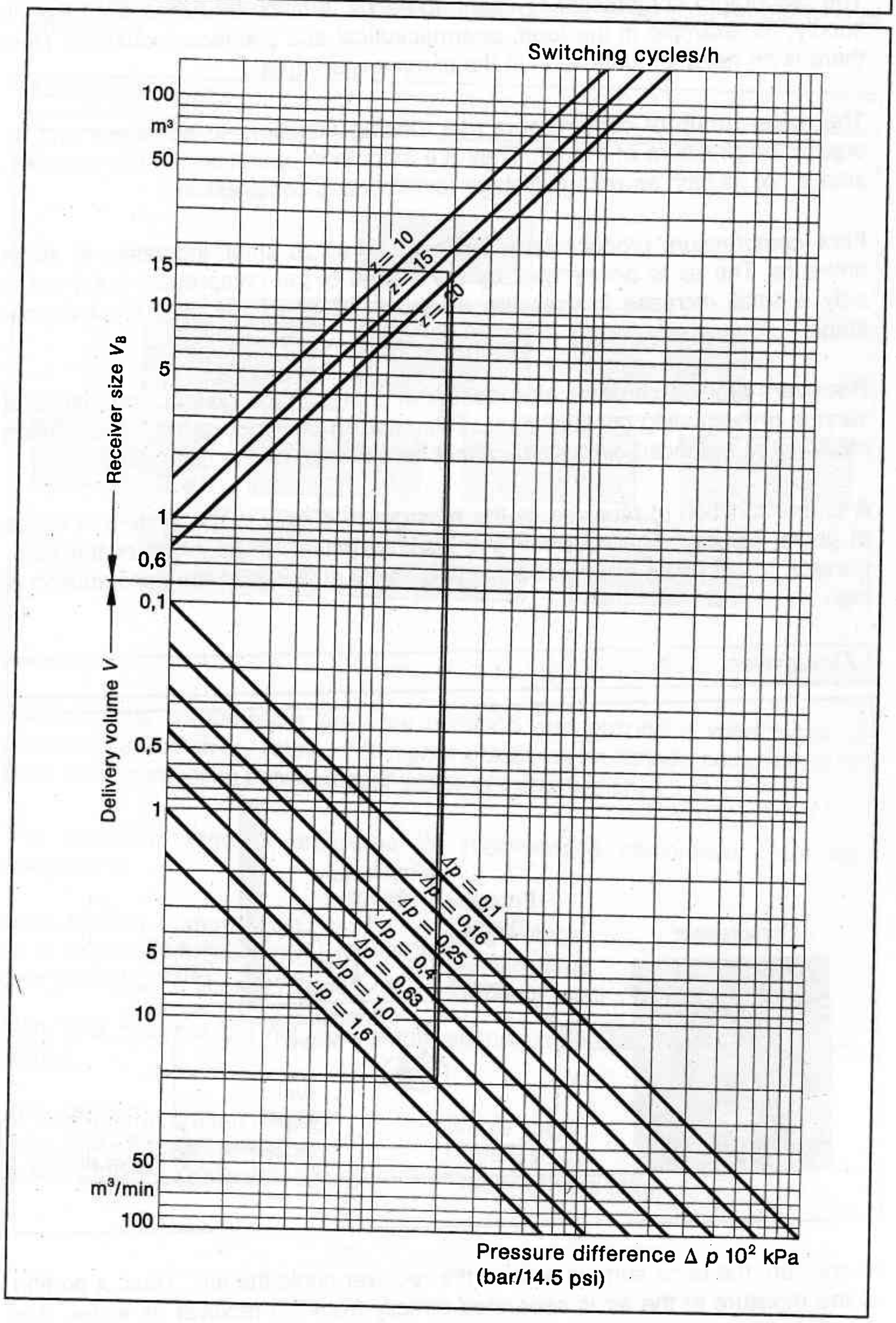
In addition, the large surface area of the receiver cools the air. Thus, a portion of the moisture in the air is separated directly from the receiver as water. It is therefore important to drain the condensate regularly.

The size of a compressed air receiver depends on the:

- Delivery volume of the compressor
- Air consumption for the applications
- Network size
- Type of compressor cycle regulation
- Permissible pressure drop in the supply network

Air receiver size

Air receiver size chart



Example

Delivery volume	$V = 20$ m³/min
Switching cycles per hour	$z = 20$
Pressure drop	$\Delta P = 1 \times 10^5$ Pa

Result:

Receiver size $V = 15$ m³ (refer to the chart)

2.3 Air dryers

Water produces a hardening of seals, corrosion and the washing-out of the original lubrication of cylinders. Oil and water may cause seals and diaphragms to swell. In paint-spraying plants, water and dust cause contamination, poor paint adhesion and the formation of blisters. In the food, pharmaceutical and chemical industries, oil, dirt, bacteria and germs destroy the storage properties of products.

The service life of pneumatic systems is considerably reduced if excessive moisture is carried through the air system to the elements. Therefore it is important to fit the necessary air drying equipment to reduce the moisture content to a level which suits the application and the elements used. There are three auxiliary methods of reducing the moisture content in air:

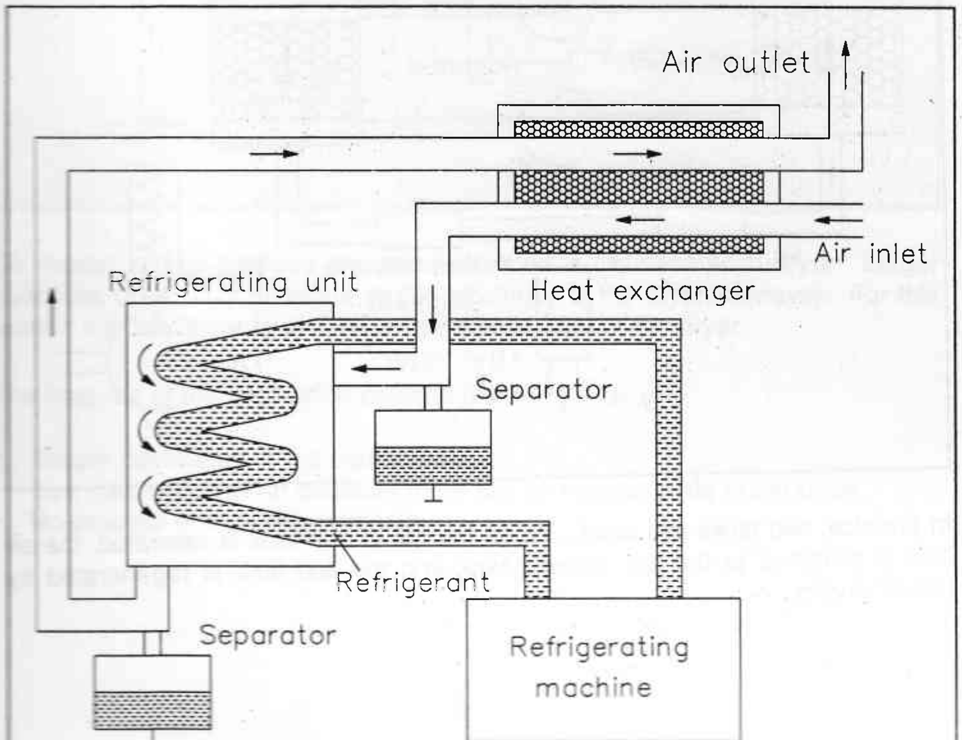
- Low temperature drying
- Adsorption drying
- Absorption drying

The additional cost of installing air drying equipment can be amortised over a short pay-back period due to the reduction in maintenance costs, reduced downtime and increased reliability of the system.

Low temperature drying

The most common type of dryer today is the refrigeration dryer. These units operate economically and reliably and the maintenance costs are low. With refrigerated drying, the compressed air is passed through a heat-exchanger system through which a refrigerant flows. The aim is to reduce the temperature of the air to a dew point which ensures that the water in the air condenses and drops out in the quantity required.

Low temperature drying



Dew Point:
The dew point temperature is the temperature to which a gas must be cooled to condense water vapour contained in the gas.

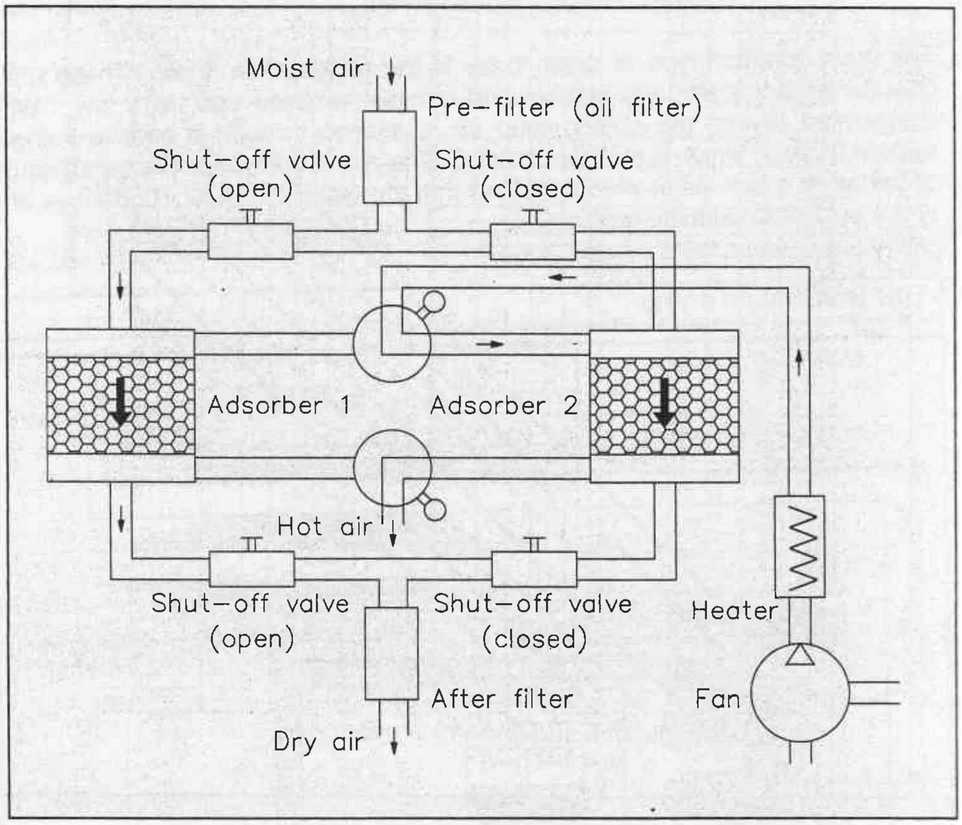
The lower the temperature the more the water will condense and reduce the amount entrapped in the air. Using refrigeration methods, it is possible to achieve dew points of between 2°C and 5°C.

Before the compressed air is output into the network, the air is heated to bring the air back to ambient conditions. The outlet temperatures are approximately 10°C in winter and approx. 30°C in summer.

Adsorption dryers

The lowest equivalent dew points (down to -90°C) can be achieved by means of adsorption drying. In this process, the compressed air is passed through a gel and the water is deposited on the surface, i.e., it is adsorbed. (Adsorb: water is deposited on the surface of solids.) The drying agent is a granular material of sharp-edged shape or in bead form. This drying agent consists almost entirely of silicon dioxide.

Adsorption drying



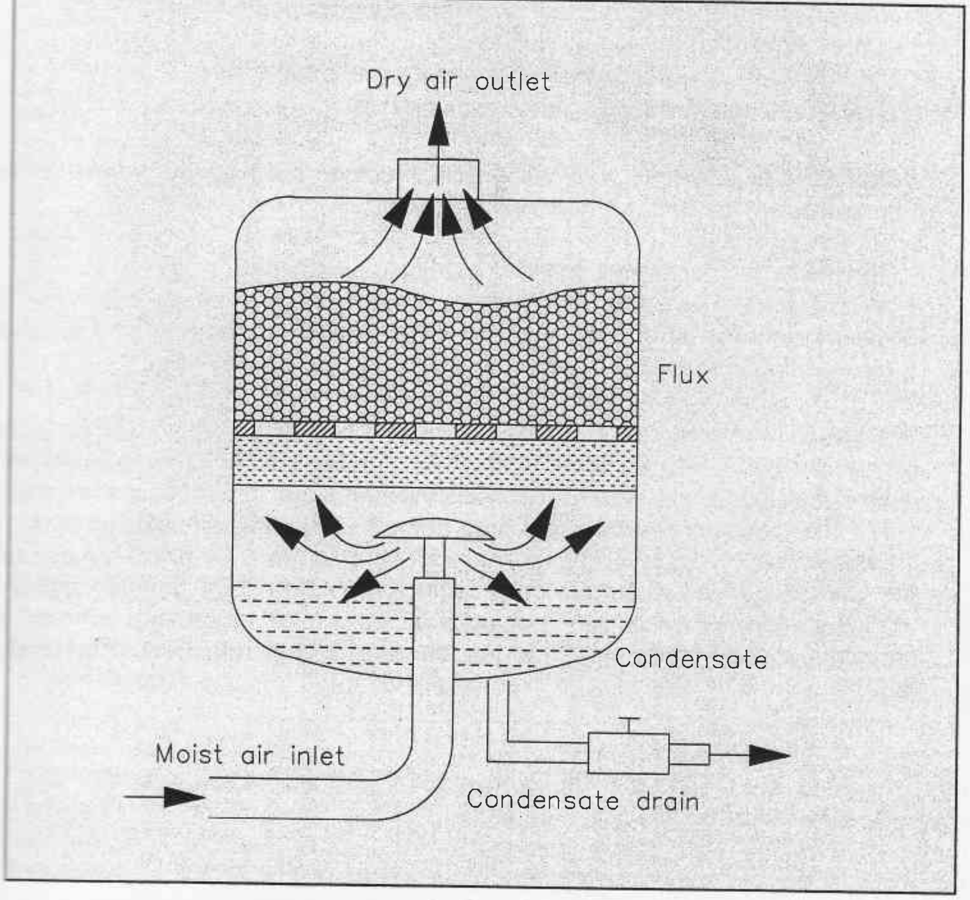
A 7.3

In practice, two tanks are used. When the gel in one tank is saturated, the air flow is switched to the dry, second tank and the first tank is regenerated by hot-air drying.

Absorption dryers

Absorption drying is a purely chemical process. The moisture in the compressed air forms a compound with the drying agent in the tank. This causes the drying agent to break down; it is then discharged in the form of a fluid at the base of the tank. Absorption drying is not of major significance in present-day practice, since the operating costs are too high and the efficiency too low for most applications.

Absorption drying



Oil vapour and oil particles are also separated in the absorption dryer. Larger quantities of oil have an effect on the efficiency of the dryer, however. For this reason it is advisable to include a fine filter in front of the dryer.

The features of the absorption process are :

- Simple installation of the equipment
- Low mechanical wear because there are no moving parts in the dryer
- No external energy requirements.

2.4 Air service equipment

As a rule the compressed air which is generated should be dry, i.e. free of oil. For some components lubricated air is damaging, for others, it is undesirable, but for power components it may in certain cases be necessary. Lubrication of the compressed air should therefore always be limited to the plant sections which require lubrication. For this purpose, mist lubricators are fitted to feed the compressed air with specially selected oils. Oils which are introduced into the air from the compressor are not suitable for the lubrication of control system components.

The problems that occur with excessive lubrication include :

- Malfunctions due to excessively lubricated components
- Oil mist pollution of the environment
- Gumming-up of parts occurs after lengthy plant standstills
- Difficulties in adjusting the lubricator correctly.

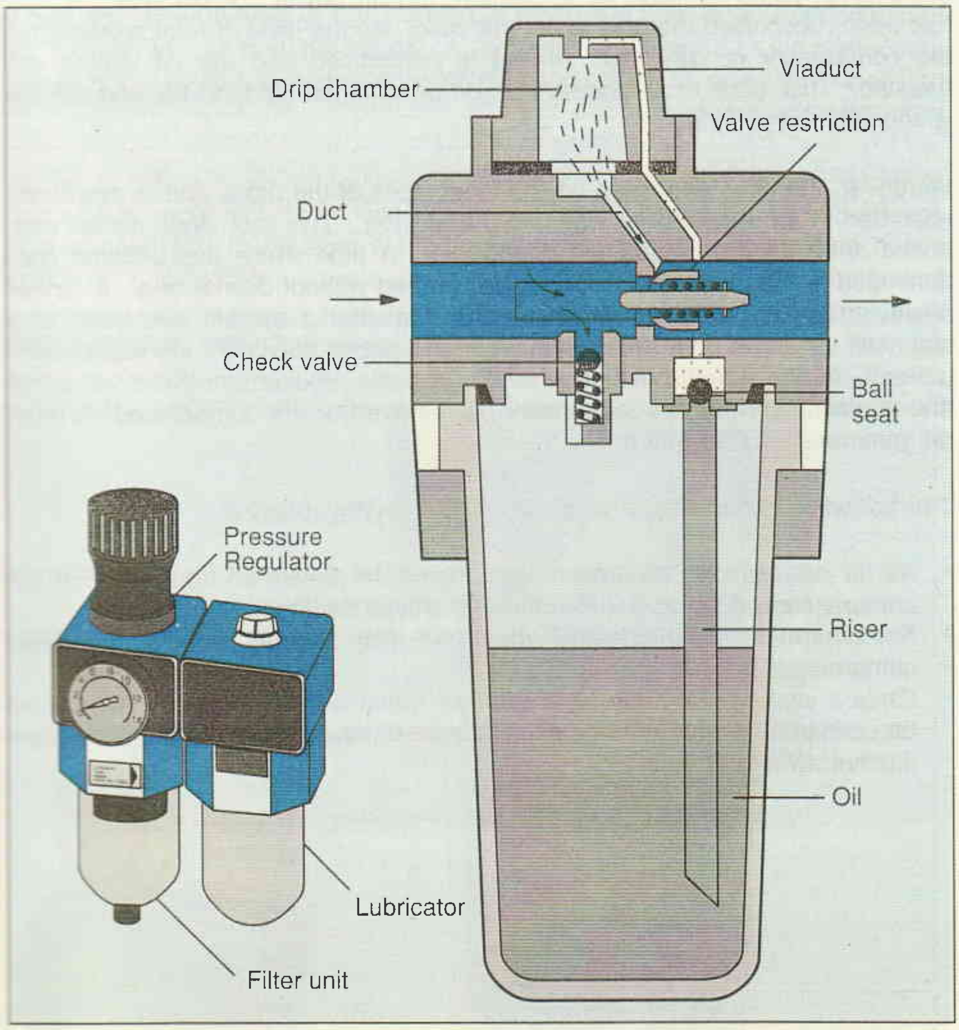
Despite these problems, lubrication of the compressed air by means of mist lubricators may be necessary in certain cases :

- Where extremely rapid oscillating motions are required
- With cylinders of large diameter, from approximately 125mm upwards. As far as possible lubricators should be installed only directly upstream of the consuming cylinders.

The selection of the correct size of lubricator is determined by the air consumption of the cylinders, since all lubricators require a minimum volumetric flow before they begin to deliver oil (check the response threshold). This means that if the lubricator is sized too large, it may under certain circumstances be ineffective, while, if it is too small, leakage air which may be present can cause the lubricator to dry out during idle periods. As a general principle cylinders with heat-resistant seals must not be supplied with lubricated compressed air, since the special grease which forms the original lubrication would be washed out.

Air lubricator

Lubricators



The compressed air passing through the lubricator causes a pressure drop between the oil reservoir and the upper part of the lubricator. The pressure difference is sufficient to force the oil upwards through a viaduct where it then drips into a nozzle which can be seen through an inspection glass. Here the oil is atomised and taken up by the air stream to a greater or lesser extent.

Checking the oil dosage

It is possible to check the oil dosage as follows:

A piece of white cardboard should be held at a distance of approximately 20 cm from the exhaust port of the power valve. If the system is then allowed to operate for some time, it should be possible to see only a pale yellow colour on the cardboard. Dripping oil is a clear sign of over-lubrication. In this case the lubricator should be readjusted.

Removing oil

Up to a few years ago, the general view was that the oil discharged by the compressor could be used as a lubricant for the power components. Now it has been recognised that this is not the case. As the level of heat produced in the compressor is very high, the oil is carbonised and the oil vapour exhausted. This leads to an abrasive action on cylinders and valves, and service is considerably reduced.

Moreover, the oil is deposited on the inner walls of the pipes and is eventually absorbed in an uncontrolled way into the air flow. This fact alone makes controlled and effective distribution impossible. A pipe which has become contaminated in this way can no longer be cleaned without dismantling. A further disadvantage is gumming, which means that after a system has been at a standstill for some time (after weekends and public holidays), lubricated components do not at first function correctly. A basic requirement therefore is that the oil discharged by the compressor be removed or the compressed air must be generated in oil-free form.

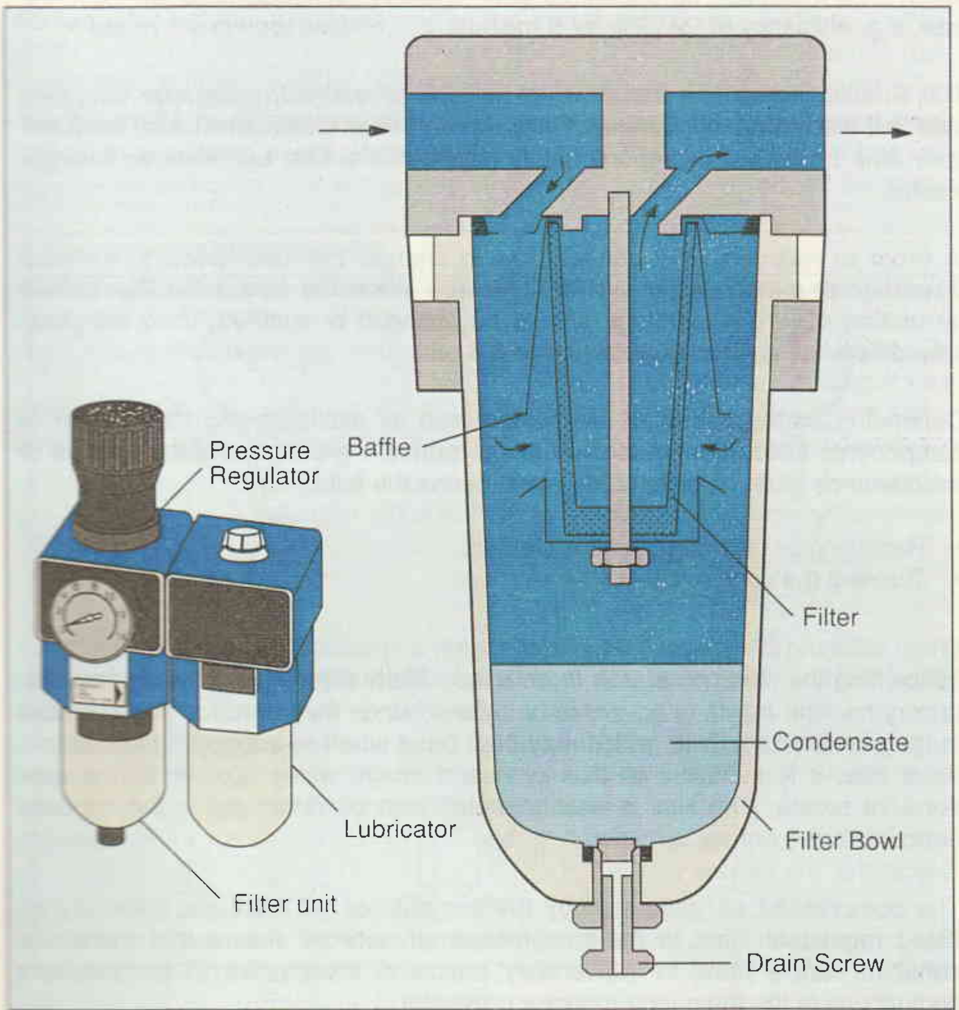
The following points should be observed in everyday practice:

- As far as possible compressor oils should be prevented from entering the compressed-air network (oil separators should be fitted)
- For operation fit components which can also operate with non-lubricated compressed air
- Once a system has been operated and run-in with oil, the lubrication must be continued since the original lubrication of the components will have been flushed away by the oil.

Compressed air filter

The selection of the correct filter plays an important role in determining the quality and performance of the working system which is to be supplied with compressed air. One characteristic of compressed-air filters is the pore size. The pore size of the filter element indicates the minimum particle size which can be filtered out of the compressed air. For example, a 5-micron filter element filters out all particles whose diameter is greater than 0.005 mm. With a suitable design, compressed-air filters are also able to separate condensate out of the compressed air. The collected condensate must be drained before the level exceeds the maximum condensate mark otherwise it will be re-introduced in the air stream.

Compressor air filter



If a large amount of condensate accumulates, it is advisable to fit an automatic drain in place of the manually operated drain cock. The automatic drain uses a float to determine the level of condensate in the bowl and when the limit is reached a control piston opens a valve seat that ejects the condensate under air pressure via a drain line.

The compressed air passes through the filter from left to right and is fed through a baffle plate in the filter bowl. The effect of the baffle plate is that the air is caused to rotate, and the heavier dust particles and water droplets are spun by centrifugal force against the inner wall of the filter bowl. They then run down the wall of the housing and collect in the filter bowl. The air which has been pre-cleaned in this way then passes through the filter element, which filters out the smaller dirt particles. The filter element in this case consists of a highly-porous sintered material. The degree of separation depends on the pore size of the filter element used. Inserts with different pore sizes are available. The usual pore sizes are between 5 microns and 40 microns.

A further important characteristic of compressed-air filters is the degree of separation, or efficiency, which indicates the percentage of particles of a particular size which can be separated out. The efficiency is quoted for a particle size, e.g. efficiency of 99.99% for 5 microns.

The filtration action of a compressed-air filter is retained, even after long service and with heavy contamination. However, under these conditions, the pressure drop becomes disproportionately high and the filter becomes an energy-waster.

In order to recognise the correct time to change the filter element, a visual inspection or a measurement of the pressure difference across the filter should be carried out. The cartridge should be changed or cleaned when the pressure difference is 40 to 60 kPa (0.4 to 0.6 bar).

Maintenance

Depending on the nature of the compressed air available and the number of components fitted, compressed-air filters require a greater or lesser amount of maintenance work. Maintenance work means the following :

- Replacing or cleaning the filter element
- Draining the condensate

When cleaning is required, the manufacturer's specifications must be observed concerning the cleaning agents to be used. Many cleaning agents are unsatisfactory for filter bowls (e.g., trichloroethylene) since they produce stress cracks in the plastic filter bowls, which may then burst when re-subjected to pressure. As a rule, it is sufficient to use lukewarm soapy water applied with a non-abrasive brush. The filter elements should then be blown out in the opposite direction to the normal air flow.

Compressed air regulators

The compressed air generated by the compressor will fluctuate. Centrally located regulators fitted to the compressed air network ensure that there is a constant supply pressure (secondary pressure) irrespective of the pressure fluctuations in the main loop (primary pressure).

Changes in the pressure level in the pipe system can adversely affect the switching characteristics of valves, the running times of cylinders and the timing characteristics of flow control and memory valves.

A constant pressure level is thus a prerequisite for the trouble-free operation of a pneumatic control. In order to provide constant pressure conditions, the pressure reducer or pressure regulator is fitted downstream of the compressed air filter and has the task of keeping the operating pressure constant, regardless of pressure fluctuations or air consumption in the system. The air pressure should be matched to individual requirements upstream of each plant section.

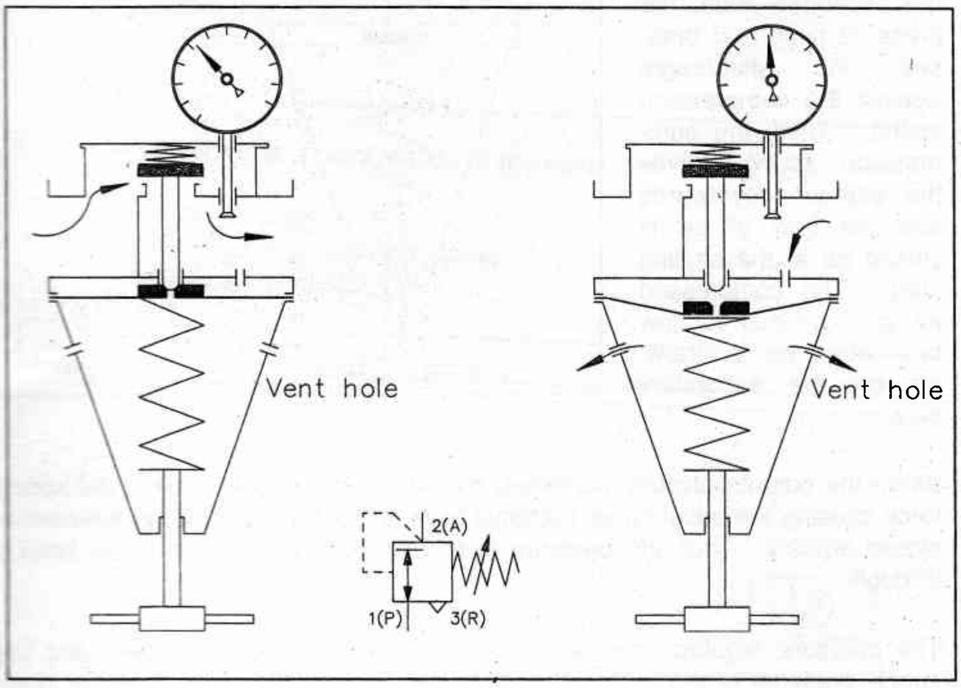
The system pressure which has proved in practice to be the best economic and technical compromise between compressed-air generation and the efficiency of the components is approximately:

- 6 bar in the power section and
- 4 bar in the control section.

A higher operating pressure would lead to inefficient energy utilisation and increased wear, whereas a lower operating pressure would lead to poor efficiency, particularly in the power section.

Pressure regulator with vent hole

Pressure regulator: relieving



The principle of operation is as follows:

The input pressure must always be higher than the output pressure. The pressure is regulated by a diaphragm. The output pressure acts on one side of the diaphragm and a spring acts on the other side. The spring force can be adjusted by means of an adjusting screw. When the output pressure increases, the diaphragm moves against the spring force causing the outlet cross-sectional area at the valve seat to be reduced or closed entirely. Thus the pressure is regulated by the volume flowing through.

When air consumption increases, the operating pressure drops and the spring force opens the valve. Regulation of the preset output pressure is thus a continual opening and closing of the valve seat. To prevent the occurrence of flutter, air or spring clamping is provided above the valve disc. The operation pressure is indicated on a gauge.

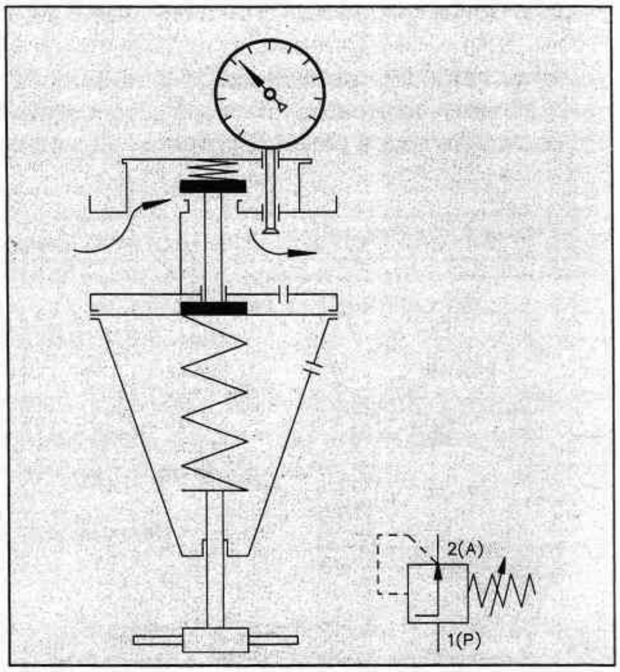
If the pressure on the secondary side increases considerably, for example during cylinder load changes, the diaphragm is pressed against the spring. The centrepiece of the diaphragm then opens and the compressed air can flow to atmosphere through the vent holes in the housing. This relieves the excessive secondary air pressure.

Pressure regulator without vent hole

Pressure regulating valves with no vent hole are available commercially. With these valves it is not possible to exhaust the excessive compressed air produced by sudden loads.

If no air is drawn off on the secondary side, the pressure rises and presses the diaphragm against the compression spring. Thus, the compression spring moves the plunger downwards and the flow of air is closed off at the sealing seat. The compressed air can continue to flow only when air is drawn off on the secondary side.

Pressure regulator: non-relieving



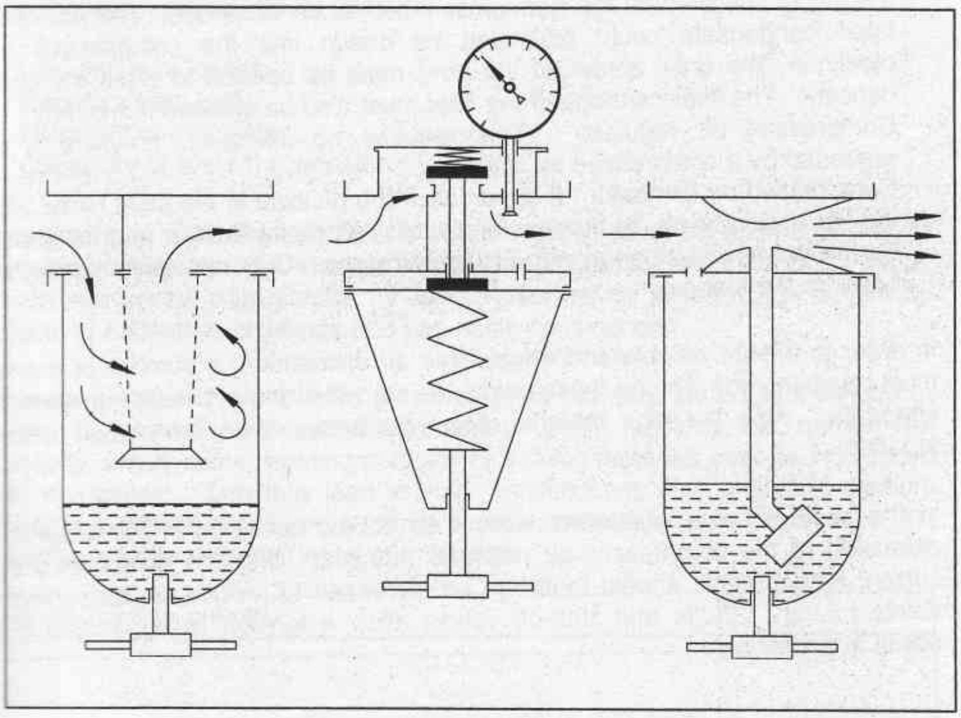
When the output pressure increases, the diaphragm moves against the spring force causing the outlet cross-sectional area at the valve seat to be reduced or closed entirely. Thus the pressure is regulated by the volume of air flowing through.

Setting and adjusting

The pressure regulator can be adjusted between the limits of zero and the supply pressure of the compressor network. The adjustment to a higher pressure is achieved by increasing spring compression. When reducing pressure settings, it is necessary to relieve the pressure well below the limit required to relieve the air from the vent and then increase the pressure up to the lower limit required. It is not possible to simply adjust the pressure directly down to the desired value as indicated on the pressure gauge.

Air service unit

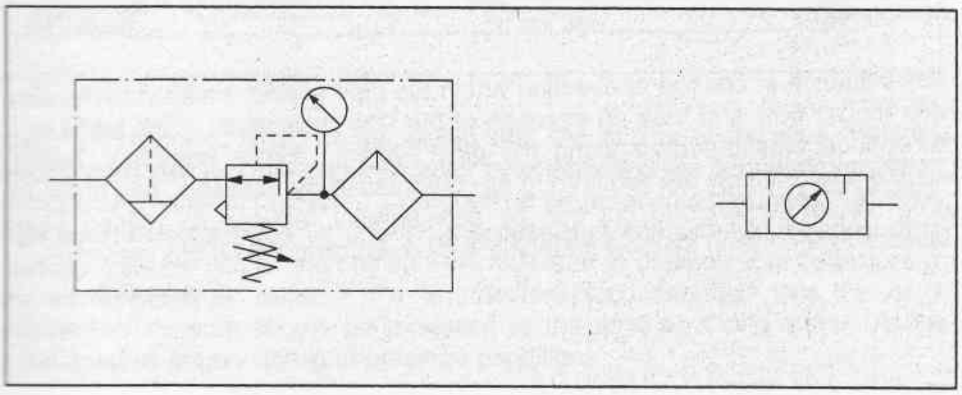
Air service unit: principle of operation



The air service unit is a combination of elements :

- Compressed air filter
- Compressed air regulator and gauge
- Compressed air lubricator

Air service unit symbols



The following points should be noted :

- The total air throughput in m^3/h determines the size of the unit. If the air throughput is too high, a large pressure drop occurs in the units. The values specified by the manufacturer should be observed.
- The working pressure may not exceed the value stated on the service unit. The ambient temperature should not exceed 50°C (maximum values for plastic bowls).

Maintenance of air service units

The following routine service measures are necessary on a regular basis.

- Compressed air filter : The condensate level must be checked regularly, as the height specified on the sight glass must not be exceeded. The accumulated condensate could otherwise be drawn into the compressed air pipelines. The drain screw on the bowl must be opened to drain the condensate. The filter cartridge in the filter must also be cleaned if it is dirty.
- Compressed air regulator : This requires no servicing, provided it is preceded by a compressed air filter.
- Compressed air lubricator : If fitted check the oil level in the sight glass and top up, if necessary, to the level indicated. The plastic filter and lubricator bowl must not be cleaned with trichloroethylene. Only mineral oils may be used for the lubricator.

2.5 Air distribution

In order to ensure reliable and trouble-free air distribution, a number of points must be observed. Among these points the correct sizing of the pipe system is important. Also the pipe material, flow resistances, pipe layout and maintenance.

Sizing pipe systems

In the case of new installations, allowance should be made in all cases for extension of the compressed-air network. The main line size determined by current requirements should therefore be increased to include an appropriate safety margin. Plugs and shut-off valves allow extension to be carried out easily at a later time.

Losses occur in all pipes due to flow resistances. Flow resistances are represented by restrictions, bends, branches and fittings. These losses must be made up by the compressor. The ideal to aim for is a pressure drop in the entire network of approximately 10 kPa (0.1 bar).

In order to achieve this value, the total pipe length must be known. For fittings, branches and bends, equivalent pipe lengths are determined. The choice of the correct internal diameter is also dependent on the operating pressure and delivery of the compressor. Selection is best made with the aid of a nomograph.

Flow resistances

Any influence or change of direction within the pipe system means interference with the air flow and thus an increase of the flow resistance. This leads to a continuous pressure drop along the pipe system. Since branches, bends, adapters and fittings are required in all compressed-air networks, this pressure drop cannot be avoided but can be considerably reduced by routing pipes favourably, choosing suitable materials and assembling the fittings correctly.

Pipe material

The choice of suitable pipe material is determined by the requirements placed on a modern compressed-air network :

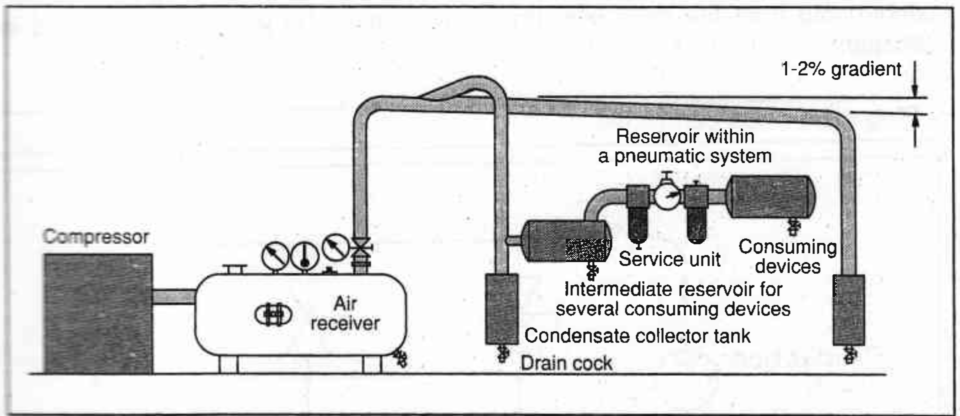
- Low pressure losses
- Freedom from leaks
- Resistant to corrosion
- Capability of system expansion

In selecting a suitable pipe material, consideration must be given not only to price per meter run but also to another major factor, the installation costs. These are lowest with plastics. Plastic pipes can be joined 100% airtight by means of adhesives or fittings and can easily be extended.

Copper and steel have a lower purchase price but must be brazed, welded or joined by means of threaded connectors; if this work is not carried out correctly, swarf, scale, welding particles or sealing materials may be introduced into the system. This may lead to major malfunctions. For small and medium diameters, plastic pipes are superior to other materials as regards price, assembly, maintenance and ease of extension.

Piping layout

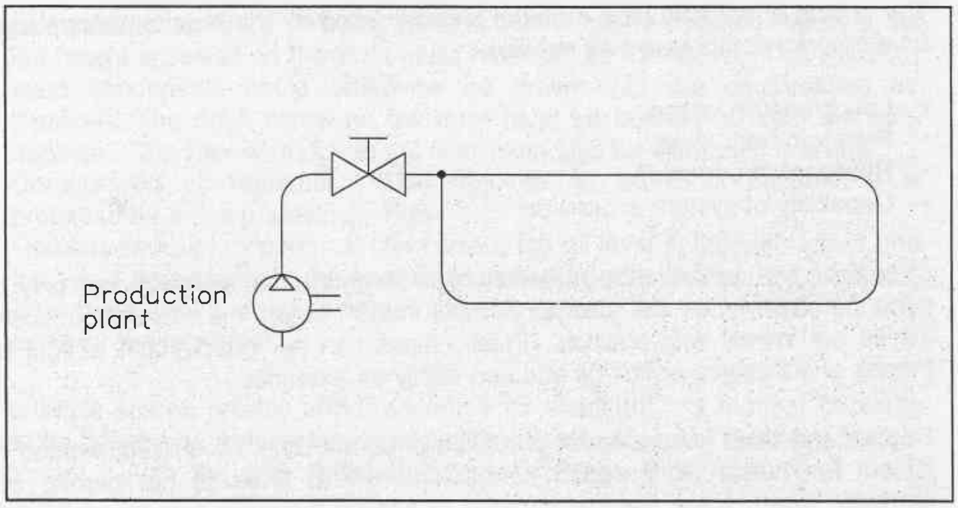
Air distribution system



Apart from correct sizing of the piping and the quality of the pipe material, correct pipe layout is the decisive factor in determining the economic operation of the compressed-air system. Compressed air is fed into the system at intervals by the compressor. It is often the case that consumption at consuming devices rises for only a short time. This may lead to unfavourable conditions in the compressed-air network. It is therefore recommended that the compressed-air network should be produced in the form of a ring main. A ring main ensures largely constant pressure conditions.

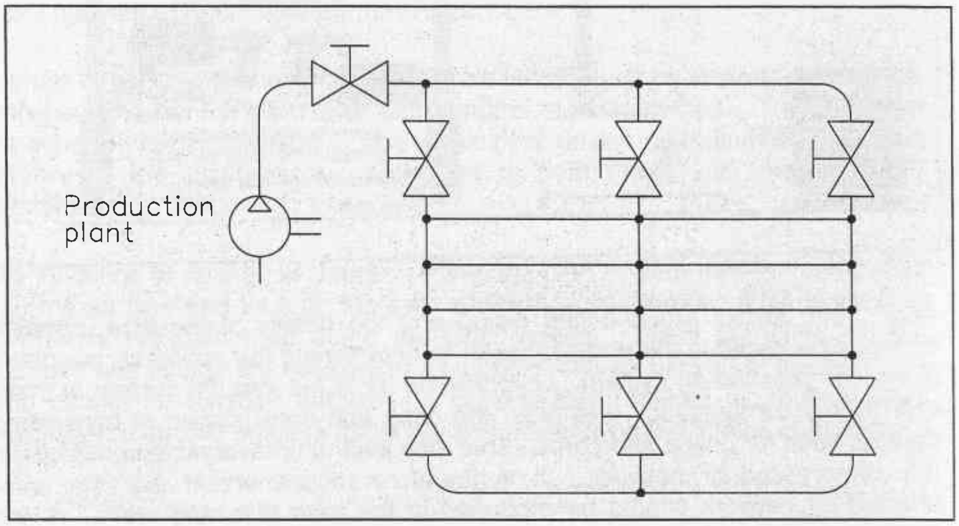
Pressure fluctuations in the network make it necessary to ensure that the pipes are mounted securely in order to avoid leakages at screwed and brazed connections.

Air ring main



For ease of maintenance, repair or extension of the network without interfering with the overall air supply, it is advisable to sub-divide the network into individual sections by means of shut-off valves. Branches with T-pieces and manifolds with plug-in couplings make it possible to supply additional consuming devices as the need arises. In order to protect the consuming devices from condensate from the main line, branch lines must be laid with an upward inclination.

Ring main cross-connected



Despite the best water separation in the pressure generating system, pressure drops and external cooling may produce condensate in the pipe system. In order to discharge this condensate, the pipes should be inclined 1-2%; this can also be carried out in steps. The condensate can then be discharged from the system via water separators at the lowest point.

It is advisable to fit the branch lines with standard ball valves or shut-off valves.

Chapter 3

Directional control valves

Directional control valves are devices which influence the path taken by an air stream. Normally this involves one or all of the following: allowing the passage of air and directing it to particular air lines, cancelling air signals as required by blocking their passage and/or relieving the air to atmosphere via an exhaust port. The directional control valve is characterised by its number of controlled connections or ways and by the number of switching positions. Additional information is given to define the methods of actuation to achieve the various switching positions. The construction of the valve is important when analysing the flow characteristics of the valve such as the flow rate, pressure losses, and switching times for a particular application. Generally the symbol is adequate to represent the operational characteristics of the valve in comparison to other elements in the circuit. The same symbol for a directional control valve may be applicable for many designs, construction methods and characteristics.

3.1 Configuration and construction

The design principle is a contributory factor with regard to service life, actuating force, switching time, means of actuation, means of connection and size.

Designs are categorised as follows :

- Poppet valves :
  - Ball seat valve
  - Disc seat valve
- Slide valves :
  - Longitudinal slide valve
  - Longitudinal flat slide valve
  - Plate slide valve

Poppet valves

With poppet valves the connections are opened and closed by means of balls, discs, plates or cones. The valve seats are usually sealed simply using elastic seals. Seat valves have few parts which are subject to wear and hence they have a long service life. They are insensitive to dirt and are robust. The actuating force, however, is relatively high as it is necessary to overcome the force of the built-in reset spring and the air pressure.

Slide valves

In slide valves, the individual connections are linked together or closed by means of spool slides, spool flat slides or sliding disc valves.

3.2 2/2 way valve

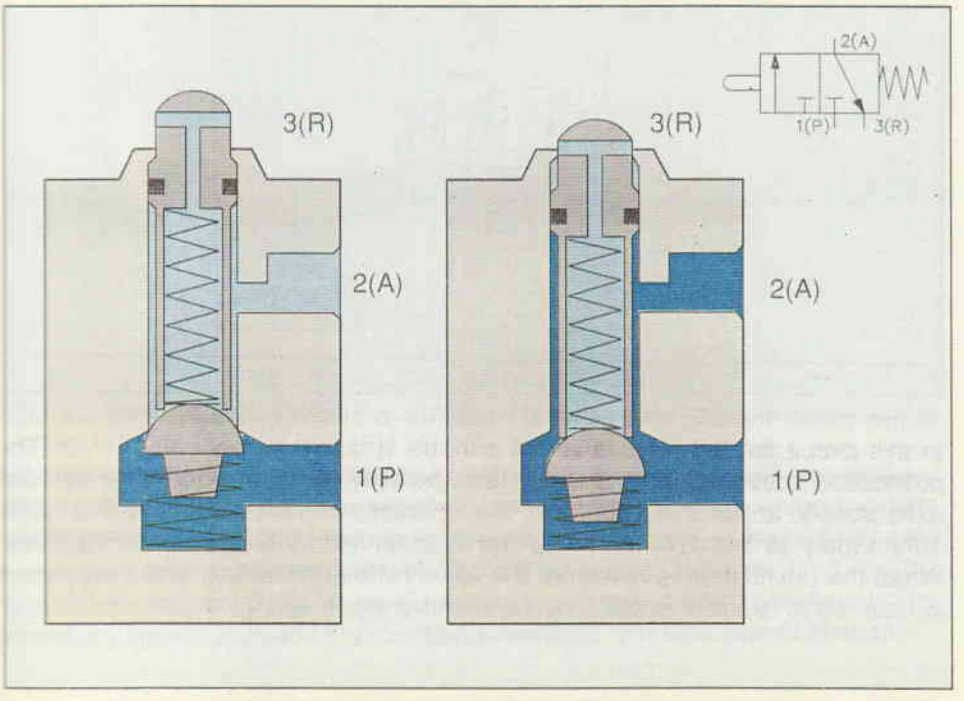
The 2/2 way valve has two ports and two positions. It is rarely used except as an on-off valve, since its only function is to enable signal flow through and cannot release the air to atmosphere once in the closed position.

If air is to be released on closing, then the 3/2 way valve must be used. The 2/2 way valve is normally of the ball seat construction similar to the 3/2 way valve. It is generally manually operated or pneumatically operated.

3.3 3/2 way valve

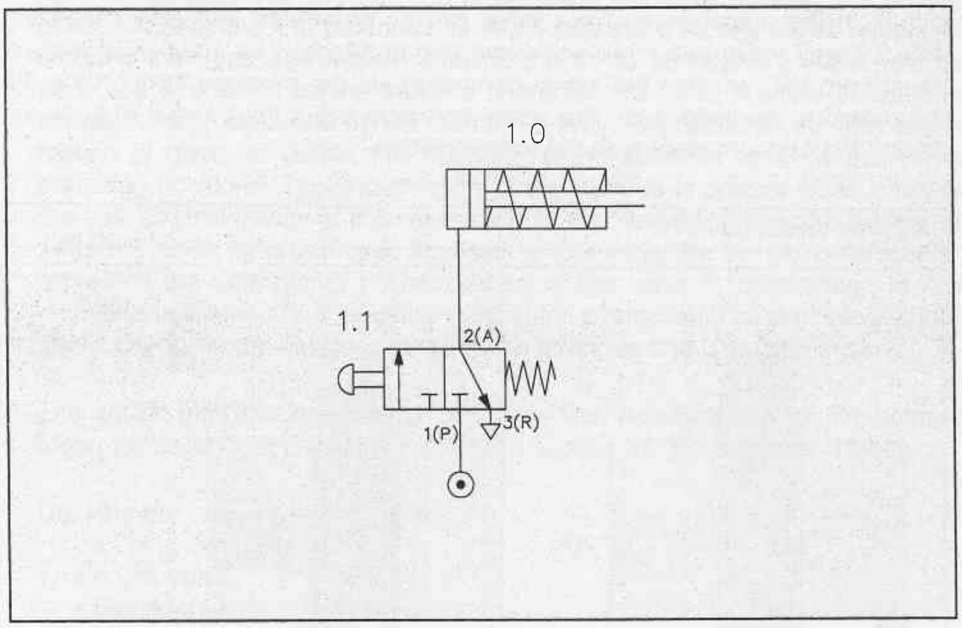
The 3/2 way valve is a signal generating valve, with the characteristic that a signal on the output side of the valve can be generated and also cancelled. The 3/2 way valve has three ports and two positions. The addition of the exhaust port 3(R) enables the signal generated via the passage through the 3/2 way valve to be cancelled. The valve connects the output signal 2(A) to exhaust 3(R) and atmosphere in the initial position.

3/2 way valve: ball seat



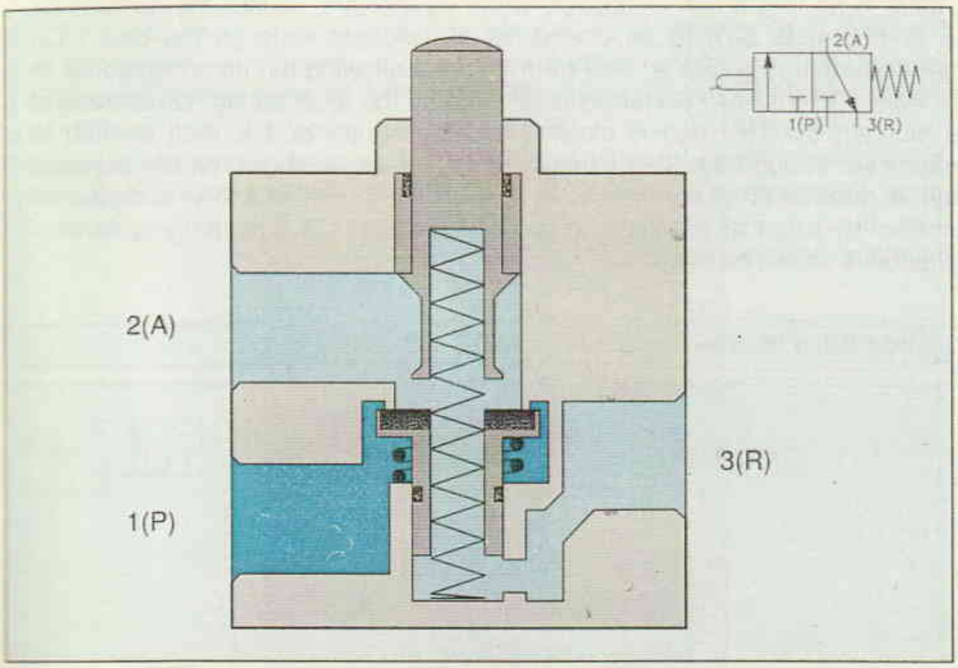
A spring forces a ball against the valve seat preventing the compressed air from flowing from the air connection 1(P) to the working line 2(A). Actuation of the valve plunger causes the ball to be forced away from the seat. In doing this, the opposing force of the reset spring and that generated from the compressed air must be overcome. The air supply is then open to the output side of the valve and a signal is generated. Once the plunger is released the 1(P) port is blocked and the output port 2(A) is exhausted up the stem of the plunger and the signal removed. The valve is actuated manually or mechanically in this case. A separate actuation head could be auxiliary mounted to the valve top to operate the plunger indirectly by pushbutton, roller or lever. The actuation force required is dependent on the supply pressure, spring force and the friction in the valve. The actuation force limits the feasible size of the valve and the cross-sectional area of the valve seat must be small. The construction of the ball seat valve is very simple and hence is relatively inexpensive. The distinguishing feature is the compact size achievable.

3/2 way valve controlling a single acting cylinder



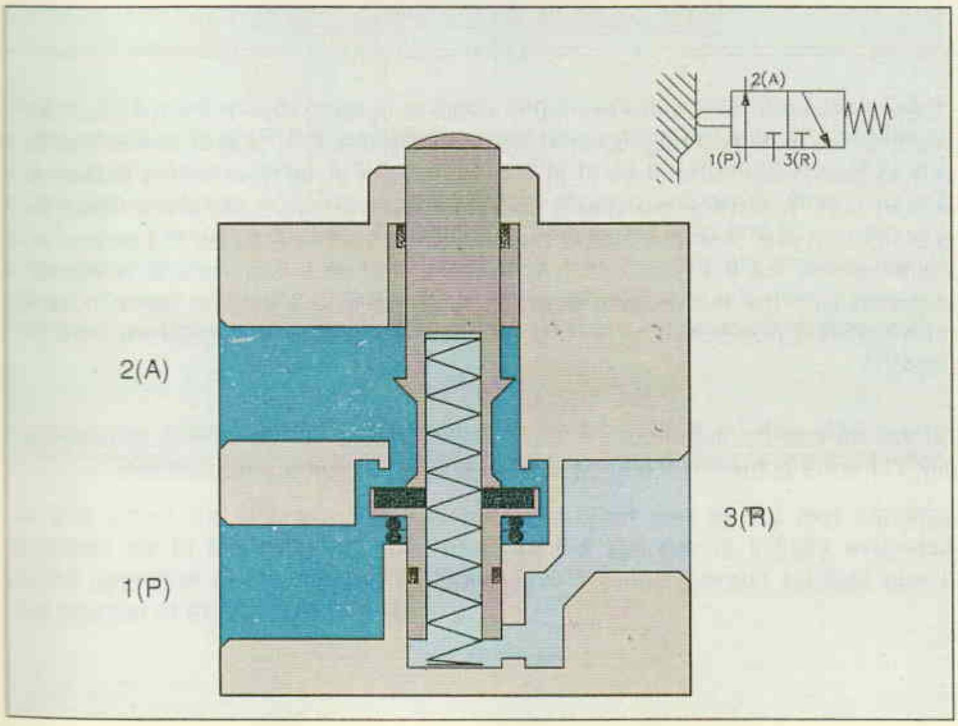
In this circuit the 3/2 way valve 1.1 controls a single acting cylinder 1.0. The pushbutton activated valve is at rest with the 1(P) port blocked and the cylinder exhausted to atmosphere via 3(R). The operation of the pushbutton diverts the 1(P) supply to the 2(A) port and the cylinder extends against spring force. When the pushbutton is released, the valve returns by spring, and the cylinder is returned to its initial position by the cylinder return spring.

3/2 way valve: disc seat normally closed, un-actuated



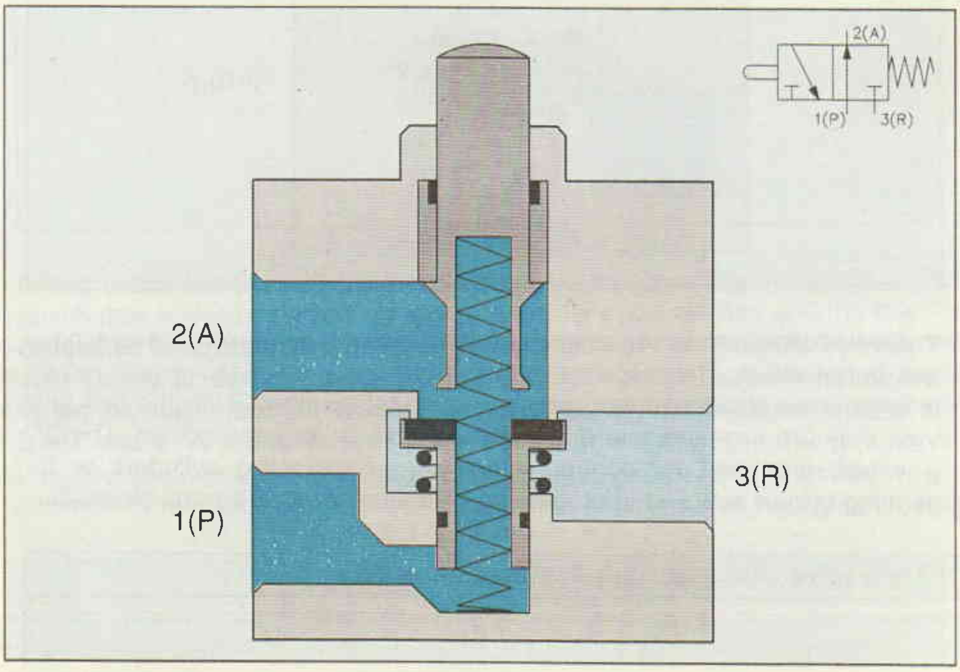
The valve shown here is constructed on the disc seat principle. The sealing is simple but effective. The response time is short and a small movement results in a large cross-sectional area being available for air flow. Like the ball seat valves, they are insensitive to dirt and thus have a long service life. The 3/2 way valves are used for controls employing single-acting cylinders or for generating signals supplied to processing elements and final control elements.

3/2 way valve: disc seat normally closed, actuated



Valves of the single disc seat type are non-overlapping. When operated slowly, there is no loss of air. Actuation of the plunger first causes the exhaust air line from 2(A) to 3(R) to be closed, as the plunger rests on the disc. On pressing further, the disc is lifted from the seat allowing the compressed air to flow from 1(P) to 2(A). Resetting is effected by the reset spring. On release of the plunger, the 1(P) port is blocked and the supply port is then opened to atmosphere through the 3(R) exhaust port. This valve, shown on the previous page, is referred to as normally closed, since the output side 2(A) is closed off from the 1(P) port at the initial, unactuated position. The normally open configuration is shown below.

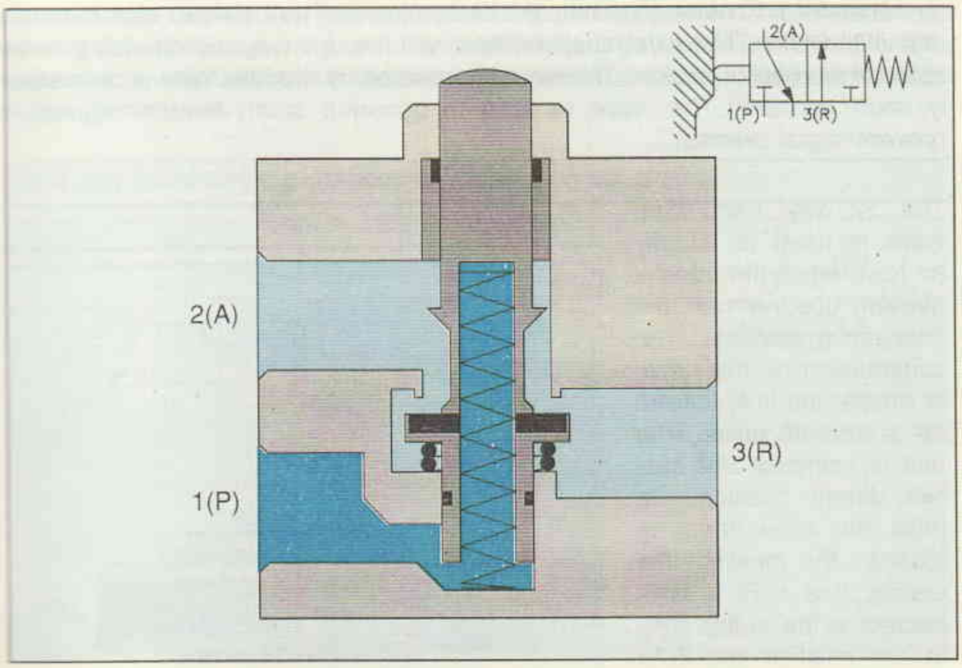
3/2 way valve: disc seat normally open, un-actuated



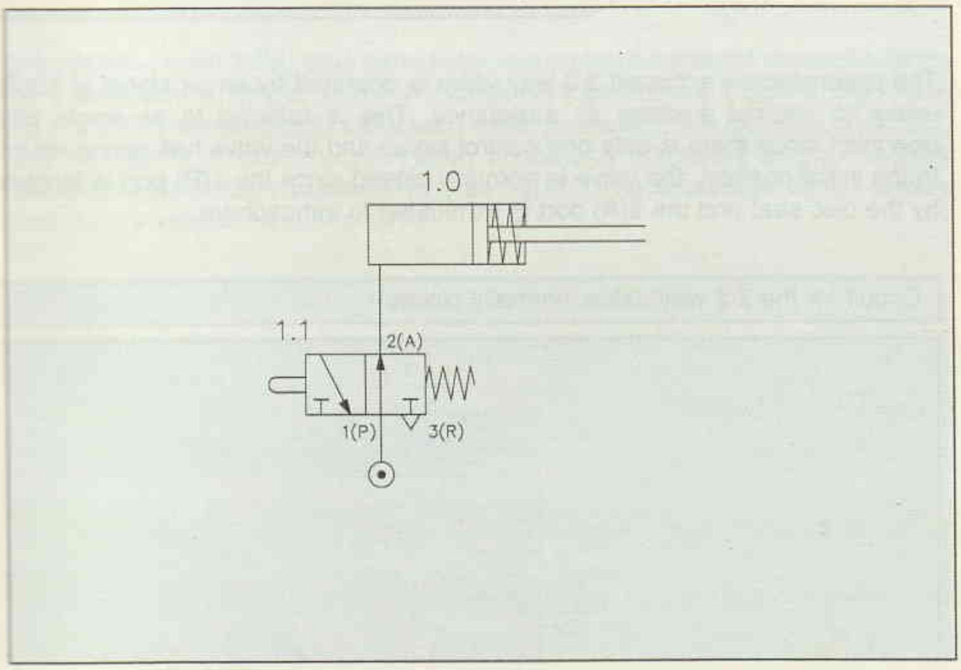
A 3/2 way valve in which the normal position is open to flow from 1(P) to 2(A), is referred to as a normally open valve. Initially the 1(P) port is connected to the 2(A) port through the stem of the valve and the valve disc seat is closed at the 3(R) port. When the plunger is operated, the 1(P) air is initially blocked by the stem seat and then the disc is pushed off its seat to exhaust the output air to atmosphere via the passage 2(A) to 3(R). When the plunger is released, the piston with the two sealing seats is returned to the initial position by the return spring. Once again the 3(R) port is blocked and air is supplied from 1(P) to 2(A).

The valves can be actuated manually, mechanically, electrically or pneumatically. Different actuation methods can be applied to suit the application.

3/2 way valve: disc seat normally open, actuated



Circuit diagram



In this circuit the 3/2 way valve is normally open and at the rest condition supplies air to the cylinder 1.0. Therefore the cylinder is initially extended. Upon operation of the manual 3/2 way valve 1.1, the cylinder retracts due to the release of air via 2(A) to 3(R).

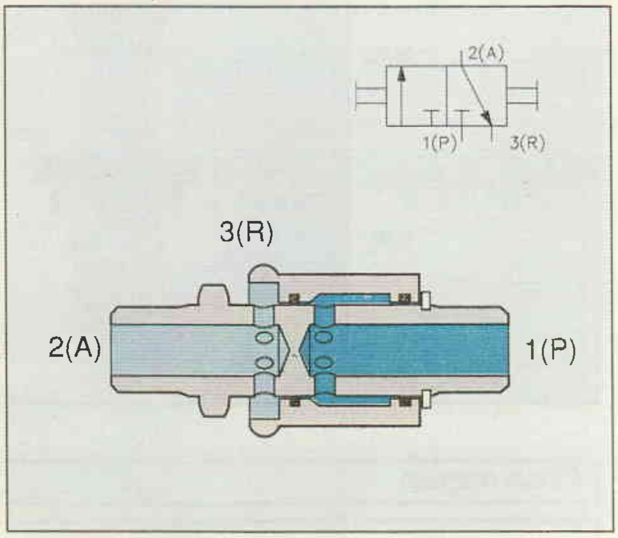
Roller lever valve with idle return

The idle roller lever valve is a one way trip valve. It is designed to operate in one direction of cam movement past the roller head. Therefore the valve must be situated just before the limit of cylinder travel. The cylinder cam overruns the limit switch. The valve must be fitted with the one way trip operating in the correct direction of motion. The signal generated by the idle roller is of relatively short duration. The valve is used to generate short duration signals to prevent signal overlap.

3/2 way hand slide valve

The 3/2 way hand slide valve is used to supply air to a leg of the supply network upstream of the consuming devices. The construction of this valve is simple and it is utilised as a shut-off valve. The unit is compact and has two detent positions to hold the valve open or closed. By moving the casing, line 1(P) is connected to the outlet 2(A) in one position and 2(A) with 3(R) in the other position which exhausts air from the network.

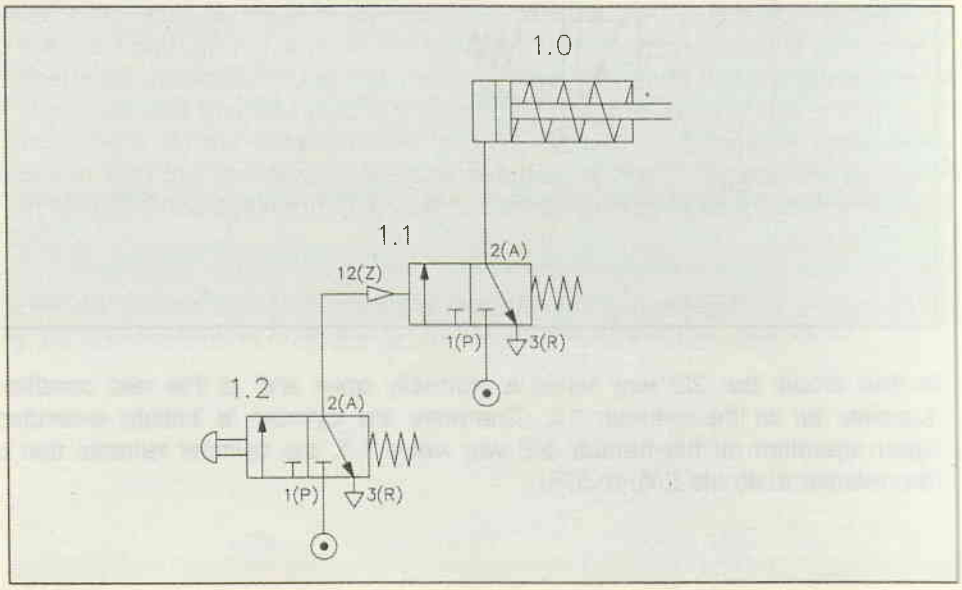
3/2 way hand slide valve



Pneumatically actuated : 3/2 way valve

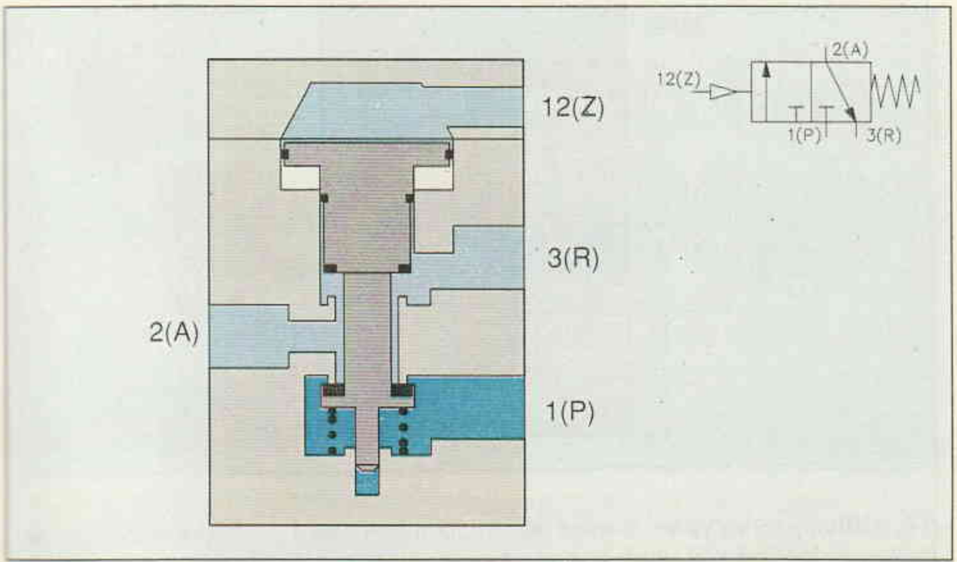
The pneumatically actuated 3/2 way valve is operated by an air signal at 12(Z), using no internal auxiliary air assistance. This is referred to as single pilot operation since there is only one control signal and the valve has spring return. In the initial position, the valve is normally closed since the 1(P) port is blocked by the disc seat and the 2(A) port is exhausted to atmosphere.

Circuit for the 3/2 way valve, normally closed



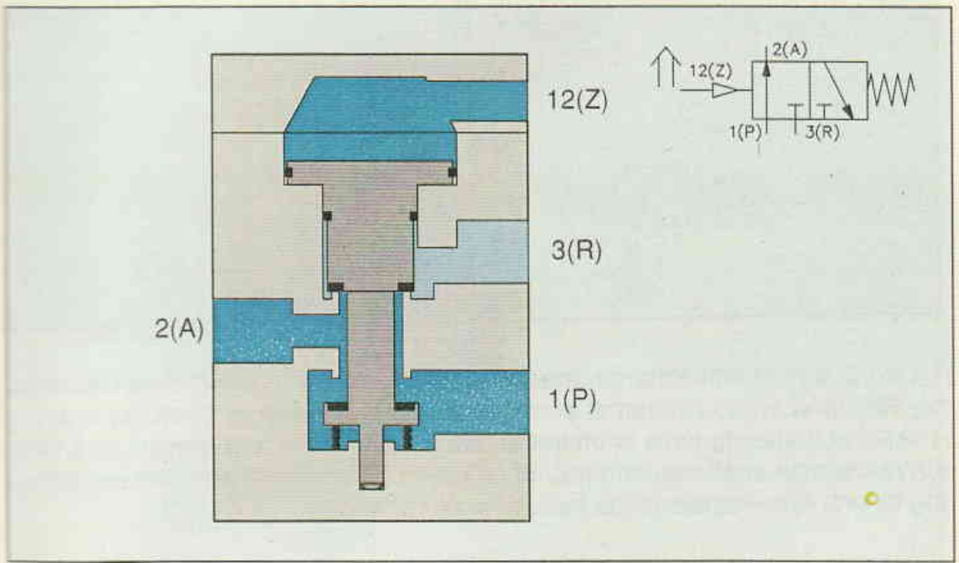
The pneumatically actuated valve can be used as a final control element, with indirect control. The signal for extension of the cylinder is initiated indirectly by a pushbutton valve 1.2 which supplies the control signal to the final control element 1.1. The valve 1.1 can be of relatively large size in comparison to the pushbutton signal element and the signal element can be fitted at a remote distance from valve 1.1.

3/2 way valve single pilot, normally closed, un-actuated



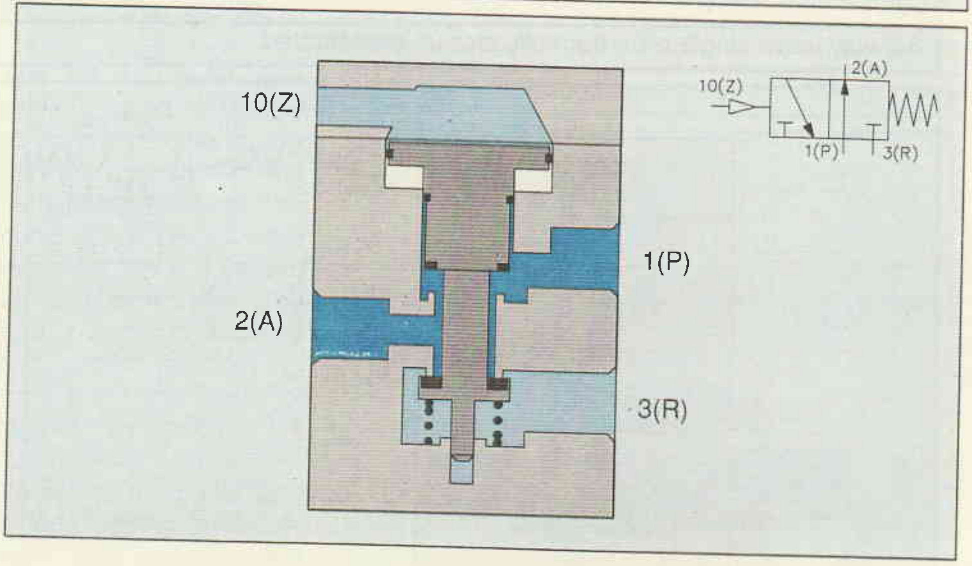
Air applied at the 12(Z) port moves the valve plunger against the reset spring. The connections 1(P) and 2(A) are connected generating a signal at port 2(A) and the 3(R) exhaust port is blocked. Upon release of the signal at port 12(Z), the pilot spool is returned to the initial position by the return spring. The disc closes the connection between 1(P) and 2(A). The excess air in the working line 2(A) is exhausted through 3(R).

3/2 way valve, single pilot, normally closed, actuated



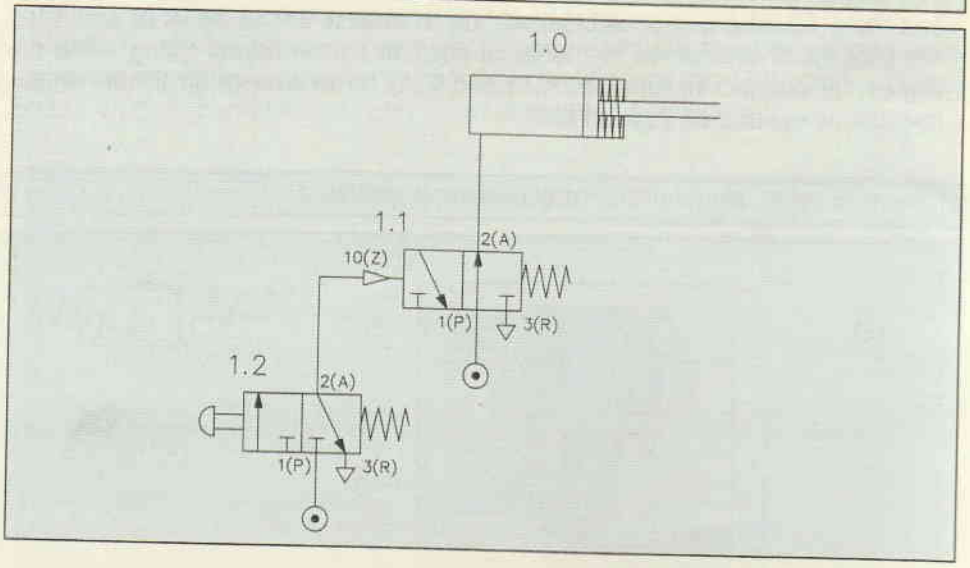
The single pilot 3/2 way valve can be configured as normally closed or as normally open. The ports have dual roles in which for the normally open function the 3(R) and 1(P) ports are interchanged. The head of the valve with port 12(Z) can be rotated 180^0.

3/2 way valve, single pilot, normally open



If a normally open valve is used at the position of valve 1.1, then the cylinder is initially extended and upon operation of the pushbutton, the cylinder retracts.

Circuit for the 3/2 way valve normally open, indirect

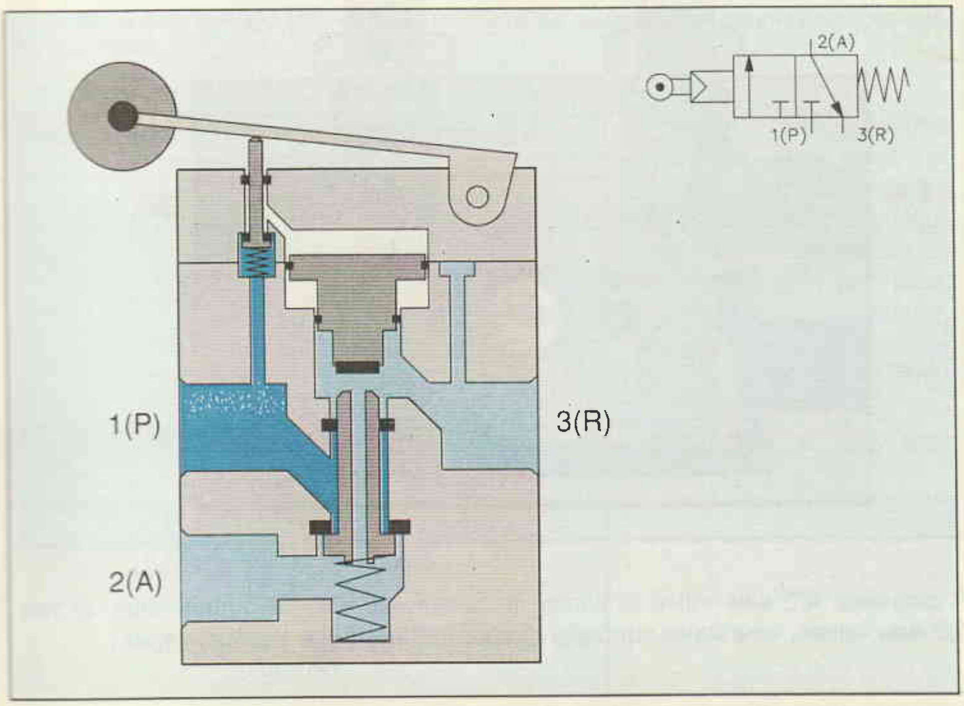


Servo controlled: 3/2 way roller lever valve

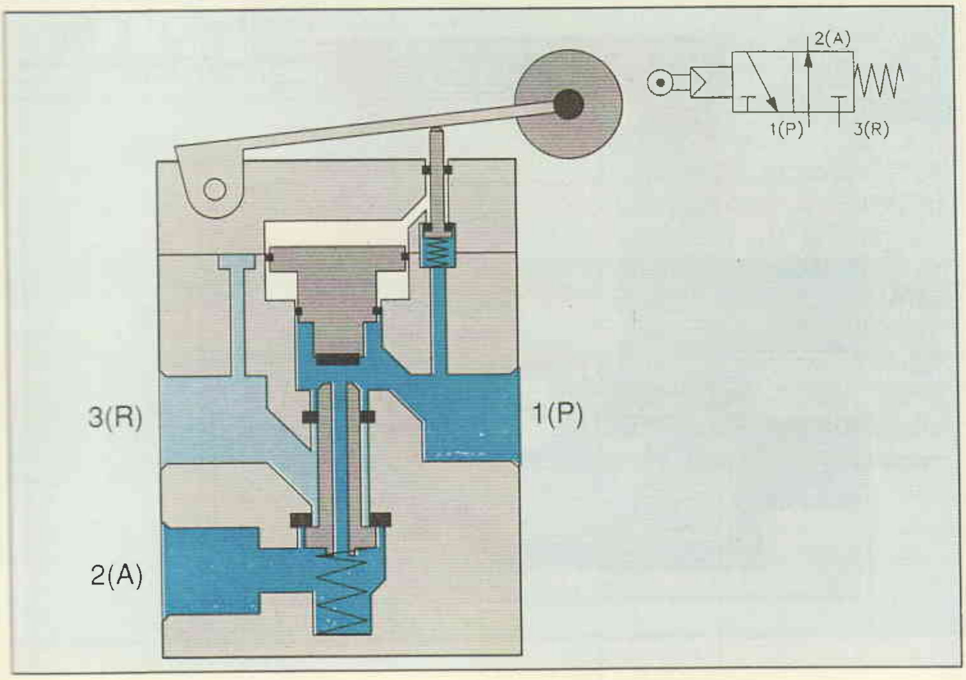
To avoid a high actuating force, mechanically controlled directional valves can be equipped with an internal pilot valve and servo piston to assist opening. The valve actuating force is often the determining factor in applications and the servo assistance allows for larger bore valves to be operated with small actuating forces. This increases the sensitivity of the system.

A small hole connects the pressure connection 1(P) and the pilot valve. If the roller lever is operated, the pilot valve opens. Compressed air flows to the servo piston and actuates the main valve disc. The first effect is the closing of the path 2(A) to 3(R) followed by the second disc seat opening the airway from 1(P) to 2(A). This type of valve can be used as either a normally closed valve or normally-open valve by changing ports and rotating the head.

3/2 way valve, internal pilot, normally closed



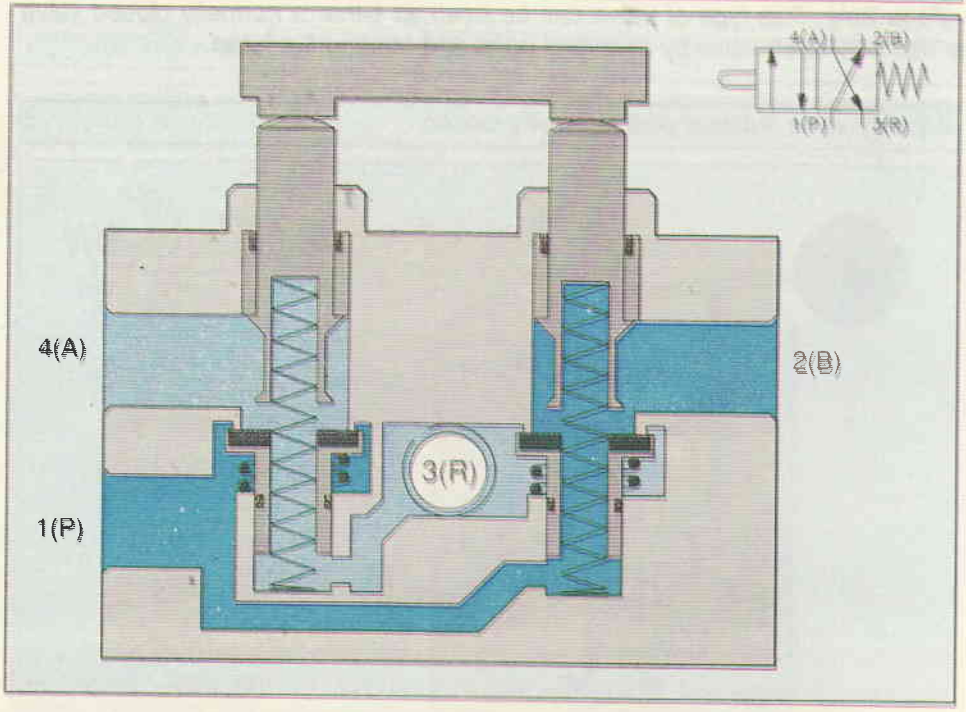
3/2 way valve, internal pilot, normally open



3.4 4/2 way valve

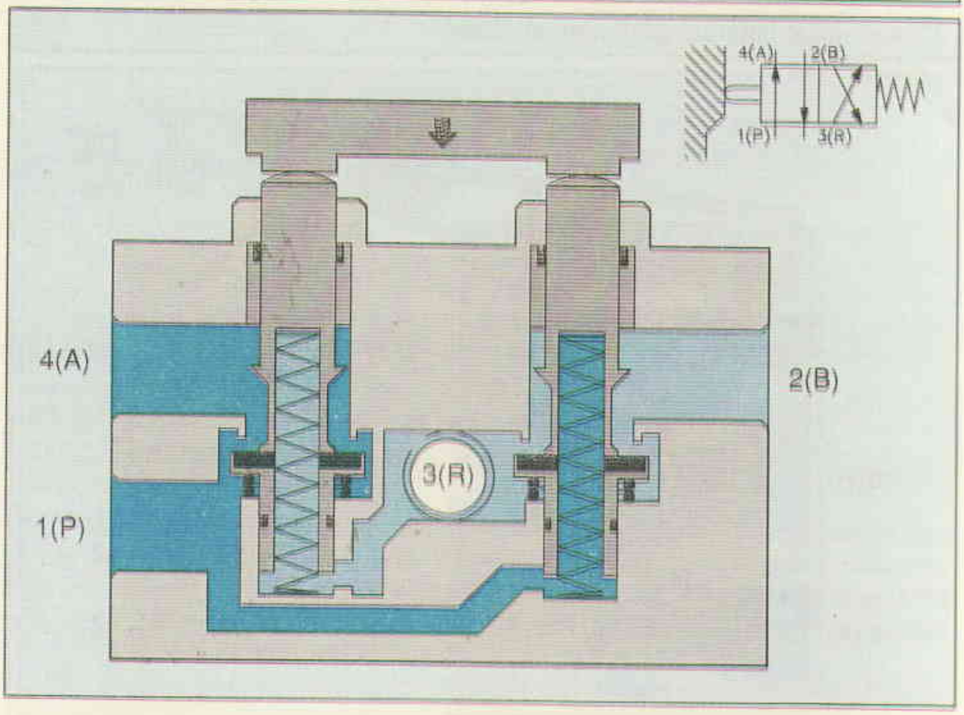
The 4/2 way valve has four ports and two positions.

4/2 way valve: disc seat, un-actuated



A disc-seat 4/2 way valve is similar in construction to the combination of two 3/2 way valves, one valve normally closed and the other normally open.

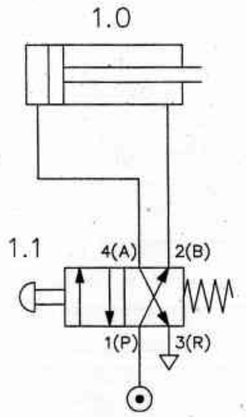
4/2 way valve: disc seat, actuated



When the two plungers are actuated simultaneously, 1(P) to 2(B) and 4(A) to 3(R) are closed by the first movement. By pressing the valve plungers further against the discs, opposing the reset spring force, the passages between 1(P) to 4(A) and from 2(B) to 3(R) are opened. The plungers can be operated by an auxiliary mounted device such as a roller arm or pushbutton.

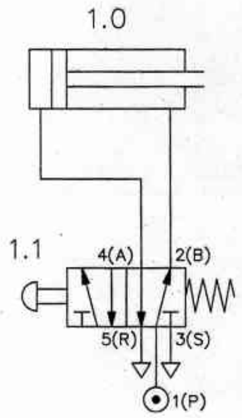
The valve has a non-overlapping exhaust connection and is returned to its start position by the spring. The valves are used for controls employing double-acting cylinders.

Circuit diagram: 4/2 way spring return valve



There are other actuating methods and types of construction available for the 4/2 way valve including pushbutton, single air pilot, double air pilot, roller lever actuated, spool and sliding plate. In the main, the 4/2 way valve is utilised in similar roles as the 5/2 way valve.

Circuit diagram: 5/2 way spring return valve

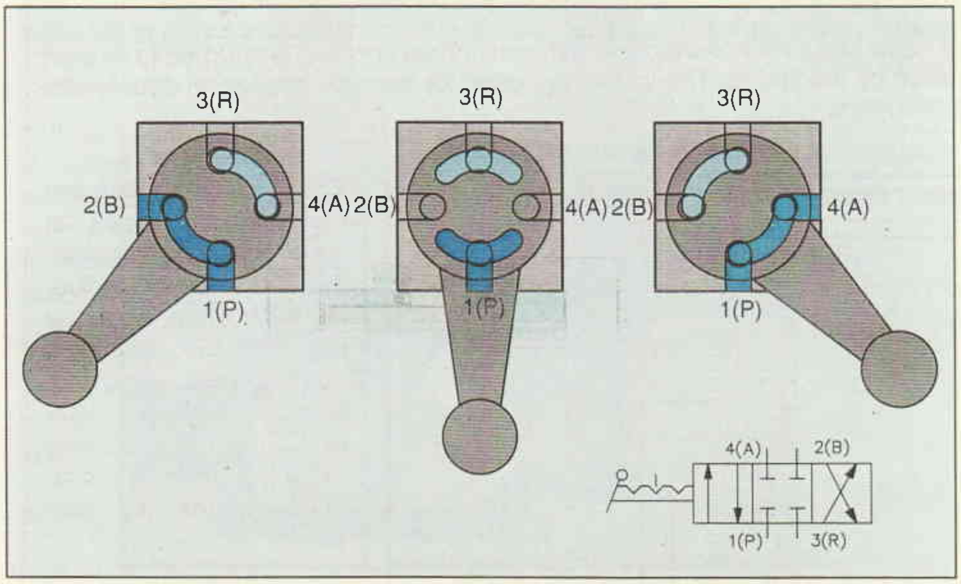


In general the 4/2 way valve is replaced by the 5/2 way valve. The 5/2 way valve has advantages in construction of passages and allowing the exhaust of both extension and retraction air for cylinders to be separately controlled. The 5/2 way valve circuit carries out the same primary control functions as the 4/2 way valve circuit.

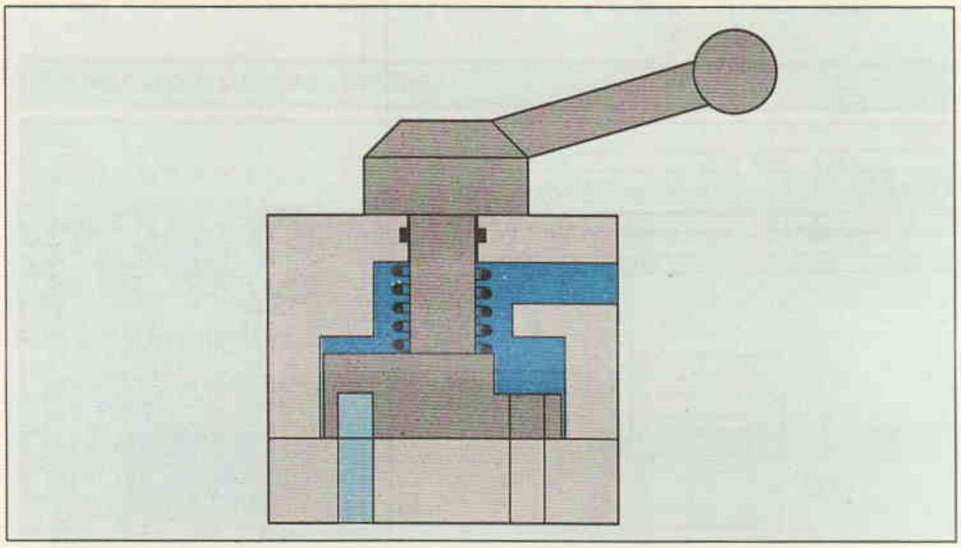
3.5 4/3 way valve

The 4/3 way valve has four ports and three positions. An example of the 4/3 way valve is the plate slide valve with hand or foot actuation. It is difficult to fit other means of actuation to these valves. By turning two discs, channels are connected with one another.

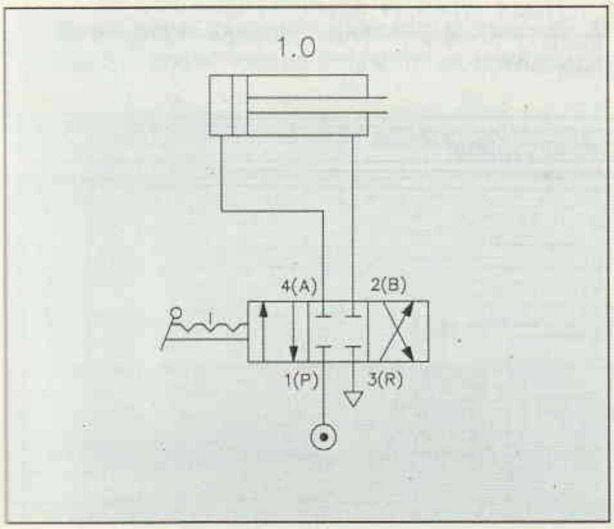
4/3 way plate slide valve, mid position closed



4/3 way plate slide valve, cross section



4/3 way valve circuit

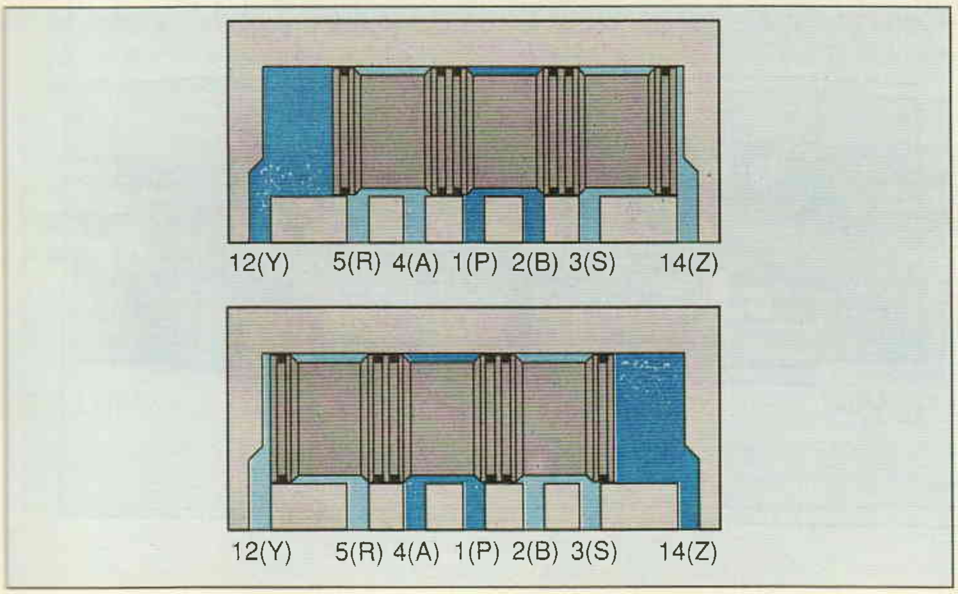


In this example the valve lines are closed in the middle position. This enables the piston rod of a cylinder to be stopped in any position over its range of stroke, although intermediate positions of the piston rod cannot be located with accuracy. Owing to the compressibility of air, another position will be assumed if the load on the piston rod changes.

3.6 5/2 way valve

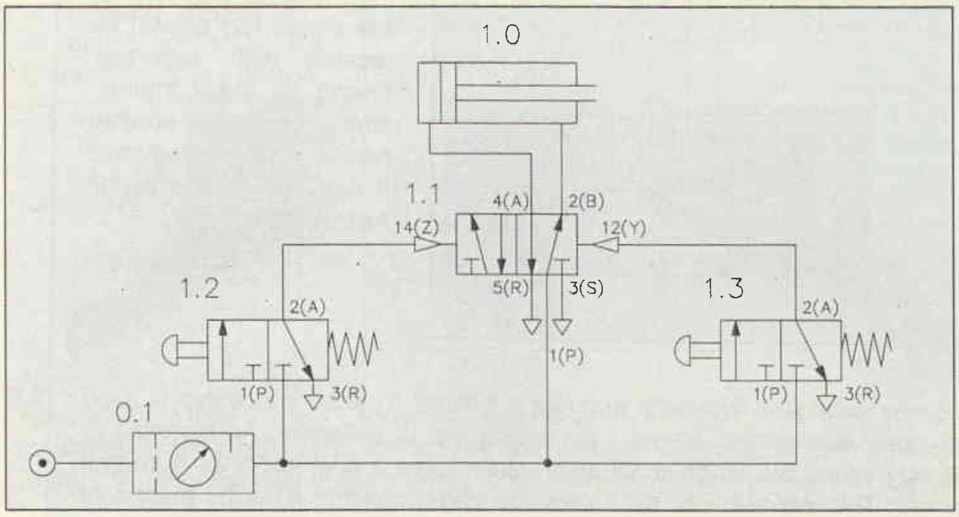
The 5/2 way valve has five ports and two positions. The 5/2 way valve is used primarily as a final control element for the control of cylinders. An example of the 5/2 way valve, the longitudinal slide valve, uses a pilot spool as a control component. This connects or separates the corresponding lines by means of longitudinal movements. The required actuating force is lower because there are minimal opposing forces due to compressed air or spring. Sealing presents a problem in this type of slide valve. The type of fit known in hydraulics as metal to metal, requires the spool to fit precisely in the bore of the housing. In pneumatic valves, the gap between spool and housing bore should not exceed 0.002-0.004 mm, as otherwise the leakage losses will be too great. To save these expensive fitting costs, the spool is often sealed with 0-rings or double-cup packings or the bore of the housing is sealed with 0-rings. To avoid damaging the seals, the connecting ports can be distributed around the circumference of the spool housing.

5/2 way valve: longitudinal slide principle



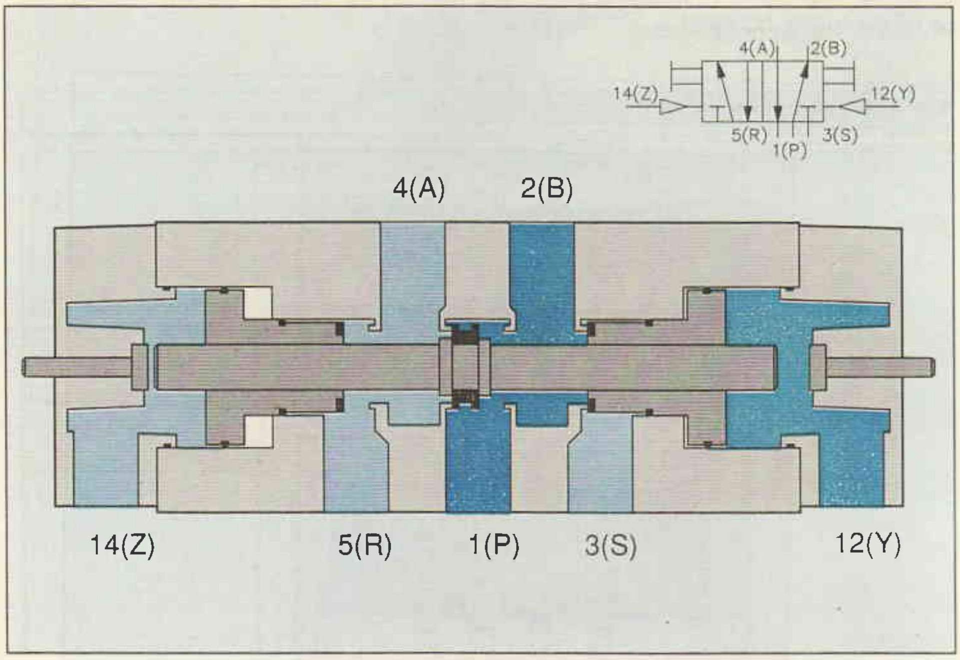
All forms of actuation can be used with longitudinal slide valves, i.e. manual, mechanical, electrical or pneumatic. These types of actuation can also be used for resetting the valve to its starting position. The actuation travel is considerably larger than with seat valves.

Circuit: 5/2 way valve and double acting cylinder



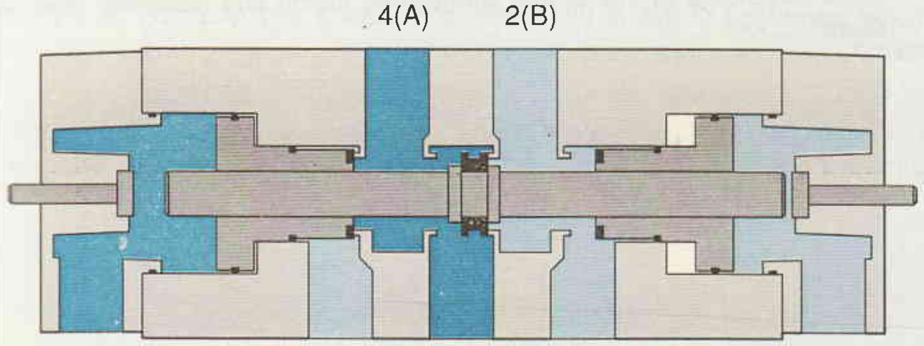
Another method of sealing is to use a suspended disc seat with relatively small switching movement. The disc seat seal connects the 1(P) port to either the 2(B) port or the 4(A) port. The secondary seals on the spool pistons connect the exhaust ports to the outlet ports. There is a manual override button at each end to manually operate the valve spool.

5/2 suspended disc seat, position 1



The 5/2 way double air pilot valve has the characteristic of memory control. The last switched position is retained until a new switching position is initiated by a unique pilot signal from the opposite side to the last signal. This new position is memorised until another unique signal occurs.

5/2 suspended disc seat, position 2



3.7 Reliable operation of valves

Mounting of roller lever valves:
The reliability of a control sequence is heavily dependent upon the correct fitting of the limit valves. For all designs of limit valves the mounting must allow simple adjustment or readjustment of the limit valve position in order to achieve precise co-ordination of the cylinder motions within a control sequence.

Fitting of valves:
Apart from a careful selection of valves, correct fitting is a further prerequisite for reliable switching characteristics, trouble-free operation and easy access for repair and maintenance work. This applies both to valves in the power section and valves in the control section.

Manually-actuated valves for signal input are generally fitted on a control panel or control desk. It is therefore practical and convenient to use valves with actuators that can be fitted onto the basic valve. Various actuators are available for a wide variety of input functions.

When fitting control valves, particular care should be taken to provide accessibility for repair, extension or modification work. Numbering the components and utilising visual indicators for the most important control signals reduces fault finding and down times considerably.

Power valves have the task of actuating pneumatic drives in accordance with a specified control sequence. A basic requirement for power valves is to allow rapid reversal of the actuator once the control signal has been triggered. The power valve should therefore be positioned as closely as possible to the actuator in order to keep line lengths, and thus switching times, as short as possible. Ideally, the power valve should be fitted directly to the drive. An additional advantage of this is that connectors, tubing and assembly time can be saved.

Chapter 4

Valves

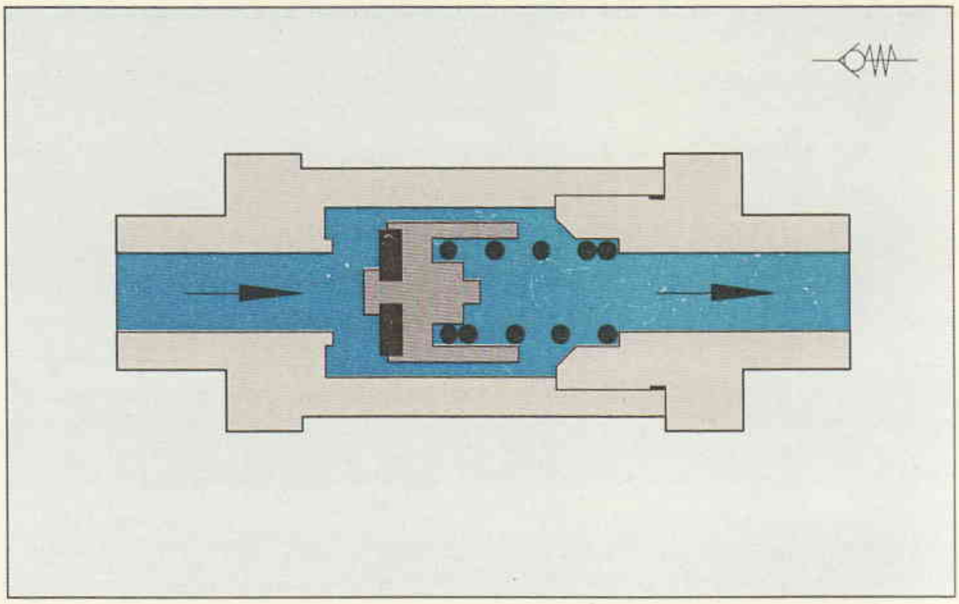
4.1 Non-return valves

Non-return valves are devices which preferentially stop the flow in one direction and permit flow in the opposite direction. The pressure on the downstream side acts against the restrictive component, thereby assisting the sealing effect of the valve.

Check valves

Check valves can stop the flow completely in one direction. In the opposite direction the flow is free with a minimal pressure drop due to the resistance of the valve. Blocking of the one direction can be effected by cones, balls, plates or diaphragms.

Check valve

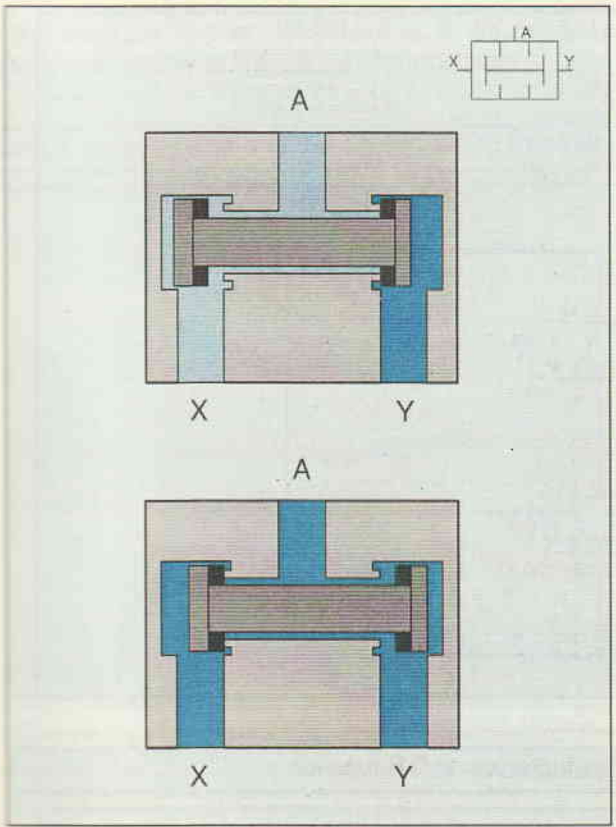


Junction elements

Elements fitted at a three way junction which have non-return characteristics direct the movement of signal air. The two valves here referred to as junction elements have logic characteristics which determine the passage of two input signals. The two pressure valve requires two signals (AND function) to produce an output and the shuttle valve requires at least one signal input (OR function) to produce an output. These are processing elements whereby two signals are processed internally and the resulting signal is output at port A.

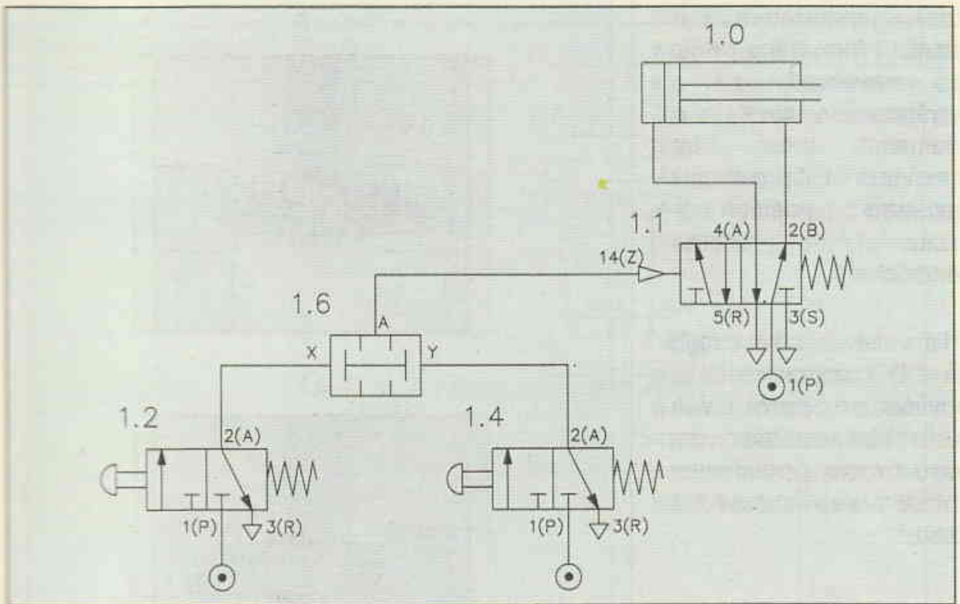
Two pressure valve: logic AND function

Two pressure valve: AND function



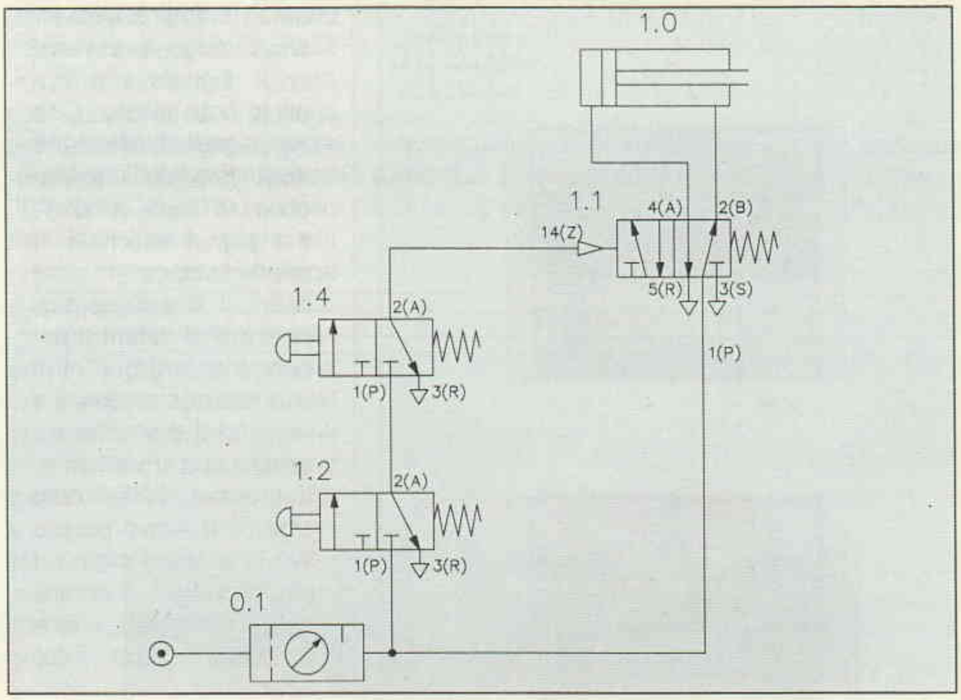
The two pressure valve has two inlets and one outlet. Compressed air flows through the valve only if signals are applied to both inlets. One input signal blocks the flow. If signals are applied to both X and Y, the signal which is last applied passes to the outlet. If the input signals are of different pressures, the larger of the two pressures closes the valve and the smaller air pressure is transferred to the outlet as an output signal. The two pressure valve is used mainly for interlocking controls, safety controls, check functions and logic operations.

Circuit: two pressure valve



The two pressure valve circuit is equivalent to the two input signalling devices in series, i.e. one after the other. The signal output is passed all the way through only if both signal elements are operated.

Circuit: series AND function

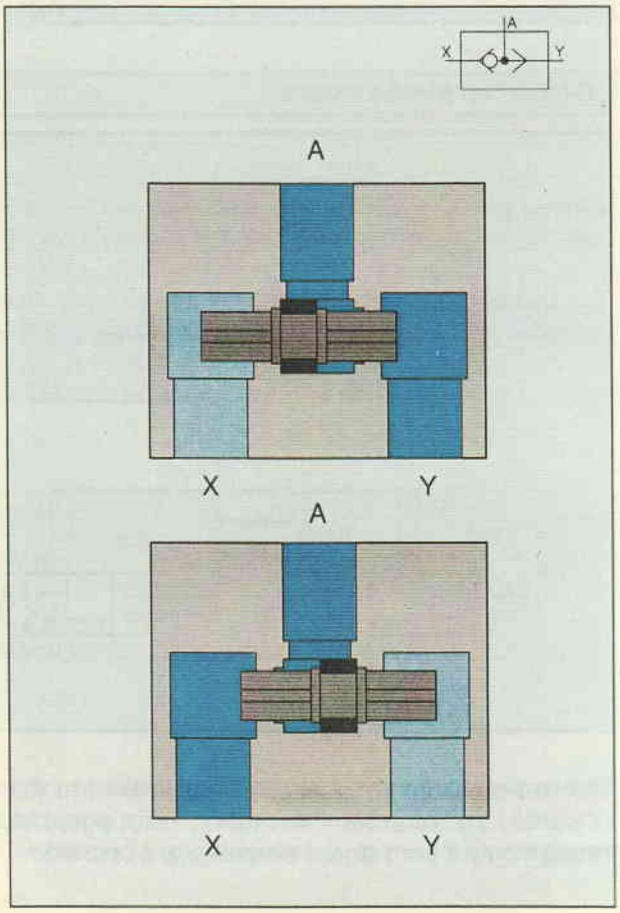


Shuttle valve: logic OR function

This non-return element has two inlets and one outlet. If compressed air is applied to the first inlet, the valve seat seals the opposing inlet. A signal is generated at the outlet. When the air flow is reversed, i.e. a cylinder or valve is exhausted, the seat remains in its previously assumed position because of the pressure conditions.

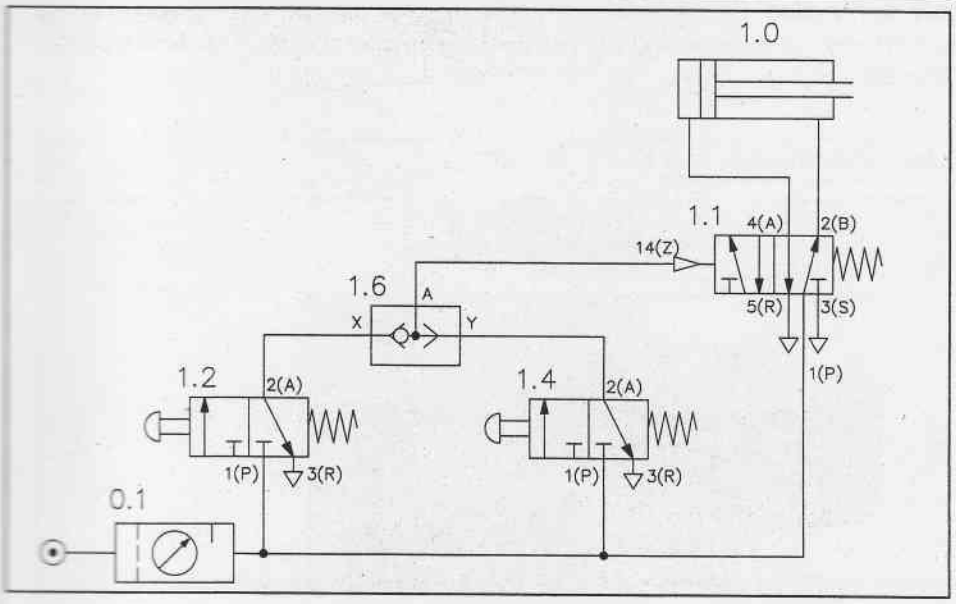
This valve is also called an OR component. If a cylinder or control valve is to be actuated from two or more positions, a shuttle valve should be used.

Shuttle valve: OR function



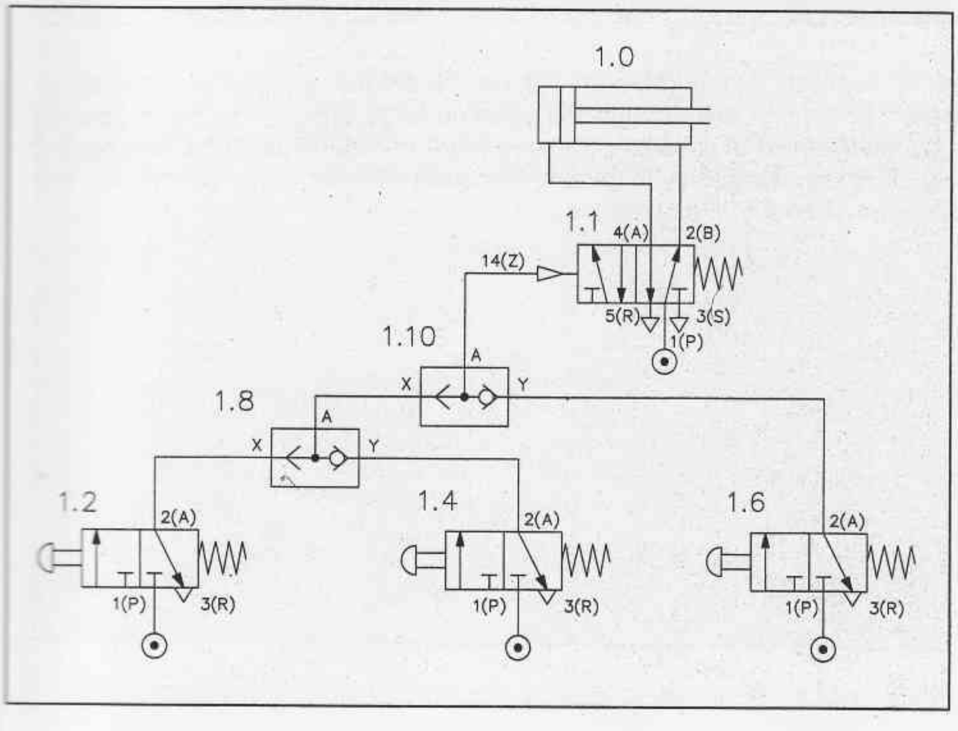
In the example shown, a cylinder is to be advanced using a hand operated valve either locally or from a remote position.

Circuit: shuttle valve and the double acting cylinder



Shuttle valves can be linked to create additional logic OR conditions e.g. as shown below: if any of three pushbuttons are operated, the cylinder 1.0 is to extend.

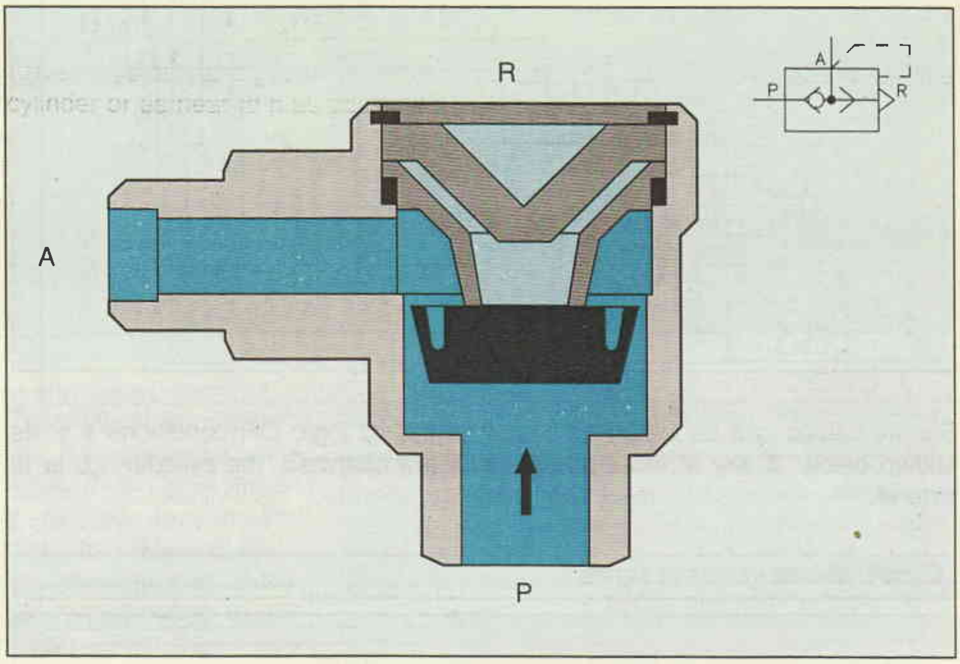
Circuit: shuttle valves in series



Quick exhaust valve

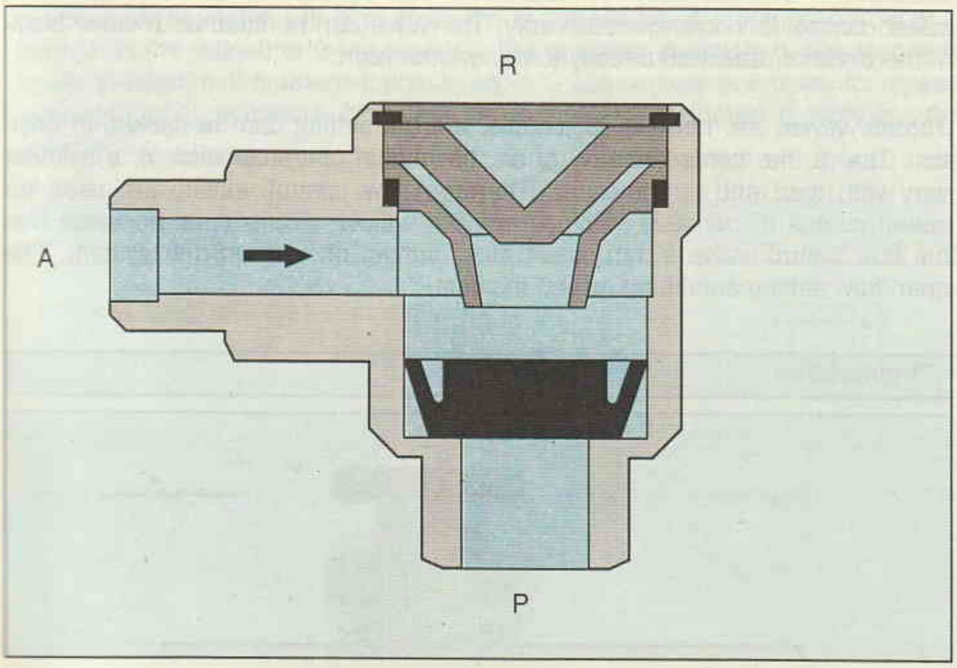
Quick-exhaust valves are used to increase the piston speed of cylinders. This enables lengthy return times to be avoided, particularly with single-acting cylinders. The principle of operation is to allow the cylinder to retract or extend at its near maximum speed by reducing the resistance to flow of the exhausting air during motion of the cylinder. To reduce resistance, the air is expelled to atmosphere close to the cylinder via a large orifice opening. The valve has a supply connection (P) and an outlet (A). In this direction of flow the air is passed freely via the opening of the check valve component. Port R is blocked by the disc.

Quick exhaust valve, flow to the cylinder

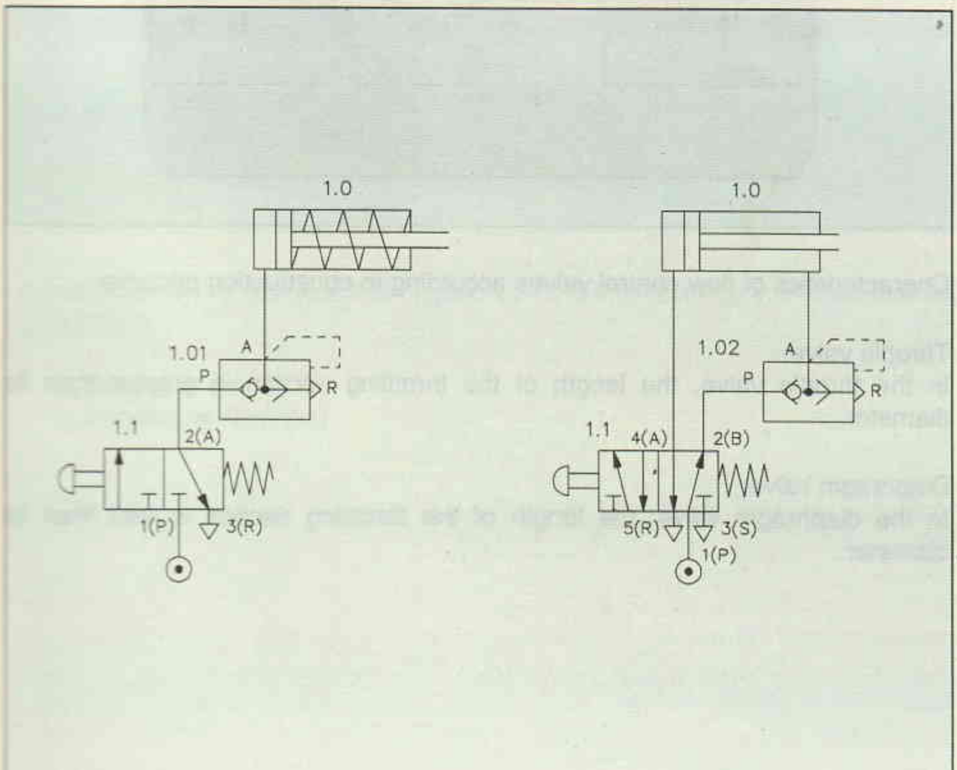


If air is supplied to the (A) port, the disc seals the (P) port and the air is expelled to atmosphere through the silenced large orifice (R). This increases the potential speed of exhaust compared with the exhaust port of a final control valve. It is advantageous to mount the quick-exhaust valve directly on the cylinder or as near to it as possible.

Quick exhaust valve, exhaust from the cylinder



Circuits: quick exhaust valve



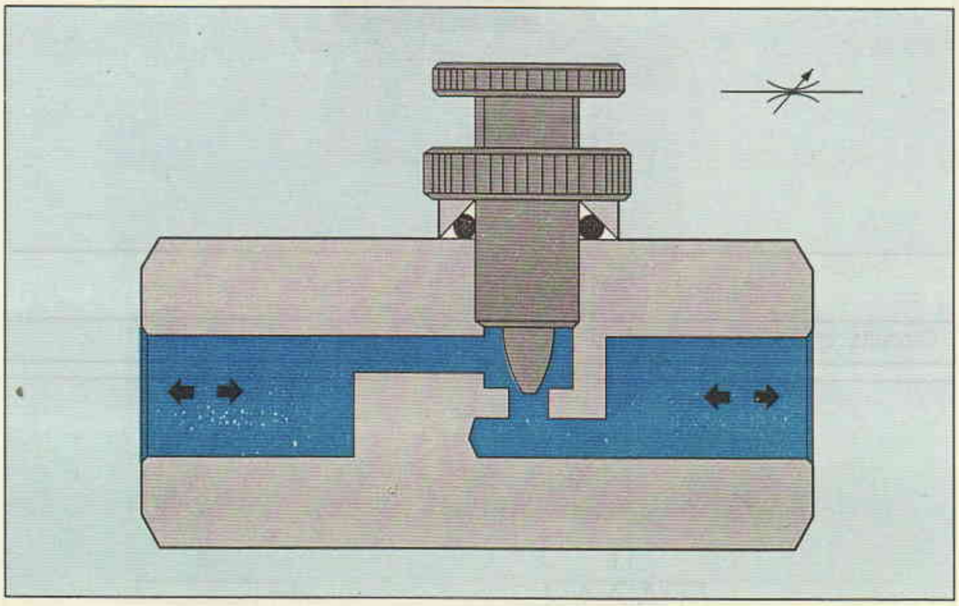
4.2 Flow control valves

Flow control valves influence the volumetric flow of the compressed air in both directions. If a check valve is fitted to the flow control valve, the influence of speed control is in one direction only. The valve can be fitted as a valve block in the circuit or attached directly to the cylinder port.

Throttle valve, bi-directional

Throttle valves are normally adjustable and the setting can be locked in position. Due to the compressibility of air, the motion characteristics of a cylinder vary with load and air pressure. Therefore flow control valves are used for speed control of cylinders within a range of values. Care must be taken that the flow control valve is not closed fully, cutting off air from the system. The open flow setting should be locked in place.

Throttle valve



Characteristics of flow control valves according to construction principle:

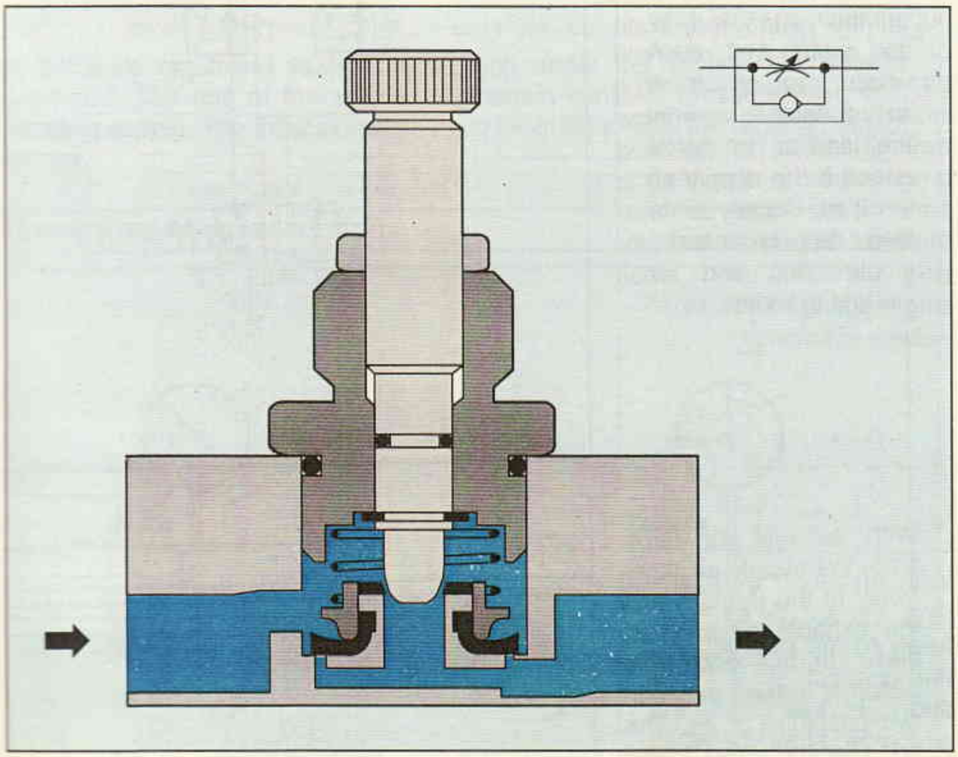
Throttle valve:
In the throttle valve, the length of the throttling section is greater than its diameter.

Diaphragm valve:
In the diaphragm valve, the length of the throttling section is less than its diameter.

One way flow control valve

The throttling device shown here is commonly known as a one way flow control valve. With this type of valve, the air flow is throttled in one direction only. A check valve blocks the flow of air in the bypass leg and the air can flow only through the regulated cross-section. In the opposite direction, the air can flow freely through the opened check valve. These valves are used for speed regulation of actuators and if possible, should be mounted directly on the cylinder.

One way flow control valve



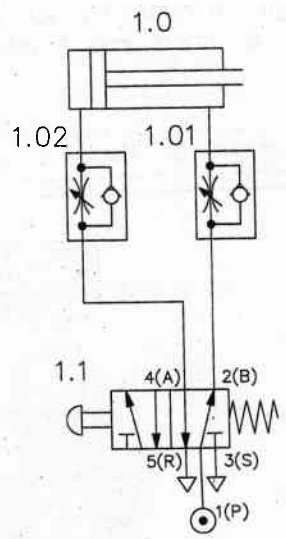
Fundamentally, there are two types of throttling circuits for double-acting cylinders:

- Supply air throttling
- Exhaust air throttling

Supply air throttling

For supply air throttling, one way flow control valves are installed so that the air entering the cylinder is throttled. The exhaust air can escape freely through the check valve of the throttle valve on the outlet side of the cylinder. The slightest fluctuations in the load on the piston rod, such as occur for example when passing a limit switch, lead to very large irregularities in the feed speed if the supply air is throttled. Supply air throttling can be used for single-acting and small volume cylinders.

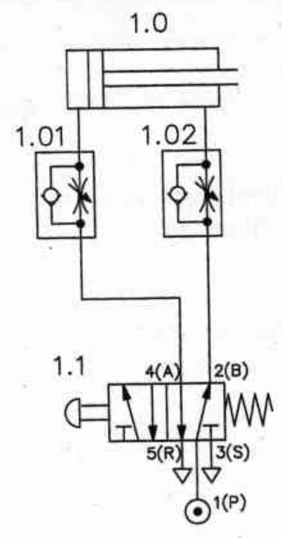
Supply air throttling



Exhaust air throttling

With exhaust air throttling, the supply air flows freely to the cylinder and the exhaust air is throttled. In this case, the piston is loaded between two cushions of air. The first cushion effect is the supply pressure to the cylinder and the second cushion is the exhausting air being restricted at the one way flow control valve orifice. Arranging throttle relief valves in this way contributes substantially to the improvement of feed behaviour. Exhaust air throttling should be used for double acting cylinders.

Exhaust air throttling



4.3 Pressure valves

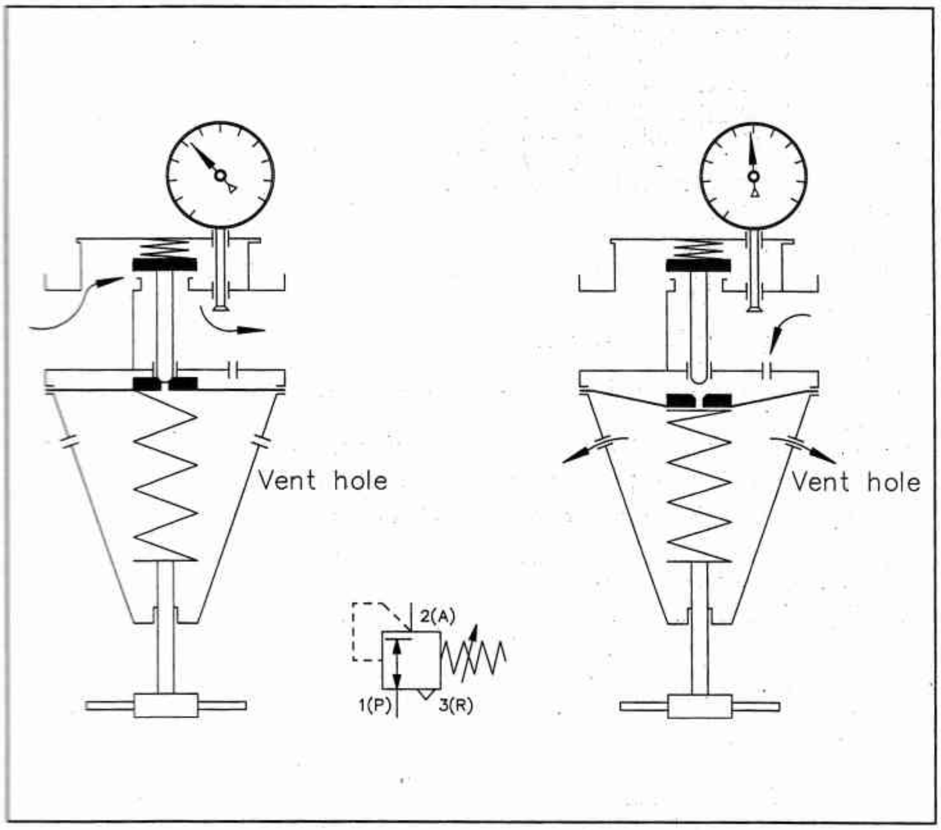
Pressure control valves are elements which predominantly influence the pressure or are controlled by the magnitude of the pressure. They are divided into the three groups:

- Pressure regulating valve
- Pressure limiting valve
- Sequence valve

B 2.4

The pressure regulating valve is dealt with under the section "Air Service Equipment". The role of this unit is to maintain constant pressure even with fluctuating supply. The input pressure must be greater than the required output pressure.

Pressure regulating valve



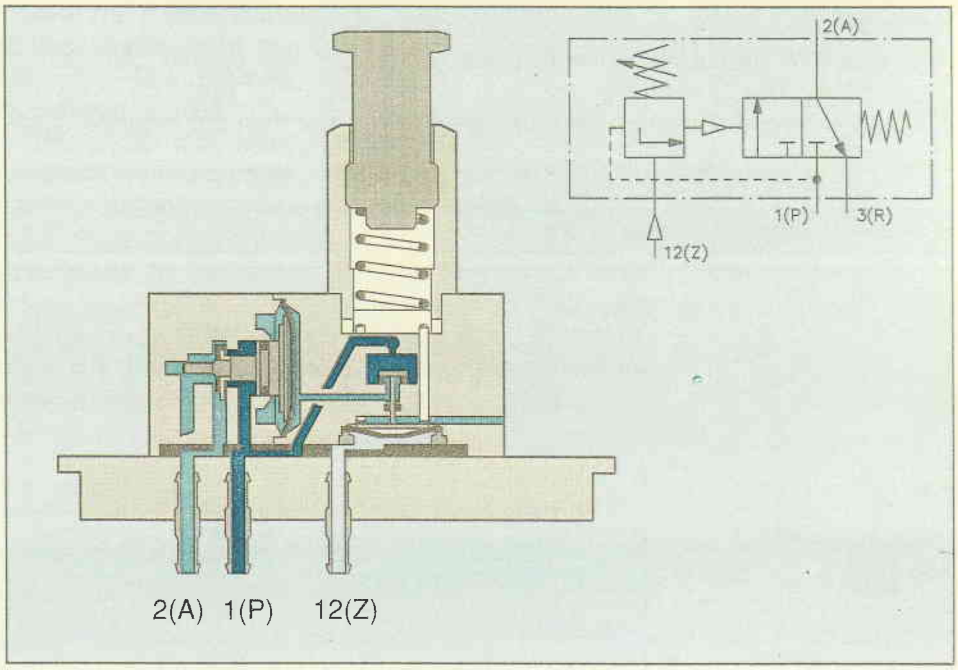
Pressure limiting valve

The pressure limiting valves are used mainly as safety valves (pressure relief valves). They prevent the maximum permissible pressure in a system from being exceeded. If the maximum pressure has been reached at the valve inlet, the valve outlet is opened and the excess air pressure exhausts to atmosphere. The valve remains open until it is closed by the built-in spring after reaching the preset system pressure.

Sequence valve

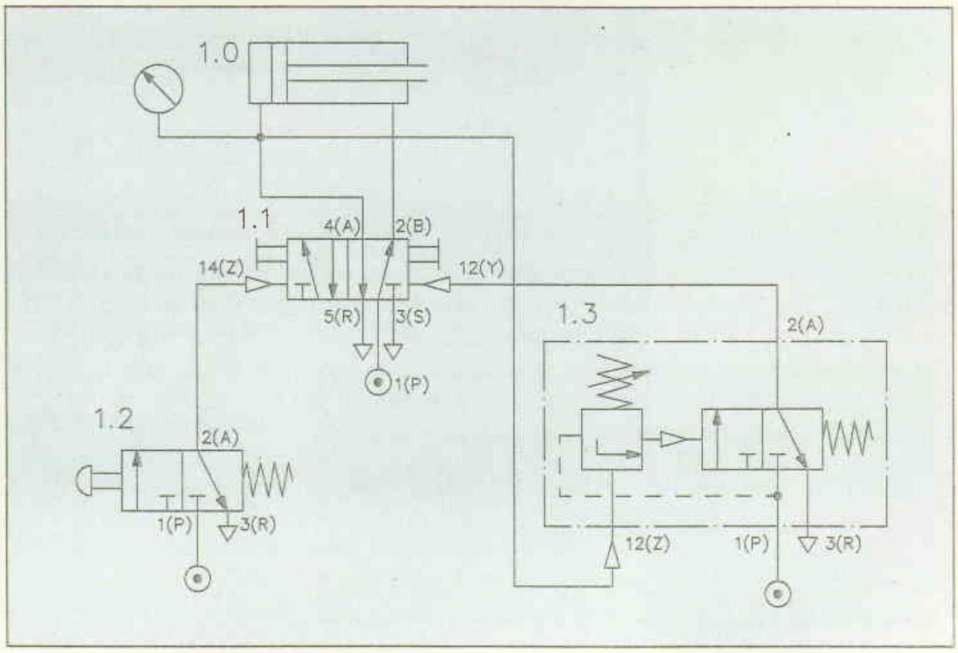
The principle on which this valve acts is the same as for the pressure limiting valve. If the pressure exceeds that set on the spring, the valve opens. The air flows from 1(P) to 2(A). Outlet 2(A) is opened only if a preset pressure has built up in pilot line 12(Z). A pilot spool opens the passage 1(P) to 2(A).

Adjustable pressure sequence valve



Sequence valves are installed in pneumatic controls where a specific pressure is required for a switching operation (pressure-dependent controls). The signal is transmitted only after the required operating pressure has been reached.

Circuit: sequence valve operation



4.4 Combinational valves

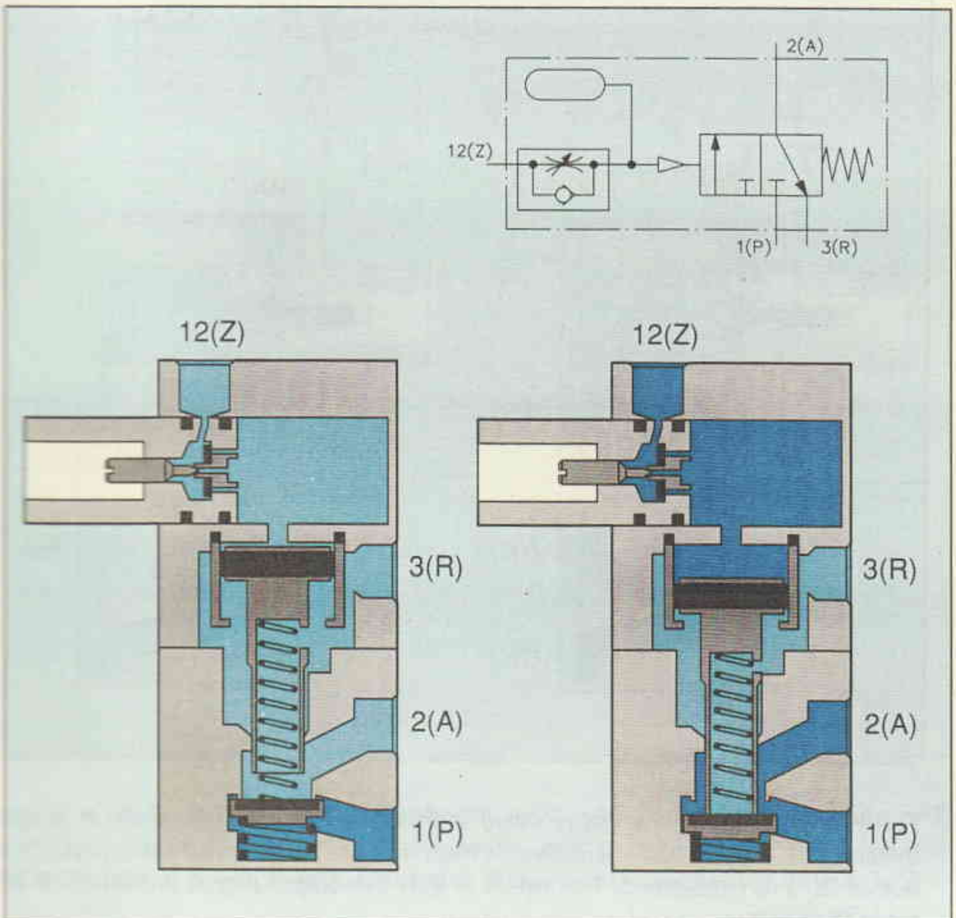
Components of different control groups can be combined into the body of one unit with the features, characteristics and construction of a combination of valves. These are referred to as combinational valves and their symbols represent the various components that make up the combined unit. The following units can be defined as combinational valves:

- Time delay valves : for the delay of signals
- Air control blocks : for reversing or oscillating cycles
- 5/4 way valve : consisting of four 2/2 way valves
- Air operated 8 way valve : two 4/2 way valve combinations
- Impulse generator : multi-vibrator cycles
- Vacuum generator with ejector : for pick and place applications
- Stepper modules : for sequential control tasks
- Command memory modules : for startup with signal input conditions

Timers

The time delay valve is a combined 3/2 way valve, one way flow control valve and air reservoir. The 3/2 way valve can be a valve with normal position open or closed. The delay time is generally 0-30 seconds for both types of valves. By using additional reservoirs, the time can be extended. An accurate switch-over time is assured, if the air is clean and the pressure relatively constant.

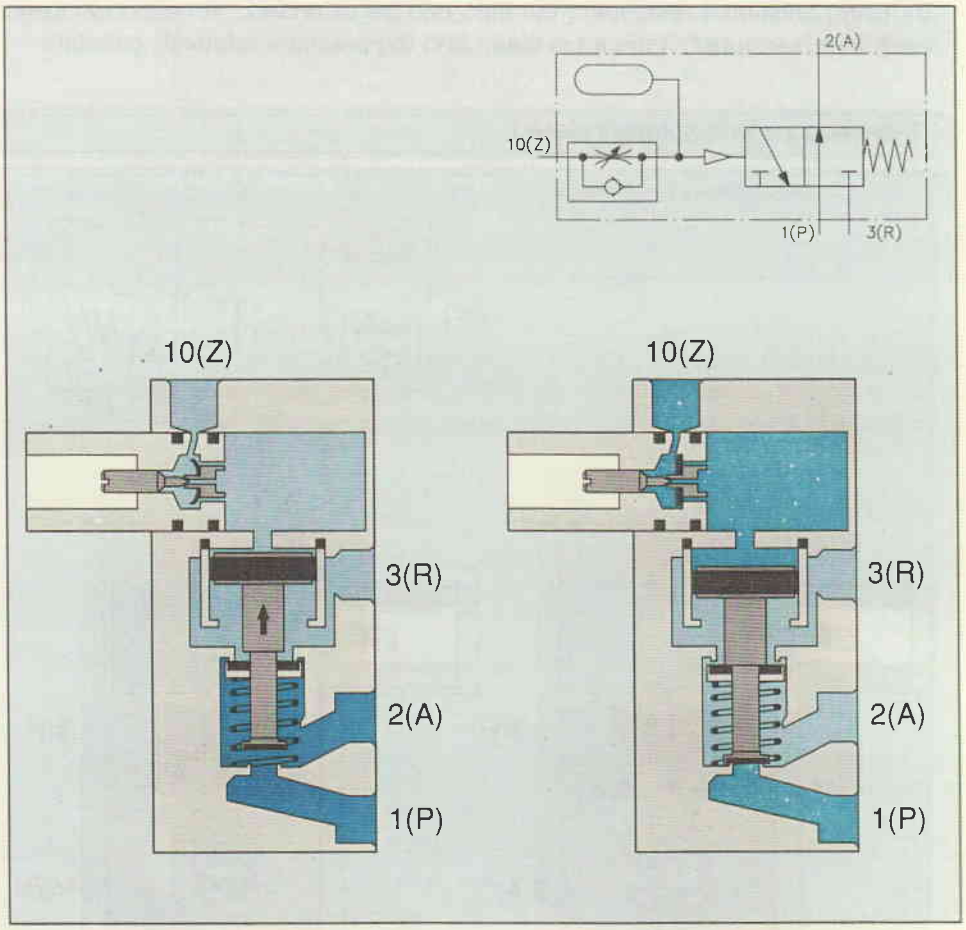
Time delay valve: normally closed



Referring to the previous diagram, the compressed air is supplied to the valve at connection 1(P). The control air flows into the valve at 12(Z). It flows through a one way flow control valve and depending on the setting of the throttling screw, a greater or lesser amount of air flows per unit of time into the air reservoir. When the necessary control pressure has built up in the air reservoir, the pilot spool of the 3/2 way valve is moved downwards. This blocks the passage from 2(A) to 3(R). The valve disc is lifted from its seat and thus air can flow from 1(P) to 2(A). The time required for pressure to build up in the air reservoir is equal to the control time delay of the valve.

If the time delay valve is to switch to its initial position, the pilot line 12(Z) must be exhausted. The air flows from the air reservoir to atmosphere through the bypass of the one way flow control valve and then to the exhaust line. The valve spring returns the pilot spool and the valve disc seat to their initial positions. Working line 2(A) exhausts to 3(R) and 1(P) is blocked.

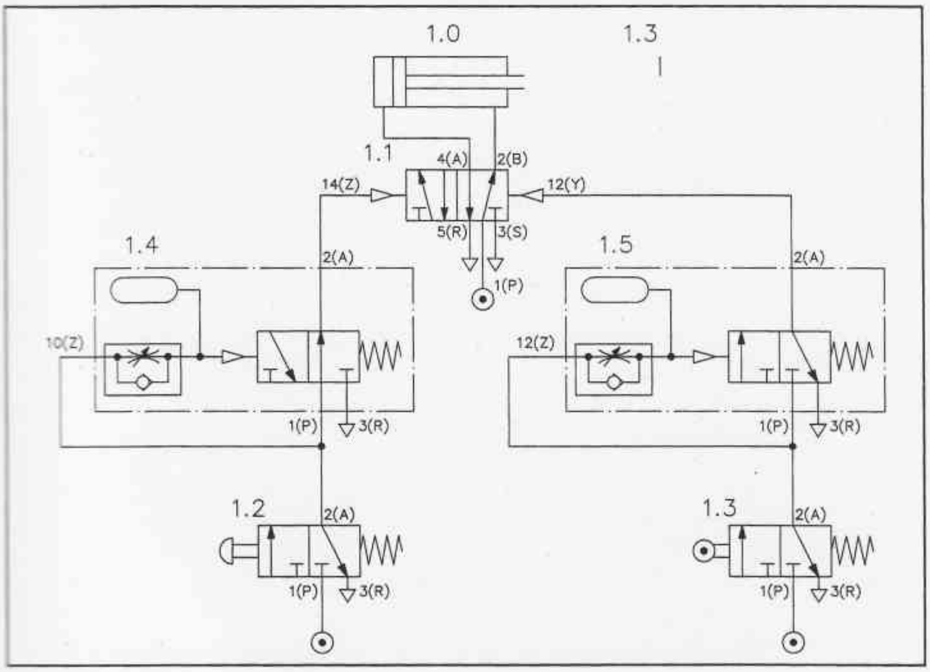
Time delay valve: normally open



The normally open time delay valve includes a 3/2 way valve which is open. Initially the output 2(A) is active. When the valve is switched by 10(Z) the output 2(A) is exhausted. The result is that the output signal is turned off after a set time delay.

The circuit below utilises two time delay valves, one a normally closed valve (1.5) and the other a normally open valve (1.4). Upon operation of the start button 1.2, the signal generated passes through the valve 1.4 and initiates the movement of cylinder extension via the 14(Z) port of the memory valve 1.1. The time delay valve 1.4 has a short time delay set of 0.5 seconds. This is long enough to initiate the start signal but then the 14(Z) signal is cancelled by the timer 10(Z) pilot signal. The cylinder operates limit valve 1.3. The time delay valve 1.5 receives a pilot signal which after the preset time opens the timer. This supplies the 12(Y) signal which reverses valve 1.1 and retracts the cylinder. The new cycle can only start if the start button has been released. The release of the pushbutton resets the timer 1.4 by exhausting the 10(Z) signal.

Circuit: time delay valves



Chapter 5

Actuators and output devices

An actuator is an output device for the conversion of supply energy into useful work. The output signal is controlled by the control system, and the actuator responds to the control signals via the final control element. Other types of output devices are used to indicate the status of the control system or actuators.

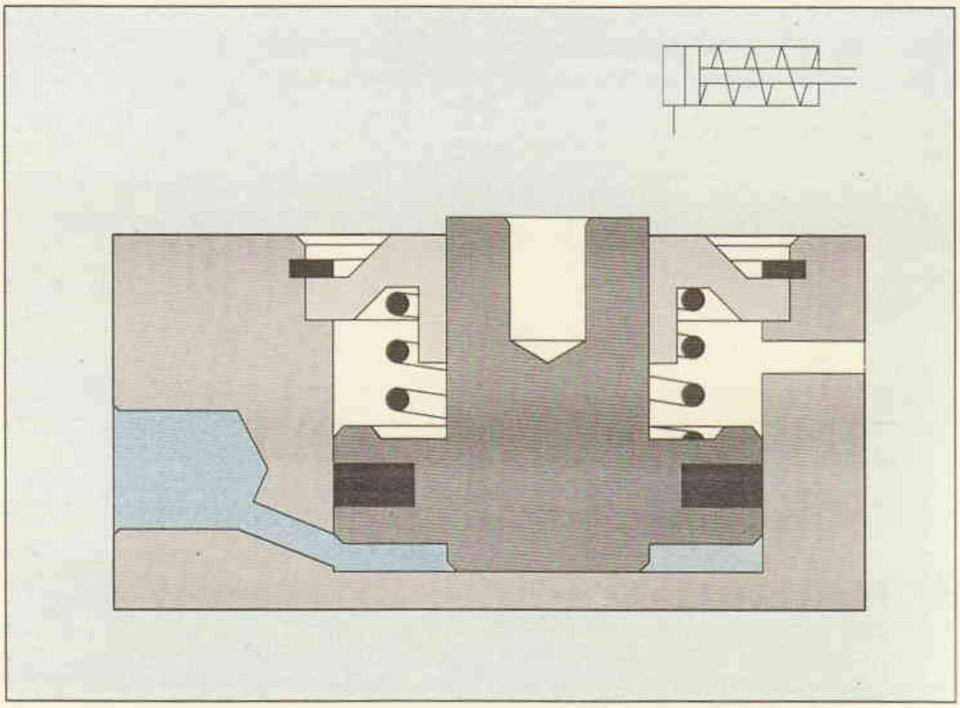
The pneumatic actuator can be described under two groups, linear and rotary:

- Linear motion
  - Single acting cylinders
  - Double acting cylinders
- Rotary motion
  - Air motor
  - Rotary actuator

5.1 Single acting cylinder

With single acting cylinders compressed air is applied on only one side of the piston face. The other side is open to atmosphere. The cylinder can produce work in only one direction. The return movement of the piston is effected by a built-in spring or by the application of an external force. The spring force of the built-in spring is designed to return the piston to its start position with a reasonably high speed under no load conditions.

Single acting cylinder



For single acting cylinders with built-in spring, the stroke is limited by the natural length of the spring. Single acting cylinders are therefore only available in stroke lengths of up to approximately 80 mm.

The construction and simplicity of operation of the single acting cylinder makes it particularly suitable for compact, short stroke length cylinders for the following types of applications:

- Clamping of workpieces
- Cutting operations
- Ejecting parts
- Pressing operations
- Feeding and lifting

Construction

The single acting cylinder has a single piston seal which is fitted to the air supply side. The exhaust air on the piston rod side of the cylinder is vented to atmosphere through an exhaust port. If this port is not protected by a gauze cover or filter, then it is possible that the entry of dirt particles may damage internal seals. Additionally a blocked vent will restrict or stop the exhausting air during forward motion, and the motion will be jerky or may stop. Sealing is by a flexible material that is embedded in a metal or plastic piston (Perbunan). During motion, the sealing edges slide over the cylinder bearing surface.

There are varying designs of single acting cylinders including:

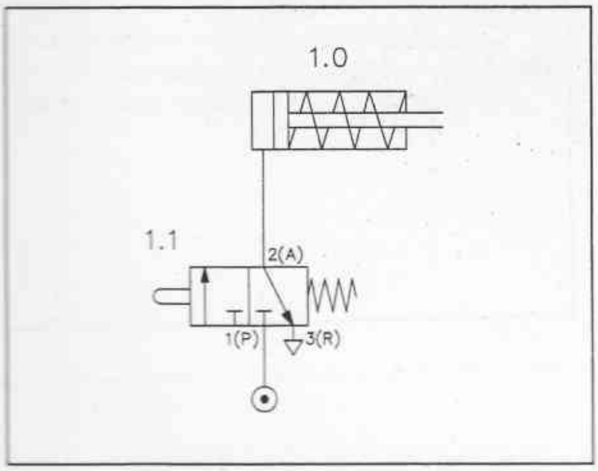
- Diaphragm cylinder
- Rolling diaphragm cylinder

With the diaphragm cylinder construction the friction during motion is less and there is no sliding motion. They are used in short stroke applications, for clamping, embossing and lifting operations.

Control of a single acting cylinder

In the example below the piston rod of the single acting cylinder advances when a button is operated. On release of the button the piston returns to the initial position. A normally closed 3/2 way valve is required for this direct control.

Direct control of a single acting cylinder

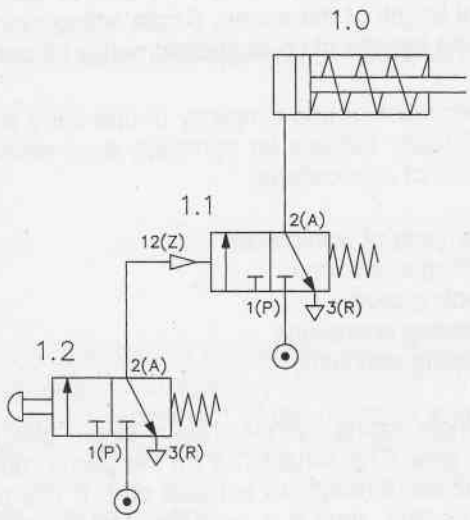


When the 3/2 way valve is actuated, compressed air flows from 1(P) to 2(A) and the exhaust port 3(R) is blocked. The cylinder extends. When the button is released the valve return spring operates and the cylinder chamber is exhausted through the 3(R) port with the compressed air connection 1(P) blocked. The cylinder retracts under spring force.

B 3.3

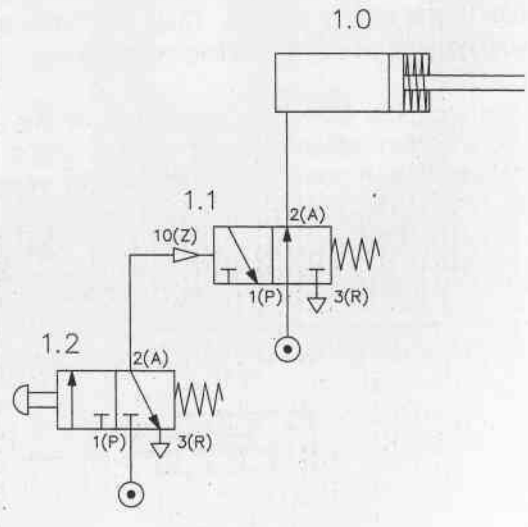
With indirect control of a cylinder the 3/2 way control valve is piloted by the 3/2 way pushbutton valve 1.2. In this way the final control element can be of large orifice size. The control valve then matches the cylinder bore size and flow rate requirements. The pushbutton valve 1.2 indirectly extends the cylinder 1.0 via the final control element 1.1. When the pushbutton is pressed, the signal 12(Z) pilots the final control element to extend the cylinder against spring force. If the button is released, the signal 12(Z) exhausts and the control element returns to the initial position retracting the cylinder.

Indirect control, normally closed valve



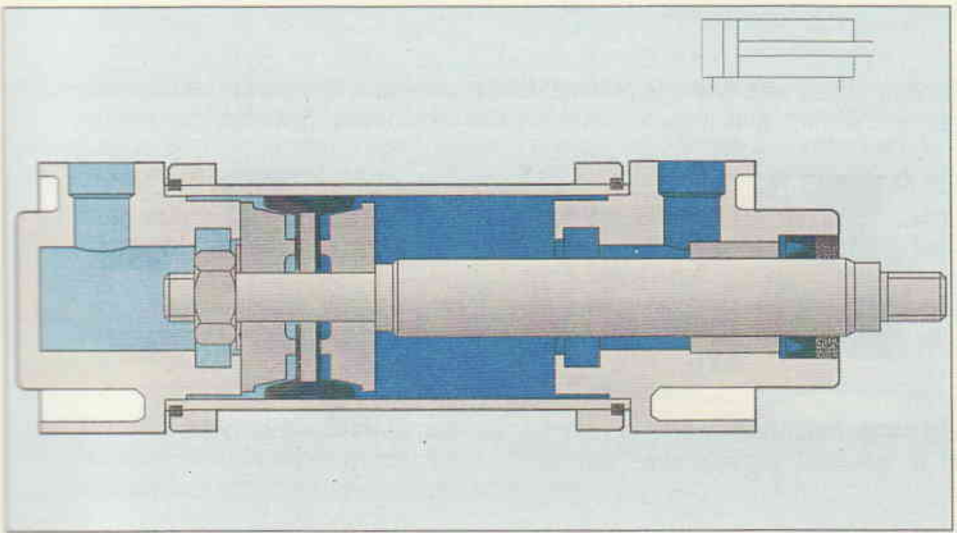
In the case of a normally open 3/2 way valve being used, the cylinder is initially extended and when the pushbutton is operated the cylinder retracts under the spring force. The final control element 1.1 is not switched at the rest position. The cylinder is pressurised whilst at rest in the initial position. The circuit is drawn with the valve 1.2 unactuated and with the cylinder initially extended due to the signal 2(A) being active at valve 1.1.

Indirect control, normally open valve



5.2 Double acting cylinder

Double acting cylinder



The construction principle of a double acting cylinder is similar to that of the single acting cylinder. However, there is no return spring, and the two ports are used alternatively as supply and exhaust ports. The double acting cylinder has the advantage that the cylinder is able to carry out work in both directions of motion. Thus, installation possibilities are universal. The force transferred by the piston rod is somewhat greater for the forward stroke than for the return stroke as the effective piston surface is reduced on the piston rod side by the cross-sectional area of the piston rod. The cylinder is under control of the supply air in both directions of motion.

In principle, the stroke length of the cylinder is unlimited, although buckling and bending of the extended piston rod must be allowed for. As with the single acting cylinder, sealing is by means of pistons fitted with sealing rings or diaphragms.

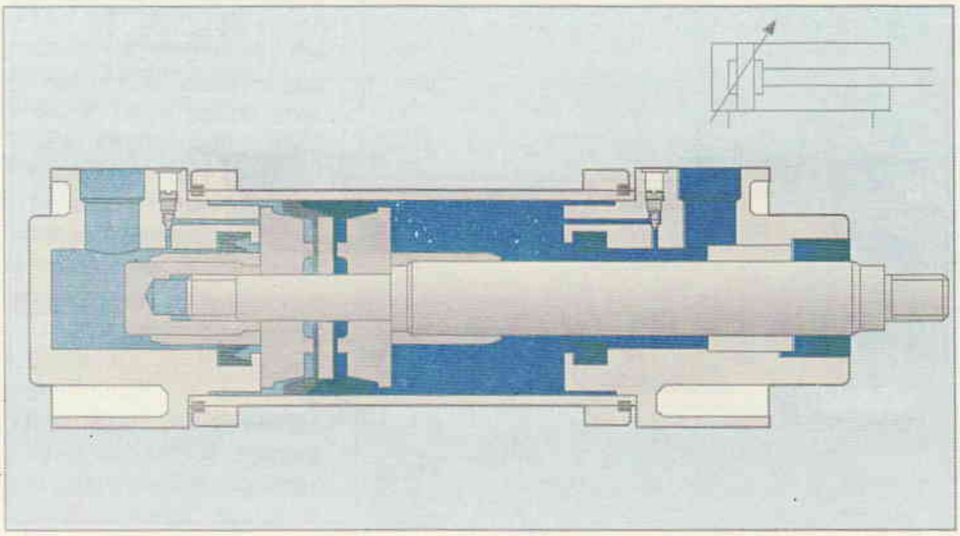
Design development

Pneumatic cylinders have developed in the following directions:

- Contactless sensing requirements - hence the use of magnets on pistons for reed switch operation
- Stopping heavy loads through clamping units and external shock absorbers
- Rodless cylinders where space is limited
- Alternative manufacturing materials such as plastic
- Protective coatings against harsh environments, i.e. acid-resistant
- Increased load carrying capacity
- Robotic applications with special features such as non-rotating piston rods, hollow piston rods for vacuum suction cups

Cylinder with end position cushioning

Cushioned double acting cylinder



If large masses are moved by a cylinder, cushioning is used in the end positions to prevent sudden damaging impacts. Before reaching the end position, a cushioning piston interrupts the direct flow path of the air to the outside. Instead a very small and often adjustable exhaust aperture is open. For the last part of the stroke the cylinder speed is progressively reduced. If the passage adjustment is too small, the cylinder may not reach the end position due to the blockage of air.

When the piston reverses, air flows without resistance through the return valve into the cylinder space. With very large forces and high accelerations extra measures must be taken such as external shock absorbers to assist the load deceleration. When cushioning adjustment is being carried out, it is recommended that in order to avoid damage, the regulating screw should first be screwed in fully and then backed off in order to allow the adjustment to be increased slowly to the optimum value.

It is important to consider fitting a magnet to the cylinder piston. Once manufactured the cylinder cannot normally be fitted with sensor magnets due to the difference in construction.

Construction

The cylinder consists of a cylinder barrel, bearing and end cap, piston with seal (double-cup packing), piston rod, bearing bush, scraper ring, connecting parts and seals.

The cylinder barrel is usually made of seamless drawn steel tube. To increase the life of the sealing components, the bearing surfaces of the cylinder barrel are precision-machined. For special applications, the cylinder barrel can be made of aluminium, brass or steel tube with hard-chromed bearing surface. These special designs are used where operation is infrequent or where there are corrosive influences.

The end cap and the bearing cap are, for the most part, made of cast material (aluminium or malleable cast iron). The two caps can be fastened to the cylinder barrel by tie rods, threads or flanges.

The piston rod is preferably made from heat-treated steel. A certain percentage of chrome in the steel protects against rusting. Generally the threads are rolled to reduce the danger of fracture.

A sealing ring is fitted in the bearing cap to seal the piston rod. The bearing bush guides the piston rod and may be made of sintered bronze or plastic-coated metal.

In front of this bearing bush is a scraper ring. It prevents dust and dirt particles from entering the cylinder space. Bellows are therefore not normally required.

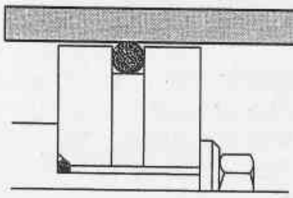
The materials for the double-cup packing seals are:

Perbunan	for – 20°C to + 80°C
Viton	for – 20°C to + 190°C
Teflon	for – 80°C to + 200°C

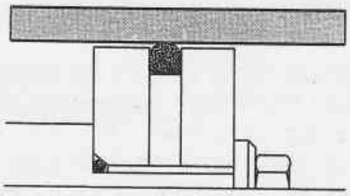
0-rings are normally used for static sealing.

Cylinder seals

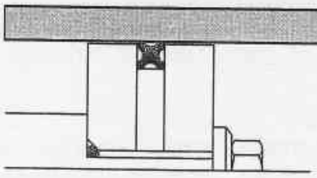
O-ring



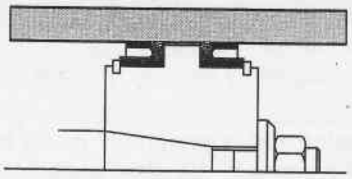
Shaped ring



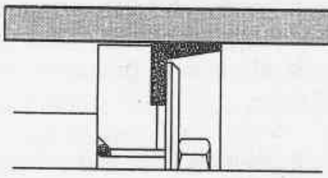
Square ring



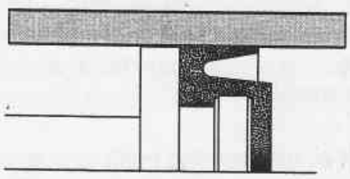
Groove rings on both sides



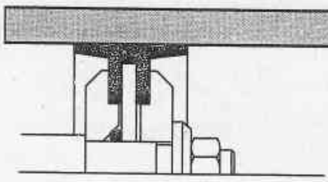
Cup packing



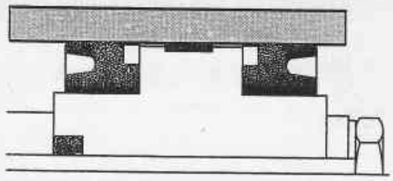
Buttoned-in groove ring packing



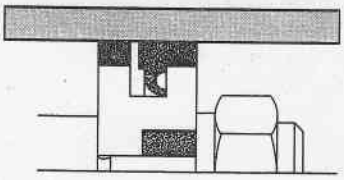
Double-cup packing



Supported groove rings with slide ring



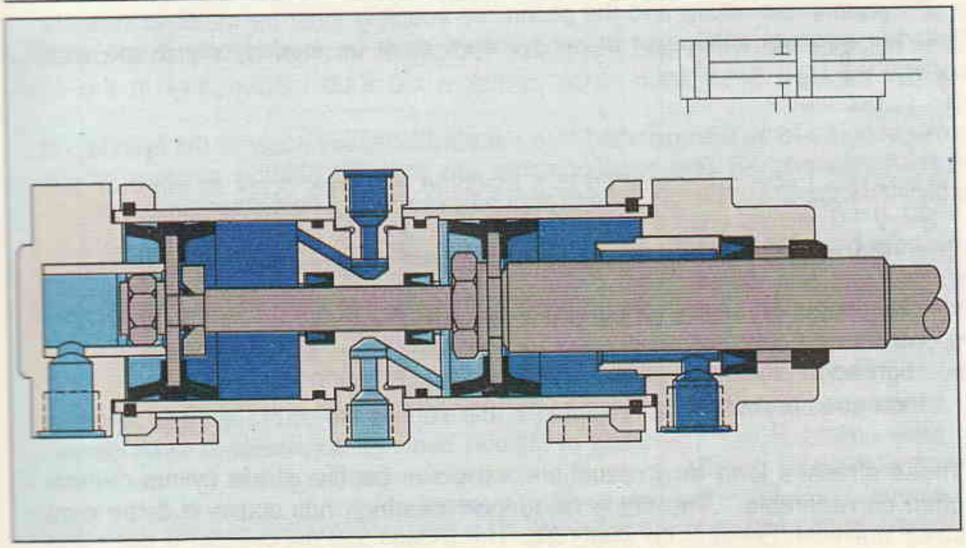
L-ring



Tandem double acting cylinder

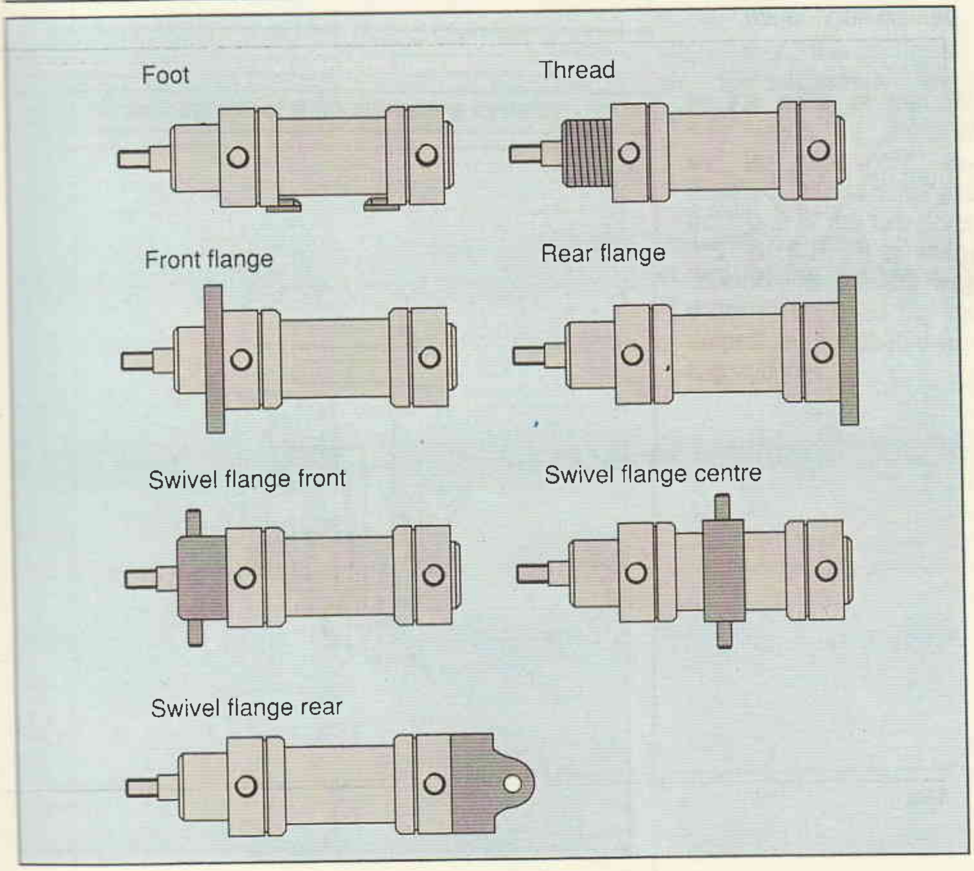
The tandem cylinder incorporates the features of two double acting cylinders which have been joined to form a single unit. By this arrangement and with the simultaneous loading of both pistons, the force on the piston rod is almost doubled. This design is suitable for such applications where a large force is required but the cylinder diameter is restricted.

Tandem double acting cylinder



Mounting

Mounting arrangements for cylinders



The type of mounting is determined by the manner in which the cylinder is to be fitted to a machine or fixture. The cylinder can be designed with a permanent type of mounting if it does not have to be altered at any time. Alternatively, the cylinder can utilise adjustable types of mounting which can be altered at a later date by using suitable accessories on the modular construction principle. This results in considerable simplification in storage, especially where a large number of pneumatic cylinders are used as only the basic cylinder and optional mounting parts need to be stored.

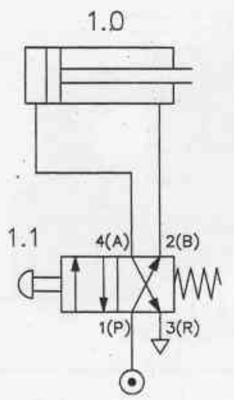
The cylinder mounting and the piston rod coupling must be matched carefully to the relevant application since cylinders must be loaded only in the axial direction.

As soon as force is transmitted to a machine, stresses occur at the cylinder. If shaft mismatching and misalignments are present, bearing stresses at the cylinder barrel and piston rod can also be expected. The consequences are :

- High edge pressures on the cylinder bearing bushes leading to increased wear
- High edge pressures on the piston rod guide bearings
- Increased and uneven stresses on piston rod seals and piston seals.

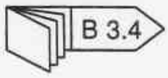
These stresses lead to a reduction in the service life of the cylinder which is often considerable. The fitting of support bearings adjustable in three dimensions makes it possible to avoid this excessive bearing stress on the cylinder almost completely. The only bending moment which then occurs is determined by the sliding friction in the bearings. This means that the cylinder is subjected only to the stress for which it was designed. It can therefore reach its full design service life.

Circuit: control of a double acting cylinder

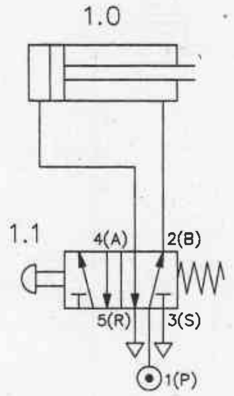


The 4/2 way valve or the 5/2 way valve can be used to control the double acting cylinder. In both cases the air is initially supplied from 1(P) to 2(B) and the 4(A) port is exhausted. The cylinder is initially held under pressure in the retracted position. When the manual valve is operated the 4(A) port is active and the 2(B) port is exhausted. The cylinder is extended, and remains extended until the valve is released. In the 4/2 way valve a single exhaust port 3(R) is used.

Control of a double acting cylinder 4/2 way valve

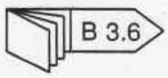


Circuit: control of a double acting cylinder



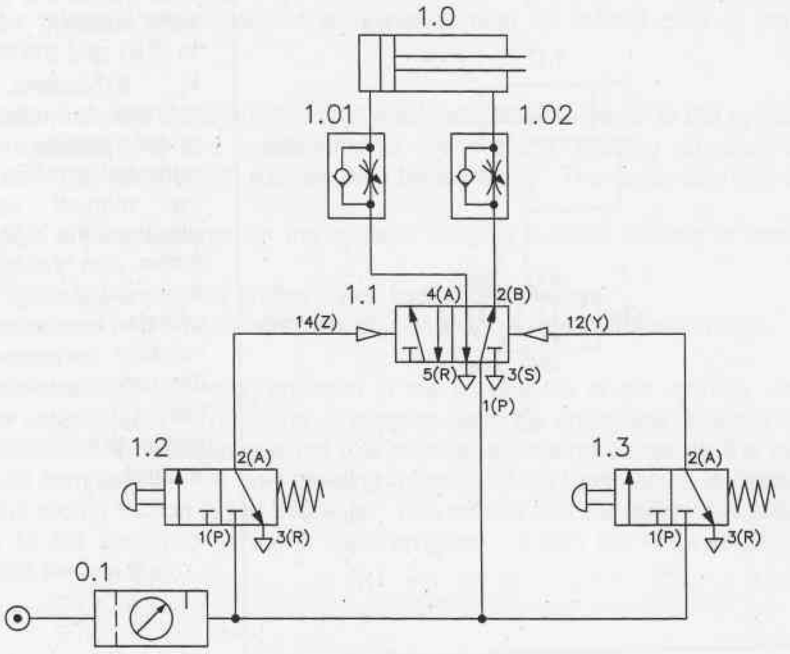
In the case of the 5/2 way valve, the exhaust air is separately exhausted to atmosphere from one of the two ports 3(S) or 5(R). It is more common for the 5/2 way valve to be used for the control of the double acting cylinder.

Control of a double acting cylinder 5/2 way valve



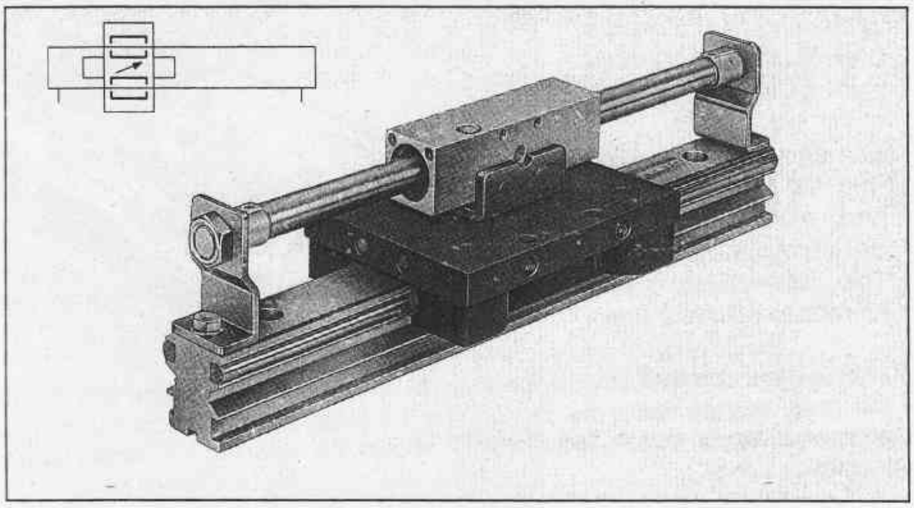
To regulate the speed of the cylinder, the flow control valves 1.01 and 1.02 are fitted to the exhaust side of the cylinder. In this control circuit a 5/2 way memory valve is used. The signalling elements 1.2 and 1.3 need only operate for a short duration to achieve switching.

Exhaust air throttling of a double acting cylinder



5.3 Rodless cylinder

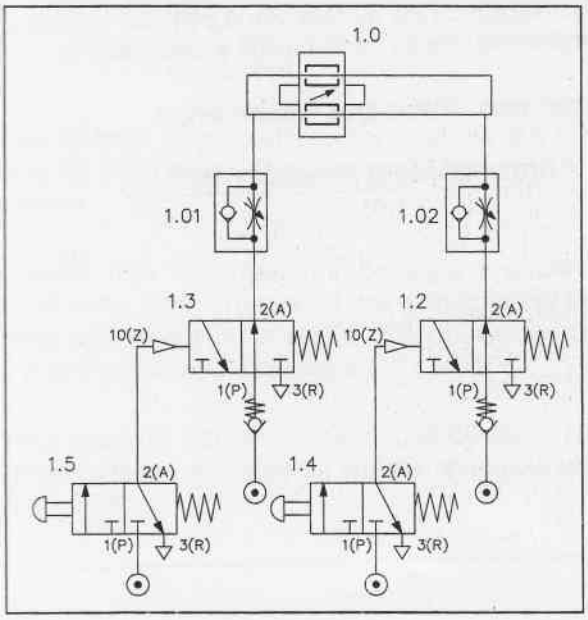
Rodless cylinder



This double acting pneumatic linear actuator (cylinder without piston rod) consists of a cylindrical barrel and rodless piston. The piston in the cylinder is freely movable according to pneumatic actuation, but there is no positive external connection. The piston is fitted with a set of annular permanent magnets. Thus, a magnetic coupling is produced between slide and the piston. As soon as the piston is moved by compressed air the slide moves synchronously with it. The machine component to be moved is mounted on the carriage. This design of cylinder is specifically used for extreme stroke lengths of up to 10m. An additional feature of the rodless design is the flat bed mounting available on the carriage as opposed to the threaded piston rod type of construction.

Control of a rodless cylinder

Rodless cylinder circuit for positioning



For the accurate positioning of the carriage, the circuit for the rodless cylinder uses check valves to prevent the carriage from creeping. Referring to the circuit, the pushbutton for the carriage to move to the right is the right hand valve 1.2. In this case the valve that exhausts the air controls the motion of the cylinder.

5.4 Cylinder performance characteristics

Cylinder performance characteristics can be determined theoretically or by the use of manufacturers data. Both methods are acceptable, but in general the manufacturers data is more relevant to a particular design and application.

Piston force

The piston force exerted by the cylinder is dependent upon the air pressure, the cylinder diameter, and the frictional resistance of the sealing components. The theoretical piston force is calculated by the formula:

$F_{th} = A \cdot p$

F_{th} = Theoretical piston Force (N)

A = Useful piston Area (m^2)

p = Operating Pressure (Pa)

Stroke length

The stroke lengths of pneumatic cylinders should not be greater than 2m and for rodless cylinders 10m.

With excessive stroke lengths the mechanical stress on the piston rod and on the nose bearing would be too great. To avoid the danger of buckling, a somewhat larger piston rod diameter should be selected for longer stroke lengths.

Piston speed

The piston speed of pneumatic cylinders is dependent on the load, the prevailing air pressure, the length of pipe, the cross-sectional area between the final control element and the working element and also the flow rate through the final control element. In addition, the speed is influenced by the end position cushioning.

The average piston speed of standard cylinders is about 0.1-1.5 m/sec. With special cylinders (impact cylinders), speeds of up to 10 m/sec are attained.

The piston speed can be regulated by one way flow control valves and speed increased by the use of quick exhaust valves.

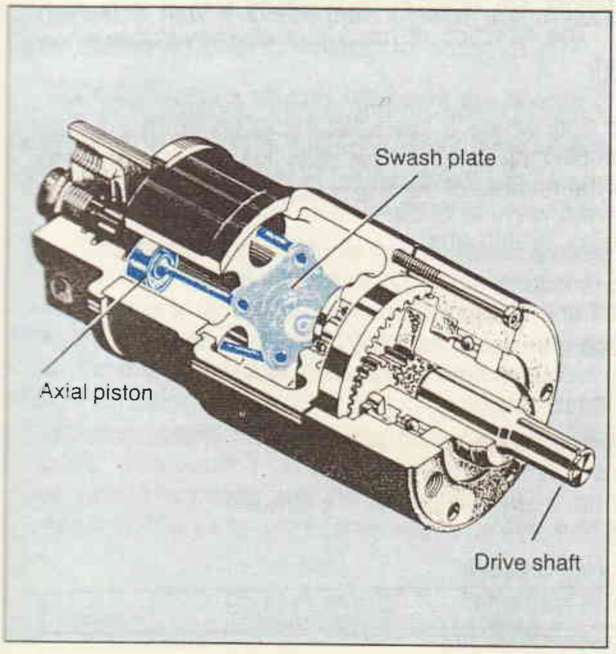
For the preparation of the air, and to obtain facts concerning power costs, it is important to know the air consumption of the system. For a particular operating pressure, piston diameter, and stroke, the air consumption is calculated by :

Air consumption = Compression ratio · Piston area · Stroke length

$$\text{The compression ratio} = \frac{1.013 + \text{operating pressure (in bar)}}{1.013}$$

5.5 Motors

Air motor



Devices which transform pneumatic energy into mechanical rotary movement with the possibility of continuous motion are known as pneumatic motors. The pneumatic motor with unlimited angle of rotation has become one of the most widely used working elements operating on compressed air. Pneumatic motors are categorised according to design :

- Piston motors
- Sliding-vane motors
- Gear motors
- Turbines (high flow)

Piston motors

This type of design is further subdivided into radial and axial piston motors. The crank shaft of the motor is driven by the compressed air via reciprocating pistons and connecting rods. To ensure smooth running several pistons are required. The power of the motors depends on input pressure, number of pistons, piston area, stroke and piston speed.

The working principle of the axial piston motor is similar to that of the radial piston motor. The force from 5 axially arranged cylinders is converted into a rotary motion via a swash plate. Compressed air is applied to two pistons simultaneously, the balanced torque providing smooth running of the motor.

These pneumatic motors are available in clockwise or anti-clockwise rotation. The maximum speed is around 5000 rpm, the power range at normal pressure being 1.5 - 19 kW (2 - 25 hp).

Sliding vane motors

Because of their simple construction and the low weight, sliding vane motors are used for hand tools. The principle of operation is similar to the sliding-vane compressor.

An eccentric rotor is contained in bearings in a cylindrical chamber. Slots are arranged in the rotor. The vanes are guided in the slots of the rotor and forced outwards against the inner wall of the cylinder by centrifugal force. This ensures that the individual chambers are sealed.

The rotor speed is between 3000 and 8500 rpm. Here too, clockwise or anti-clockwise units are available as well as reversible units. Power range 0.1 - 17 kW (0.1 - 24 hp).

Gear motors

In this design, torque is generated by the pressure of the air against the teeth profiles of two meshed gear wheels. One of the gear wheels is secured to the motor shaft. These gear motors are used in applications with a very high power rating (44 kW/60 hp). The direction of rotation is also reversible when spur or helical gearing is used.

Turbines (flow motors)

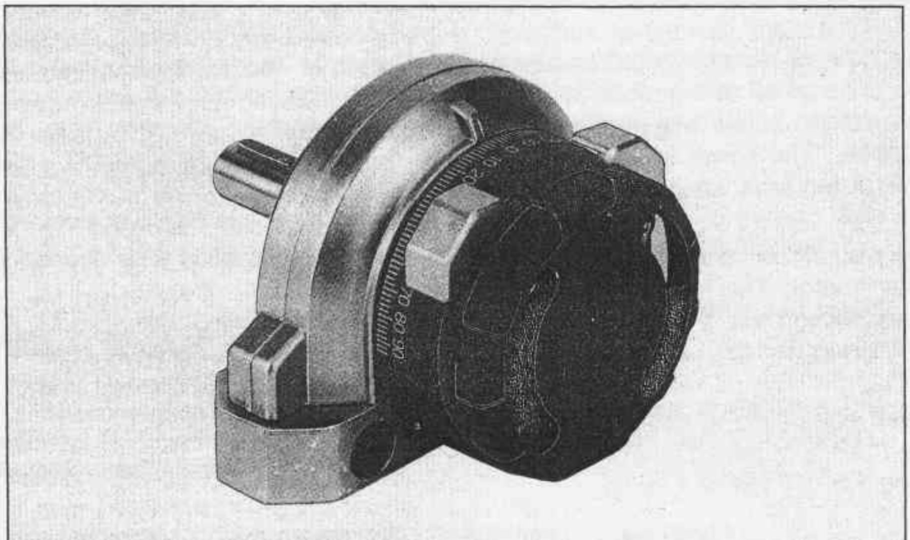
Turbine motors can be used only where a low power is required. The speed range is very high. For example, the Dentists' air drills operates at 500,000 rpm. The working principle is the reverse of the flow compressor.

Characteristics of pneumatic motors are:

- Smooth regulation of speed and torque
- Small size (weight)
- Overload safe
- Insensitive to dust, water, heat, cold
- Explosion proof
- Large speed selection
- Maintenance minimal
- Direction of rotation easily reversed

5.6 Rotary actuators

Rotary actuator



Design features of pneumatic rotary actuators:

- Small and robust
- Precision machined and hence very efficient
- Available with contactless sensing
- Adjustable for angular displacement
- Constructed from lightweight material
- Easy to install

The compact rotary actuator is suited to robotics and materials handling applications where there is limited space.

5.7 Indicators

Optical indicators visually represent the operating status of the pneumatic system and serve as diagnostic aids.

Some of the visual devices are :

- Optical indicators, single and multiple coloured units
- Pin type optical indicators, for visual display and tactile sensing
- Counters, for displaying counting cycles
- Pressure gauges, to indicate air pressure values
- Timers, with visual indication of time delay

Optical indicators

With the optical indicators the colour codes represent certain functions in the cycle. The visual indicators are mounted on the control panel to indicate status of control functions and the sequential steps currently active. The colours for visual indicators in accordance with VDI/VDE 0113/57113 are:

Colour	Meaning	Notes
Red	Immediate danger, alarm	Machine status or situations requiring immediate intervention. No entry.
Yellow	Caution	Change or imminent change of conditions.
Green	Safety	Normal operation, safe situation, free entry.
Blue	Special information	Special meaning which cannot be made clear by red, yellow or green.
White or Clear	General information	Without special meaning. Can also be used in cases where there is doubt as to the suitability of the three colours red, yellow or green.

Chapter 6

Systems

6.1 Selection and comparison of media

A 1.1

To select the control media consideration must be given to the following :

- The work or output requirements
- The preferred control methods
- The resources and expertise available to support the project
- The systems currently installed which are to be integrated with the new project

The total project may require mixtures of medium both on the control side and the work side. Therefore, the interface or conversion device will be an important element of the process to ensure continuity and uniformity of signals and data.

Firstly, the individual advantages and disadvantages of the mediums available must be considered, both as a control medium and as a working medium. Then the selections can be developed towards a solution.

6.2 Control system development

The development of the control system solution requires that the problem is defined clearly. There are many ways of representing the problem in a descriptive or graphical form. The methods of representing the control problem include:

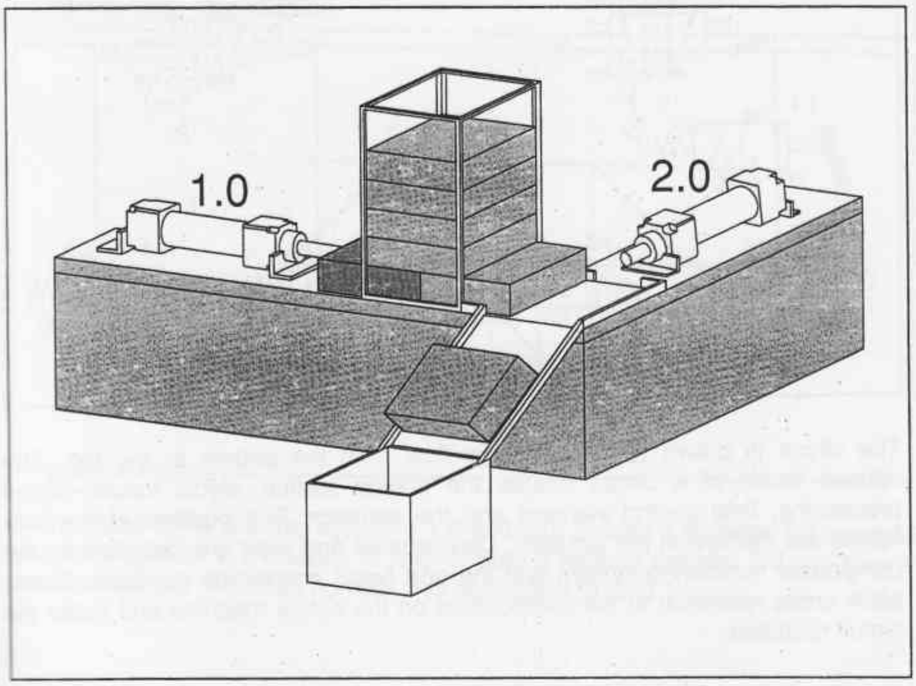
- Positional sketch
- Circuit diagram
- Displacement-step diagram
- Displacement-time diagram
- Control diagram
- Flow chart
- Function chart

At the fundamental level of pneumatic control the most commonly used representations are the positional sketch, circuit diagram, displacement-step diagram and the displacement-time diagram.

Positional sketch

The positional sketch shows the relationship between the actuators and the machine fixture. The actuators are shown in the correct orientation. The positional sketch is not normally to scale and should not be too detailed. The diagram will be used in conjunction with the description of the machine operation and the motion diagrams.

Positional sketch example

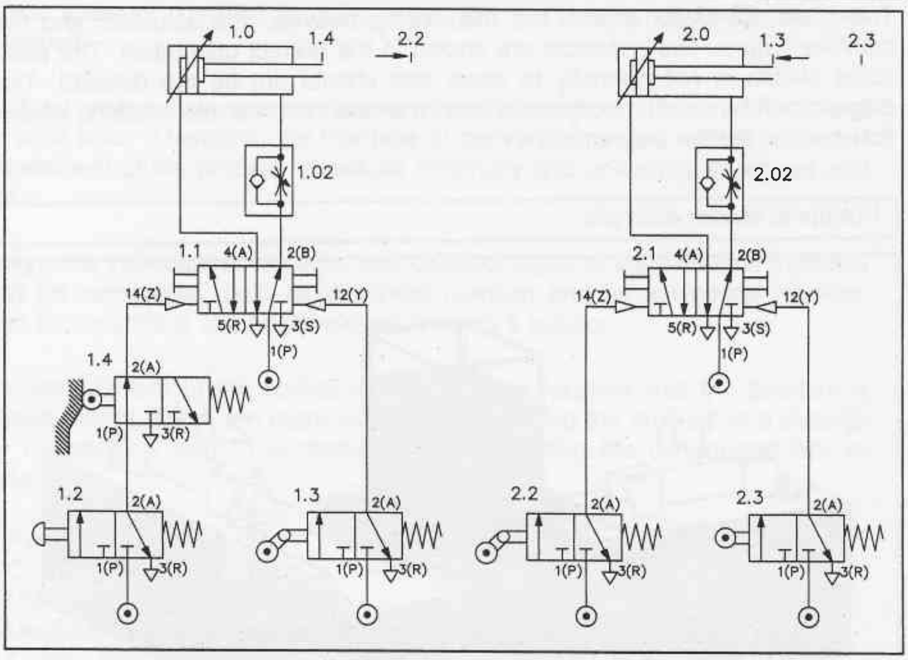


Circuit diagram

A 4.1

The circuit diagram shows signal flow, relationship between components and the air connections. There is no mechanical layout representation with the circuit diagram.

Circuit diagram

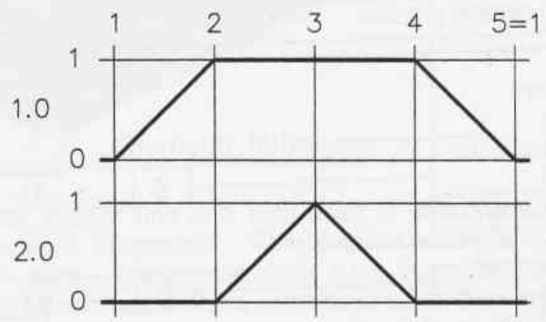


The circuit is drawn with the energy flow from the bottom to the top. The various levels of a circuit include the energy source, signal inputs, signal processing, final control element and the actuator. The position of the limit valves are marked at the actuator. Components and lines are identified by the component numbering system and the port (way) connection numbers. These allow cross reference to the components on the actual machine and make the circuit readable.

Displacement-step diagram

The displacement-step diagram is used for motion sequences in the pneumatic and hydraulic fields. The diagram represents the operating sequence of the actuators; the displacement is recorded in relation to the sequence step. If a control system incorporates a number of actuators, they are shown in the same way and are drawn one below the other. Their interrelation can be seen by comparing the steps.

Displacement-step diagram

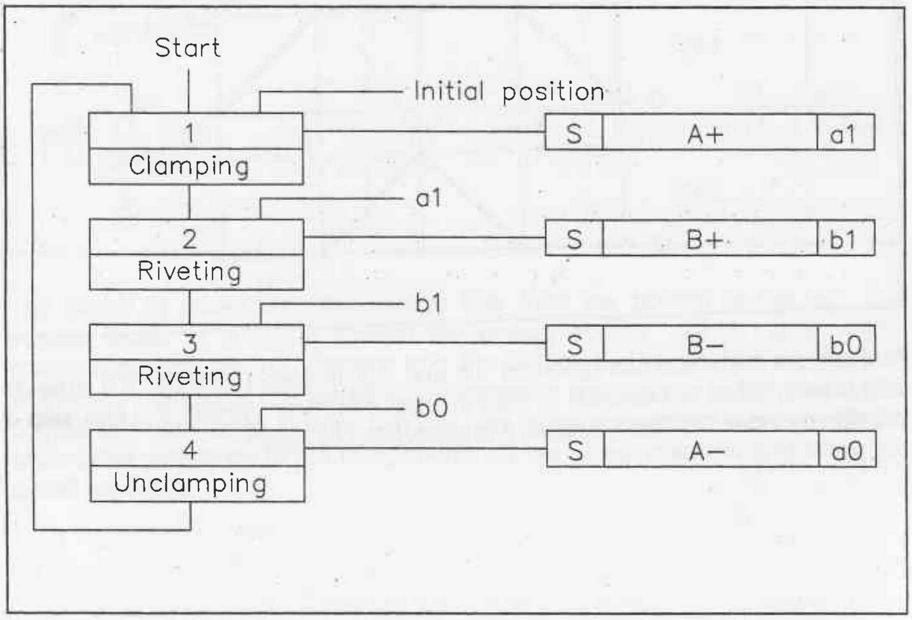


In this case there are two cylinders 1.0 and 2.0. In step 1 cylinder 1.0 extends and then cylinder 2.0 extends in step 2. Step 3 retracts cylinder 2.0 and step 4 retracts cylinder 1.0. Step number 5 is equivalent to step 1.

Function chart

The flow chart and the function chart are more common in the development of electrical and electronic control systems, although the function chart does give a clear picture of action, and reactions in pneumatic sequences.
In this case the sequence is described using the cylinder designations A and B instead of 1.0 and 2.0. The extension signal is represented as a **+** and the retraction as a **-** . The limit valves are given the same letter as the cylinder in lower case, with the designation of 0 for the retracted position and 1 for the extended position. The clamp cylinder is extended (A+) and the limit valve then operated is a1. This limit a1 initiates the extension of B cylinder (B+) which is the riveting process. The riveting cylinder fully extends and operates the limit b1. The limit b1 initiates the retraction of the riveting cylinder (B-). The limit b0 is then operated which initiates the movement of cylinder A unclamping (A-). The full retraction of cylinder A is indicated by the limit a0 and this is the initial condition required in conjunction with the start condition for a new cycle to commence.

Function chart: riveting process

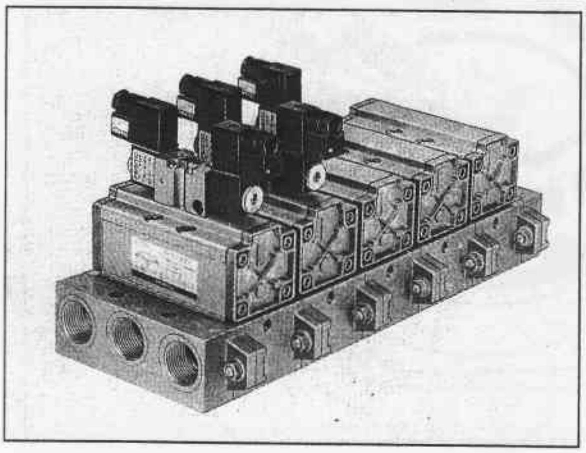


6.3 Field systems (actoric)

An important component in the transfer of power from the processor to the linear or rotary actuator is the directional control valve (DCV). The selection of the size and type of valve determines many of the operating characteristics of the actuator. The development in directional control valves is towards :

- Sub-base and manifold mounting with common supply and exhaust
- Low power requirements for pilot or solenoid operation
- Multiple function valves where characteristics are changed via wafer and seal variations
- Material changes and in particular plastic and die casting methods
- Multiple valves in single unit construction
- Mounting of the DCV on the cylinder

Manifold mounting of valves



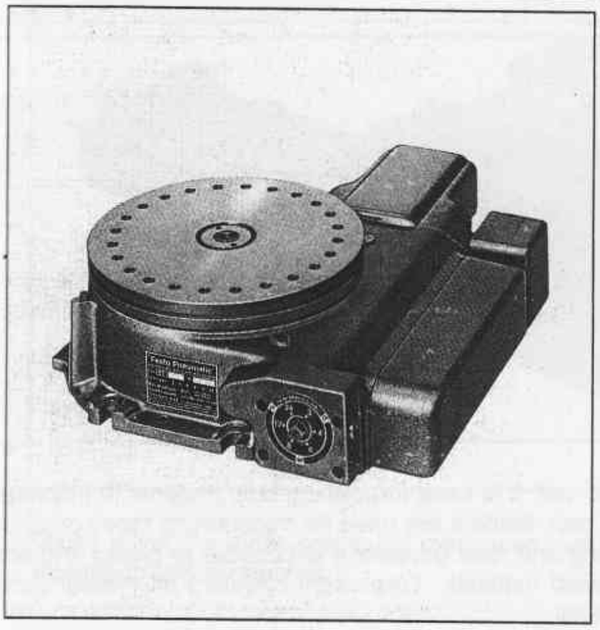
The manifold mounted valves utilise a common supply port (centre) and exhaust ports (outside). The exhausts can be tubed away separately or locally silenced as required. The compact and rigid mounting is suitable for a control cabinet construction.

6.4 Special units and assemblies

In pneumatics, special unit is a term used to describe a combination of actuator and control component. The simplest example is a combination of cylinder and valve. These assemblies have the outstanding feature of only requiring one air connection to be operational when they are installed. Various types of cylinder and valve can be combined in an assembly according to requirements, producing a linear actuator to perform a specific function.

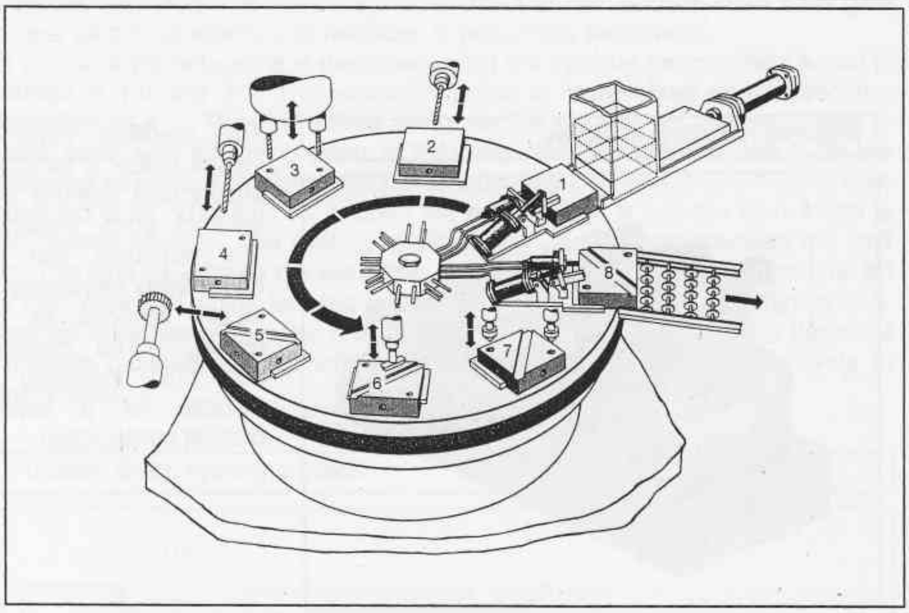
Rotary indexing table

Rotary indexing table



In many manufacturing processes, it is necessary to perform feed motions in a circular path. Rotary indexing tables are used for this purpose. The powering device in a rotary indexing table is a pneumatic cylinder in conjunction with an air control block which controls the movement cycles.

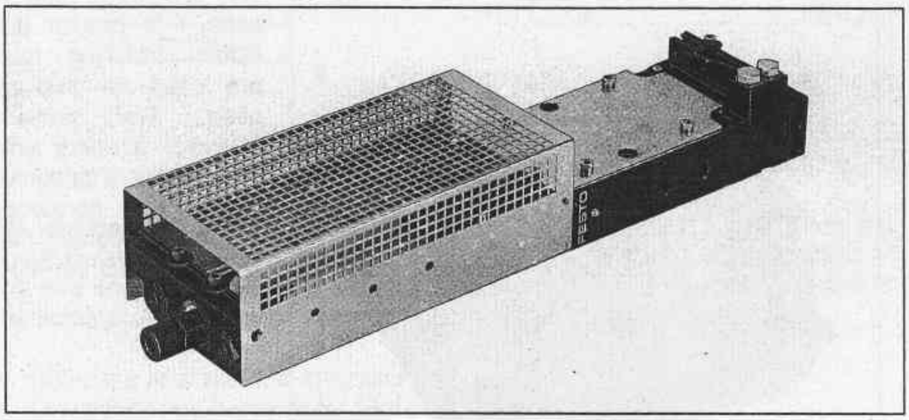
Rotary indexing table application



The rotary indexing table can be used for the one-off production of machine tools for pitch circle drilling patterns, shift holes, gears and so on.

In series production the rotary indexing table is used on drilling and tapping machines or on rotary cycling machines. It can also be used for testing, assembling, drilling, riveting, spot welding, punching, in other words anywhere where rotary cyclic production is required.

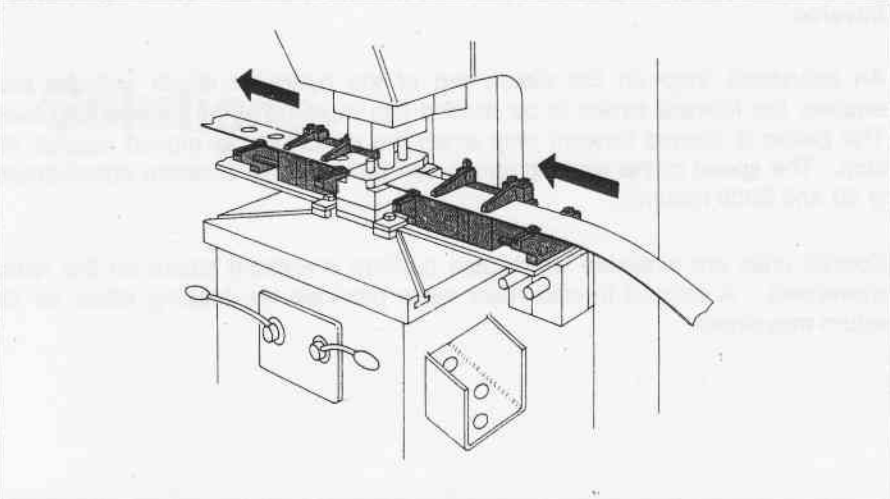
Pneumatic feed unit



This unit is a gripper feed unit. It is used for feeding strip material to machines or presses. For the most part, feeders are used for transporting tapes or strips. By using different clamping and feed grippers it is possible to clamp and feed rods, tubes and also profiled material. Diaphragm cylinders alternately clamp and open to grip the material.

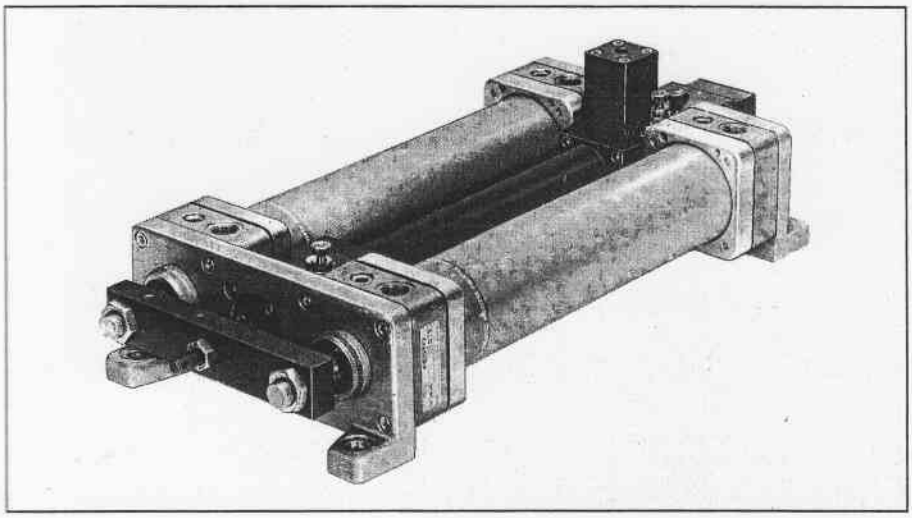
All movements made by the unit, the feed movements as well as the clamping movements are controlled by two 4/2 way valves.

Strip feeder unit in synchronous operation



The width of the material can be up to 200mm. If particular attention is paid to certain values (high cycling speed, dead weight of the material) a feed accuracy of 0.02 to 0.05mm can be attained.

Hydro-pneumatic feed unit



These units, like those previously mentioned, are mainly used where a uniform working speed is required.

The pneumatic cylinders, hydraulic check cylinder and air control block form a compact unit. The two cylinders are connected by a cross-tie. The pneumatic cylinder is retained as the working element.

When compressed air is applied to the pneumatic cylinder, the piston in the hydraulic check cylinder is carried along with it. This piston displaces the oil through a throttle relief valve to the other side of the piston. The throttle valve can be adjusted, thereby regulating the feed speed. Here too, the oil prevents the feed from being uneven when the working resistance changes.

On the return stroke, the oil can pass quickly to the other side of the piston through the return valve and thus the return stroke can also be made in rapid traverse.

An adjustable stop on the piston rod of the hydraulic check cylinder also enables the forward stroke to be divided into rapid traverse and working feed. The piston is carried forward only when the cross-tie has moved against the stop. The speed of the working stroke can be regulated between approximately 30 and 6000 mm/min.

Special units are available which also perform a working stroke on the return movement. A second throttle relief valve provides the braking effect on the return movement.

Section C

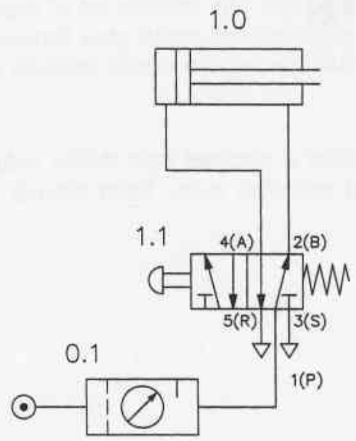
Solutions

Exercise 1:
Direct control of a double acting cylinder

Problem definition

A double acting cylinder is to extend when a pushbutton is operated. Upon release of the pushbutton the cylinder is to retract. The cylinder is of small bore (25mm diameter) requiring a small flow rate to operate at the correct speed.

Circuit diagram with 5/2 way valve



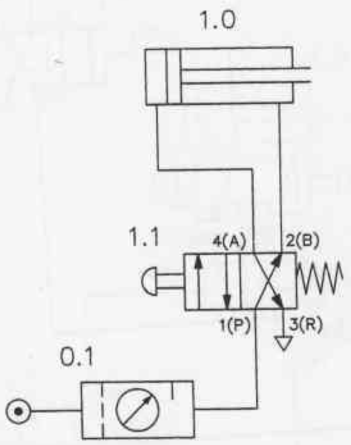
Knowledge

The control valve for a double acting cylinder can be selected as a 4/2 way or a 5/2 way valve. In this case since the cylinder has a small capacity the operation can be directly controlled by a pushbutton control valve with spring return.

On operating the pushbutton, the air passes through the valve from 1(P) to the 4(A) port and extends the piston rod. On release of the pushbutton, the valve spring returns the control valve to its initial position and the cylinder retracts. Air returns from the cylinder via the exhaust port.

Since the cylinder is the only working element or actuator in the circuit, it is designated 1.0. The final control element that extends the cylinder is designated 1.1.

Circuit diagram with 4/2 way valve



Solution

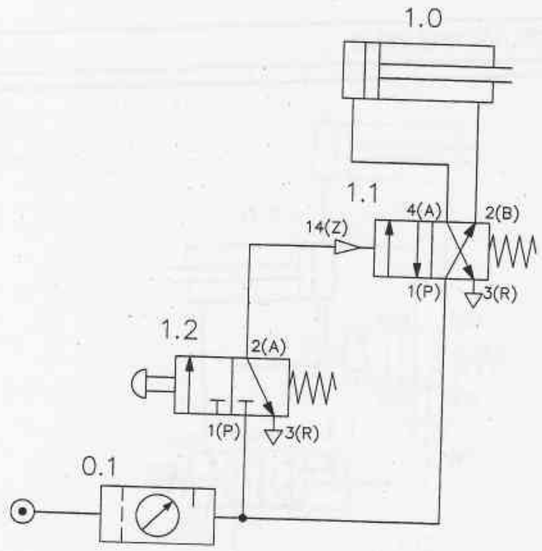
If the pushbutton is pressed for a very short period, the cylinder only partially extends and then retracts, since the spring resets the control valve as soon as the pushbutton is released. The cylinder and valve will return to their initial position. Therefore with this circuit, it is possible that the cylinder never reaches full extension. To try and achieve full extension in this case, the push-button must be held down until the cylinder moves fully forward.

Exercise 2:
Indirect control of a double acting cylinder

Problem definition

A double acting cylinder is to extend when a pushbutton is operated. Upon release of the pushbutton the cylinder is to retract. The cylinder is 250mm diameter and consumes a large volume of air.

Circuit diagram



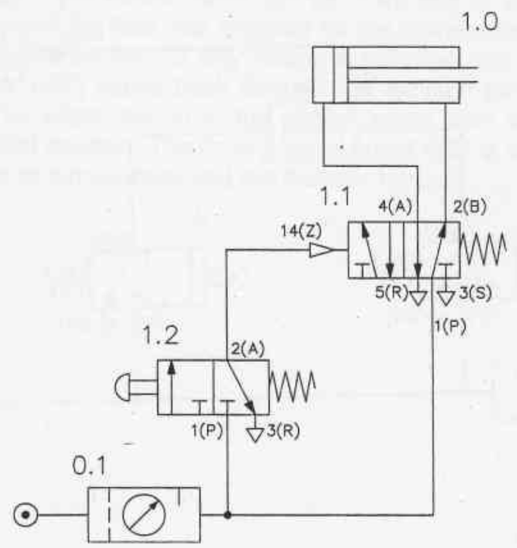
Knowledge

For controlling cylinders at high speed or of large diameter, the air flow required determines that a large size control valve should be used. The operating force to actuate the valve may be relatively large and in this case indirect control is preferable. A similar situation exists when a cylinder operates at high speed, and requires a large valve that cannot be operated directly. The control element will have a large orifice size and flow rate and be operated by pilot air to assist opening against the switching force. This is defined as indirect control. The supply line can also be short since the control valve can be mounted close to the cylinder. The other advantage is that the signal element (i.e., pushbutton 3/2 way valve) can be small, as it only provides a signal to operate the control valve and is not required to operate the cylinder directly. This signal element will be of smaller size and have a shorter switching time.

Solution

The valve 1.2 when operated supplies a pilot signal to the 14(Z) port of the control valve 1.1. This generates a signal at the outlet 4(A) and the cylinder extends until the pushbutton is released. If the pushbutton is released the return signal is supplied from the 2(B) port of valve 1.1 and the air is vented from the unpressurised side of the cylinder via the valve 1.1 exhaust port 5(R).

Circuit diagram



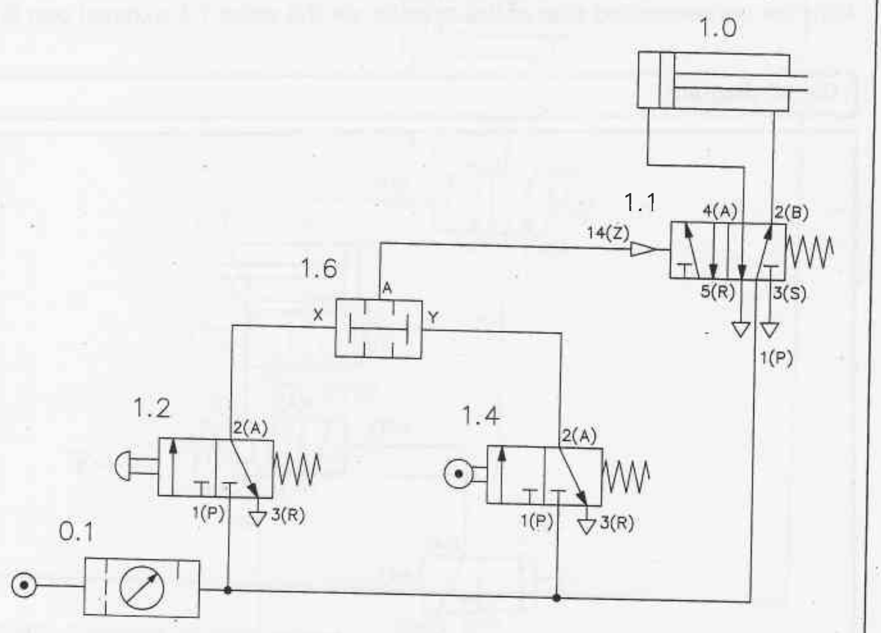
If the pushbutton is released before the cylinder fully extends, the cylinder immediately returns to the initial position. Even though indirect control is used, the final control element is a single pilot valve and does not have the characteristic of memory. Therefore the control valve requires a sustained signal for it to remain operated. Once the pushbutton is released, this pilot signal is exhausted through the 3/2 way valve exhaust port 3(R) and the cylinder retracts.

Exercise 3:
The logic AND function; the two pressure valve

Problem definition

A transfer station removes a product from a conveyor belt. If the product is detected as present and if the operator presses the pushbutton, the pick-up cylinder 1.0 extends. The product is sensed by a 3/2 way roller lever valve. Upon the release of the pushbutton the cylinder 1.0 is to retract to the initial position.

Circuit diagram



Solution

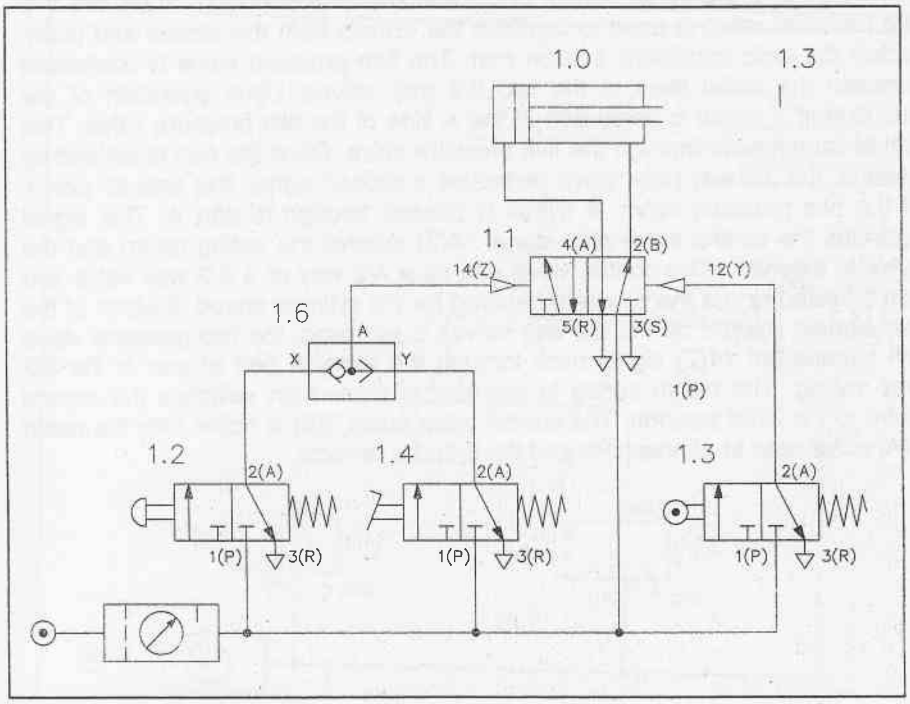
The operating condition for the pick-up cylinder to extend is a logic AND function between the product sensor and the operator pushbutton. Therefore if a two pressure valve is used to combine the signals from the sensor and pushbutton the logic conditions can be met. The two pressure valve is connected between the outlet lines of the two 3/2 way valves. Upon operation of the pushbutton a signal is generated at the X side of the two pressure valve. This signal cannot pass through the two pressure valve. Once the part is sensed as present, the 3/2 way roller valve generates a second signal, this time at port Y of the two pressure valve. A signal is passed through to port A. This signal operates the control valve pilot signal 14(Z) against the spring return and the cylinder extends. The control valve can be a 4/2 way or a 5/2 way valve and can be sized to suit the flow rate required for the cylinder speed. If either of the two signals created by the 3/2 way valves is removed, the two pressure valve will release the 14(Z) signal back through the exhaust port of one of the 3/2 way valves. The return spring in the control valve then switches the control valve to the initial position. The control valve outlet 2(B) is active with the outlet 4(A) exhausted to atmosphere and the cylinder retracts.

Exercise 4:
The logic OR function; the shuttle valve

A cylinder is used to transfer parts from a magazine. If either a pushbutton or a footpedal is operated, then the cylinder is to extend. Once the cylinder is fully extended, it is to retract to the initial position. A 3/2 way roller lever valve is to be used to detect the full extension of the cylinder.

Problem definition

Circuit diagram



Solution

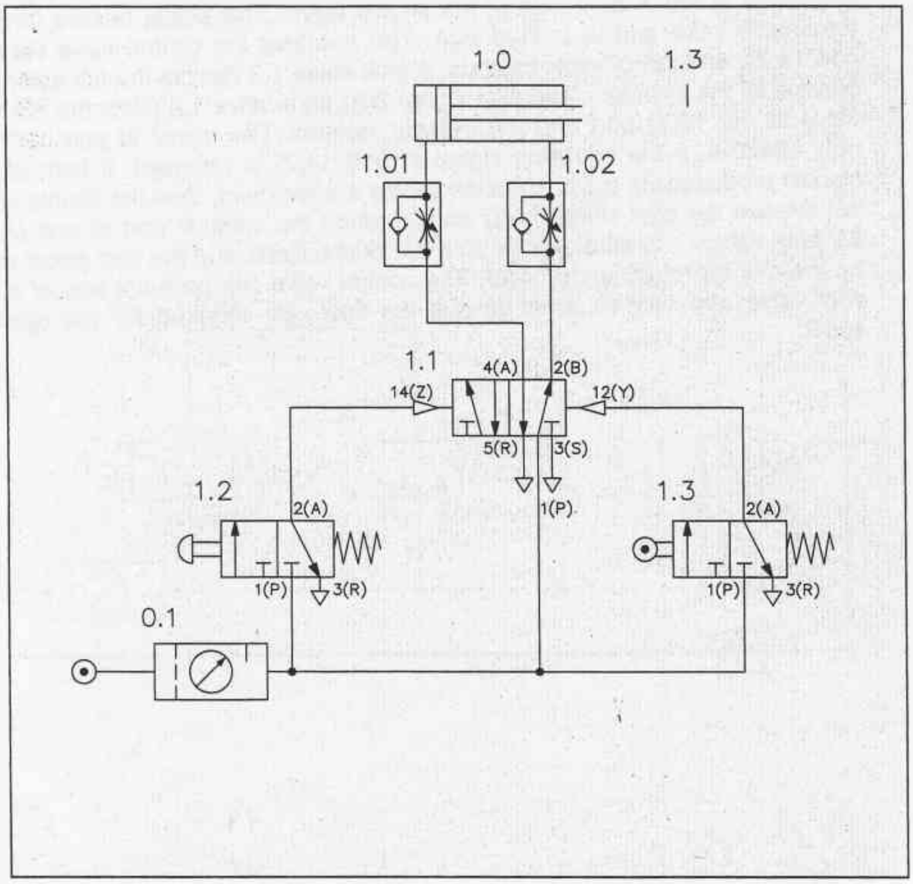
The shuttle valve is connected to the junction between the two manual 3/2 way valves. Upon operation of one of the manual 3/2 way valves, a signal is generated at the X or Y side of the shuttle valve. This signal passes through the shuttle valve and is emitted at A. This operates the control valve via pilot port 14(Z), and the cylinder extends. A limit valve 1.3 senses the full extension position of the cylinder. The pilot signal 2(A) from valve 1.3 pilots the 5/2 way valve at the 12(Y) port and the cylinder retracts. The signal at port 12(Y) is only effective, if the opposing signal at port 14(Z) is released. If both of the signals produced via the pushbutton valves are removed, then the shuttle valve will release the pilot signal 14(Z) back through the exhaust port of one of the 3/2 way valves. In other words both the pushbuttons and the foot pedal must be inactive for retraction to occur. The control valve can be a 4/2 way or a 5/2 way valve and can be sized to suit the flow rate required for the cylinder speed.

Exercise 5: Memory circuit and speed control of a cylinder

A double acting cylinder is to extend fully when a pushbutton is operated. The cylinder is not to retract until full extension is reached. Extension is confirmed by a roller lever valve. The cylinder is to continue forward even if the pushbutton is released before full extension is reached. The speed of the cylinder is to be adjustable in both directions of motion.

Problem definition

Circuit diagram



Solutions

Question 1

1. The memory control valve 1.1 when first fitted could be in either of the two positions 14(Z) or 12(Y), which means that it is not easy to predict the position of the valve when fitted. If a manual override button is available, then the valve should be manually set to the 12(Y) position before turning on the air supply to ensure that the cylinder remains retracted initially.

Question 2

2. For normal operation of the circuit, the valve 1.1 should be initialised to the 12(Y) position before air is applied. The air can be turned on and the pushbutton valve 1.2 then operated to extend the cylinder 1.0. Operation of valve 1.1 produces a signal at 14(Z) of valve 1.1 which switches the air to the 4(A) port of the control valve. At the same time air is exhausted from the unpressurised side of the cylinder, via the 3(S) port. Once the cylinder travels to the limit valve 1.3, a pilot signal is sent to the 12(Y) port of the control valve. This signal will switch the control valve if the pushbutton valve is released. The valve 1.1 then supplies air to the return side of the cylinder via port 2(B) and the unpressurised side of the cylinder is exhausted via port 5(R) of valve 1.1.

The speed of extension and retraction are controlled by the throttle valves 1.01 and 1.02 and in both cases the speed control is by exhaust air throttling. The valve 1.01 controls the return speed and the valve 1.02 controls the advance speed. The check valves fitted in the throttle act as by-pass valves for the supply air to the cylinders. Only the exhausted air is throttled.

Question 3

3. If the pushbutton is held operated even after full extension is reached, the cylinder will remain extended until the pushbutton valve 1.2 is released. The final control element 1.1 is a memory valve with the characteristic that the last position will be retained until a unique opposing signal is received. Thereby, if the signal 14(Z) is applied continuously to the valve 1.1, then a signal applied at 12(Y) by the limit valve 1.3 cannot have any effect until the pushbutton valve 1.2 is released.

Question 4

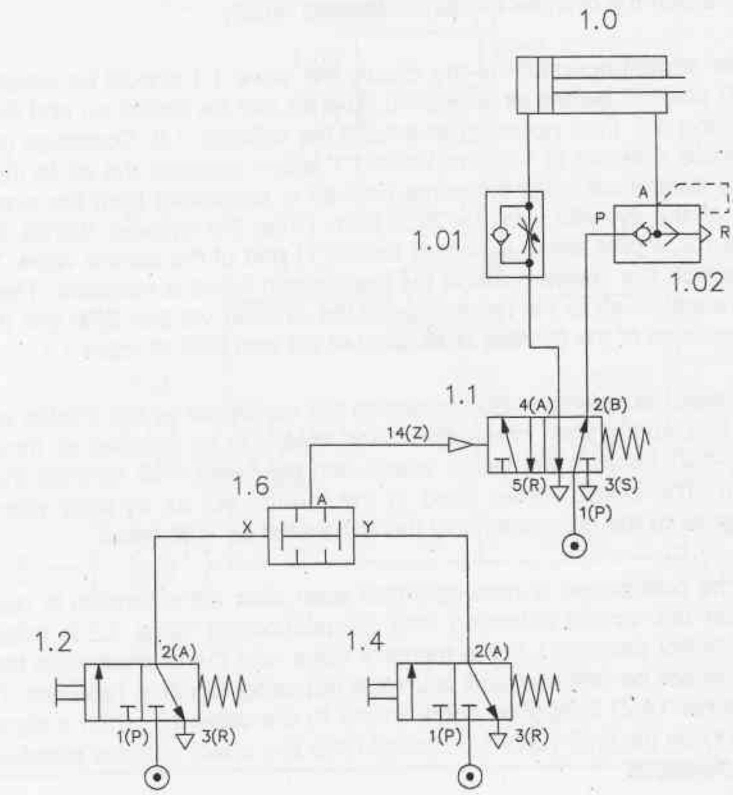
4. If the roller lever valve is fitted at the mid-stroke position of the cylinder, the cylinder will extend up to the limit switch and retract (if the pushbutton is already released). If the pushbutton is inadvertently held down then the cylinder will extend up to the limit switch and then overrun to the fully extended position. In this case the cylinder will not return since the only signal available to return the cylinder has been bypassed (roller valve 1.3). Therefore it would be necessary to manually reset the control valve 1.1 and this would retract the cylinder. A return stroke is only possible if the roller lever valve is manually operated or with the help of the manual override of the final control element.

Exercise 6:
The quick exhaust valve

Problem definition

The operation of two identical pushbutton valves advances a forming tool on an edge-folding device. For rapid forward travel, the circuit utilises a quick exhaust valve. The forward movement folds the edge of a flat sheet. If either of the two pushbuttons are released, the double acting cylinder is to return slowly to the initial position.

Circuit diagram



Solution

Initial position: In the initial state, the cylinder assumes the retracted position. If both of the 3/2 way valves are actuated, a signal is present at the output port A of the two pressure valve 1.6. This reverses the 5/2 way control valve. The cylinder extends with air being supplied via an unrestricted passage through the one way flow control valve 1.03. The actuator travels rapidly to its forward end position since the pressure space on the piston rod side is rapidly exhausted through the quick exhaust valve. If both 3/2 way valves remain actuated, the cylinder remains in the forward end position.

If at least one of the two pushbuttons is released, the actuator is no longer pressurised, since the control valve reverses via the return spring. The actuator travels to its initial position under conditions of restricted flow (valve 1.03) and therefore at a reduced speed.

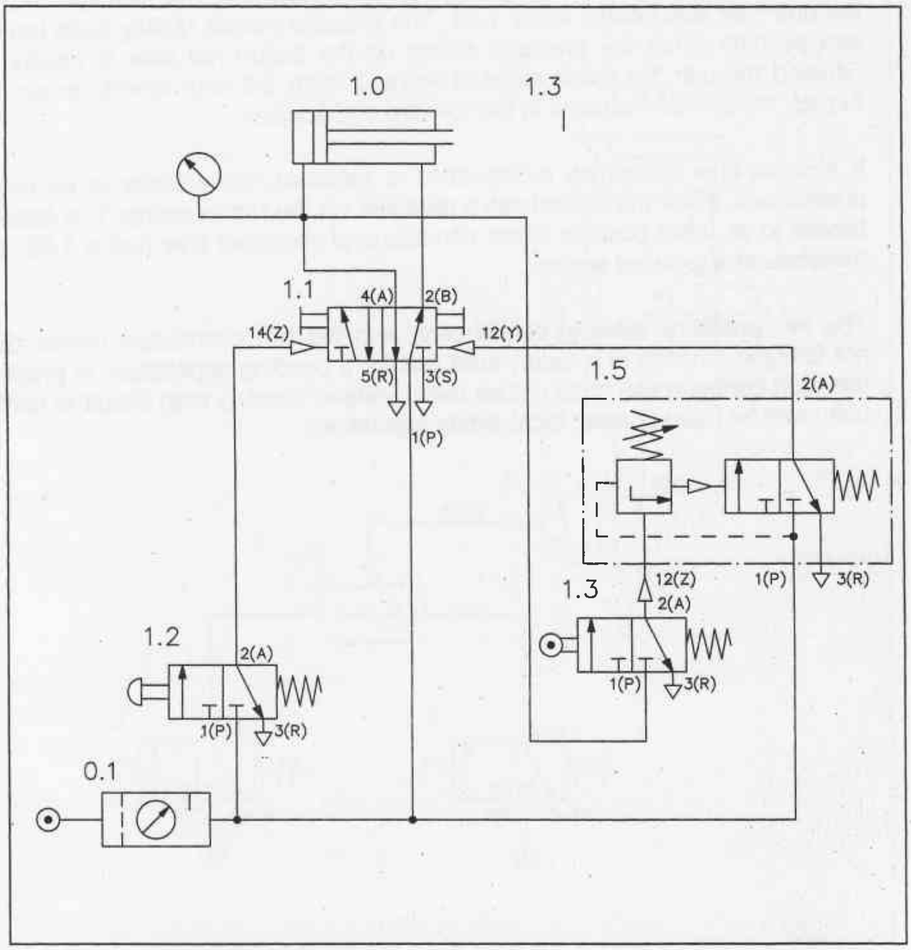
The two pressure valve in combination with the two pushbutton valves does not fulfil the function of a safety start unit for a bending application. In practice, this start configuration must not be used. Instead a safety start circuit or control unit must be used to meet local safety regulations.

Exercise 7:
Pressure dependent control; embossing of plastic components

Problem definition

A plastic component is embossed using a die powered by a double acting cylinder. The die is to advance and emboss the plastic when a pushbutton is operated. The return of the die is to be effected when the cylinder rod has fully extended to the embossing position and the preset pressure is reached. A roller limit valve is to be used to confirm full extension. The pressure in the piston chamber is indicated on the pressure gauge.

Circuit diagram



Knowledge

The power circuit must firstly be initialised by operating the 5/2 way memory valve manually (via the manual overrides) with the air off. The air can then be turned on.

Solution

The cylinder extends if the 5/2 way directional control valve 1.1 is switched via the 14(Z) port by the operation of the pushbutton valve 1.2. The plastic component is embossed under pressure by the die until the preset pressure set on the sequence valve is achieved. The pressure on the advancing side of the cylinder is fed from a junction to the limit valve 1.3 and then in series to the sequence valve. The signal port 12(Z) at the sequence valve acts against the preset compression of the adjustable spring. If the limit valve 1.3 is operated due to full extension of the cylinder and the preset value is reached, then the sequence valve opens from 1(P) to 2(A) and sends a pilot signal to port 12(Y) of the control valve 1.1. If there is no signal at 14(Z), then the memory valve switches and air is supplied from the 2(B) port to retract the cylinder. At the same time the air in the 4(A) port is exhausted and the pilot signal at the sequence valve is therefore relieved through the exhaust port of the limit valve. Therefore the sequence valve cancels the output signal 2(A) and thus the pilot signal 12(Y). The cylinder retracts to the initial position. The pilot signals at 14(Z) and 12(Y) need only to be very short pulses to effect the position of the 5/2 way control valve.

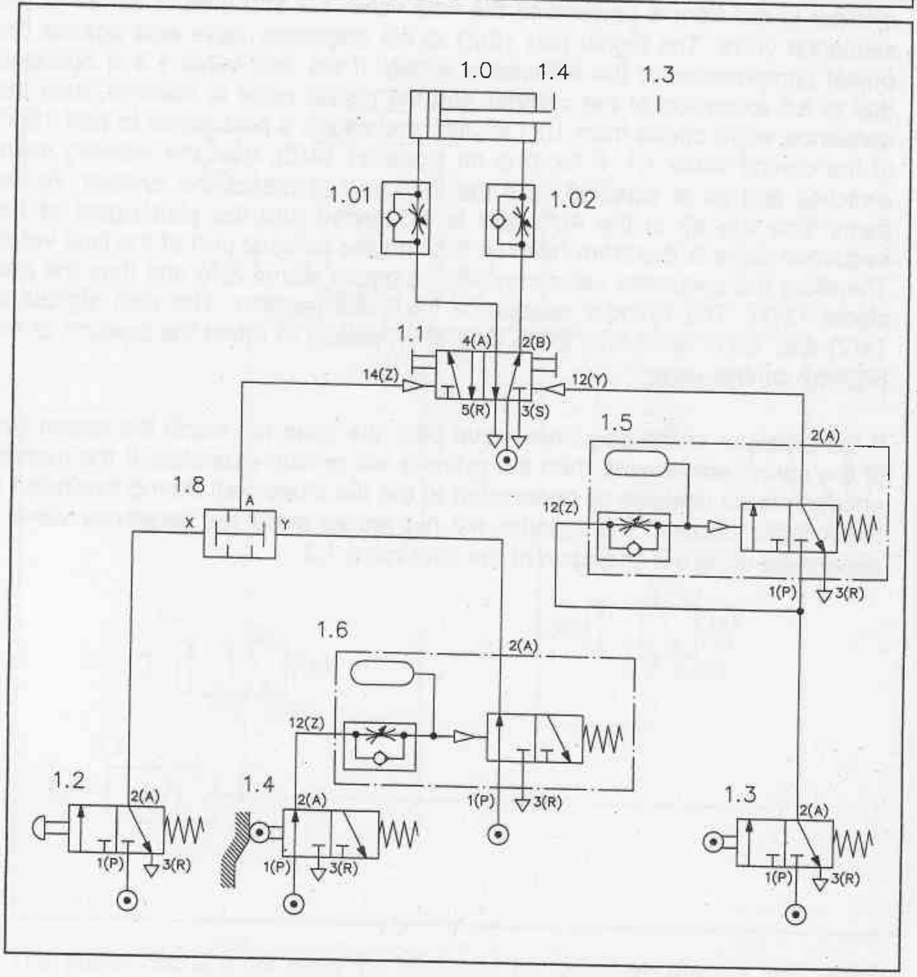
If the pressure at the sequence valve pilot line does not reach the preset limit of the spring adjustment, then the cylinder will remain extended. If the cylinder encounters an obstacle or obstruction to the die movement during extension to the forward position, the cylinder will not retract since the sequence valve is dependent upon the operation of the limit valve 1.3.

Exercise 8:
The time delay valve

Problem definition

A double acting cylinder is used to press together glued components. Upon operation of a pushbutton, the clamping cylinder extends and trips a roller lever valve. Once the fully extended position is reached, the cylinder is to remain for a time of T = 6 seconds and then immediately retract to the initial position. A new start cycle is only possible after the cylinder has fully retracted and after a delay of 5 seconds. The cylinder extension is to be slow and the retraction adjustable, but relatively fast.

Circuit diagram



Knowledge

Initially the cylinder should be at the rest position but this is dependent on the position of the 5/2 way valve 1.1. This memory valve must be positioned manually before air is supplied to the circuit to ensure that the cylinder will be retracted initially.

Solution

The start conditions for the extension of the double acting cylinder 1.0 are the acknowledgement of the retracted position (roller limit valve 1.4) a delay of five seconds after the end of cycle due to timer 1.6 and the operation of the start button valve 1.2. The output signal A at the two pressure valve 1.8 pilots the 5/2 way memory valve at 14(Z). The signal 4(A) extends the cylinder at a preset speed via the flow control valve 1.02 (exhaust throttling). The limit switch 1.4 is deactivated and therefore even if the start button is still held down, the signal at 14(Z) is exhausted by the removal of the limit switch signal, which resets the timer 1.6 until the cylinder has retracted again.

The cylinder reaches the limit valve 1.3 and produces a pilot signal for the time delay valve 1.5. The time delay valve is normally closed and only opens port 2(A) if the preset time, as determined by the adjustable throttle, is reached. The air reservoir in the time delay valve fills, and a pressure is reached that is sufficient to operate the timer against the spring return. A pilot signal is produced 6 seconds after the limit valve 1.3 is operated and that signal is then sent to the 5/2 way valve port 12(Y). The 5/2 way valve switches to the initial position with 2(B) active and 4(A) exhausted. The air to the cylinder is supplied to the return side and the speed controlled by the valve 1.01. The roller limit 1.3 is deactivated and the pilot signal to the timer 1.5 is cut-off, thereby removing the 12(Y) signal from the 5/2 way valve. The cylinder retracts to the limit valve 1.4. A new start signal can only occur if the roller of valve 1.4 is active. The timer 1.6 activates after 5 seconds and the start button must be pressed for a new cycle to commence.

List of standards and references

ISO 1219	Fluid power systems and components; graphic symbols
DIN 19226	Terminology for control systems
DIN 19237	Control technology, concepts
ISO 5599	Pneumatic fluid power; 5-port directional control valve mounting surfaces; general

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