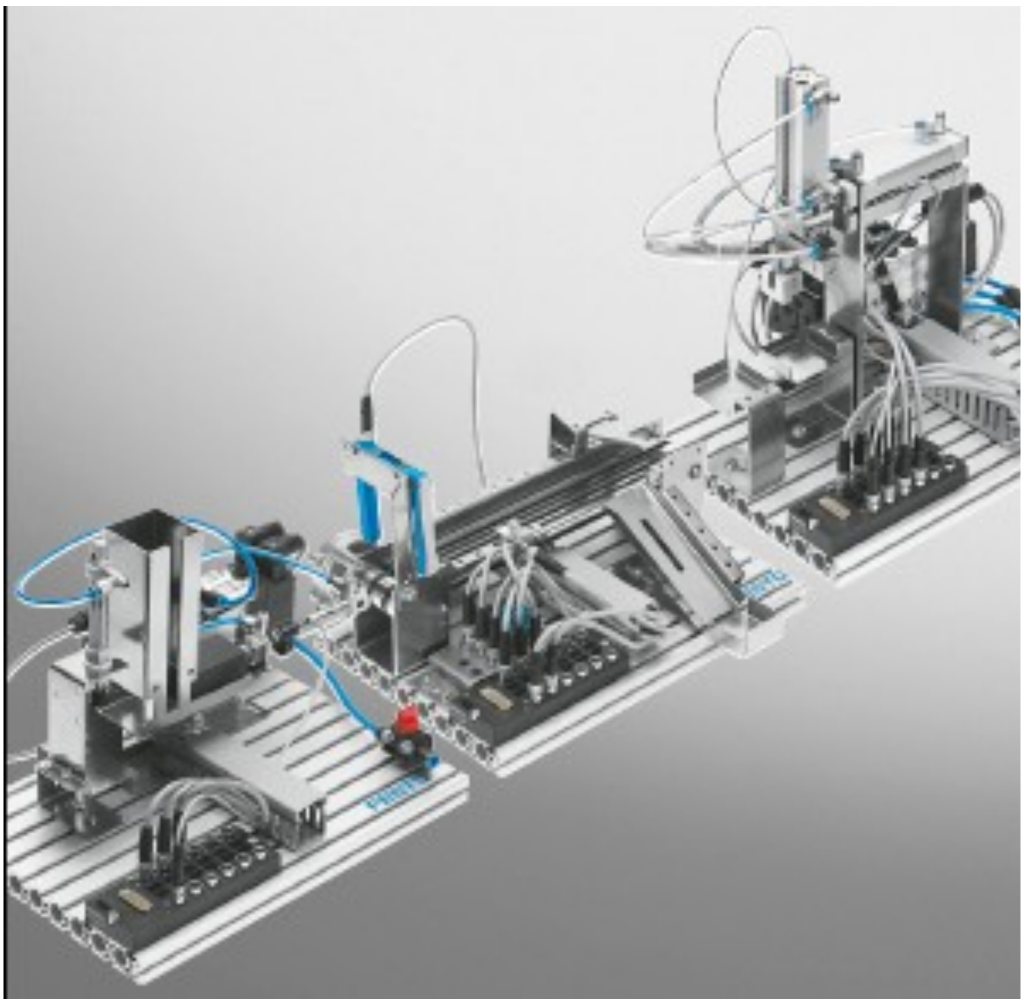
# Festo Learning Systems



# Automation Technology

FESTO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# Engineering

Engineering, like all other sciences, is a discipline with its own language, practices and tools. It draws on principles from other fields, in particular mathematics, physics and social sciences. Many of the findings in these other fields are based on the results of research carried out in the field of engineering.

Unlike natural science, engineering is not concerned with discovering the laws of nature but rather with creating technical solutions to satisfy human needs.

The engineer asks "How can I solve this problem?". This leads to an approach called "black-box thinking". Black box thinking means that engineers use technical systems without regard to how the individual components (in the technical system) work in detail. At this stage the only thing the engineer needs to know is that the device will deliver a specific output when a specific input is applied to the "system".

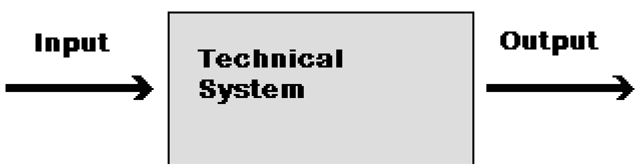



Figure 1.1: Black box representation of a technical system

A machine designer doesn't need to know exactly how an electric motor works. The designer does, however, need to select the right motor using characteristics such as dimensions, torque, speed, current ratings, output, etc.

In contrast, engineers that design electric motors must have an in-depth knowledge of the operation and physical fundamentals of electric motors and components.

## Engineering

Another feature of engineering is the manner in which technical solutions are represented. Engineers use standardized description tools, most of which are graphical. These tools include:

- Technical drawings and parts lists
- Circuit diagrams
- Flow charts and programs
- Technical plans and schematic diagrams

### Technical Drawings and Parts Lists

Technical drawings are used to illustrate the design of a product. They show the dimensions, tolerances, surface finish and materials of the work pieces (dimensional drawings) or the assembly of modules (assembly drawings).

The views of a work piece are arranged on paper using a standard protocol where each view shows the work piece rotated by 90° to the plane of projection. A maximum of six views are possible with this approach. Normally only the views that show all the dimensions required for production are reproduced. Figure 1.2 is an example of a dimensional drawing.

# Engineering

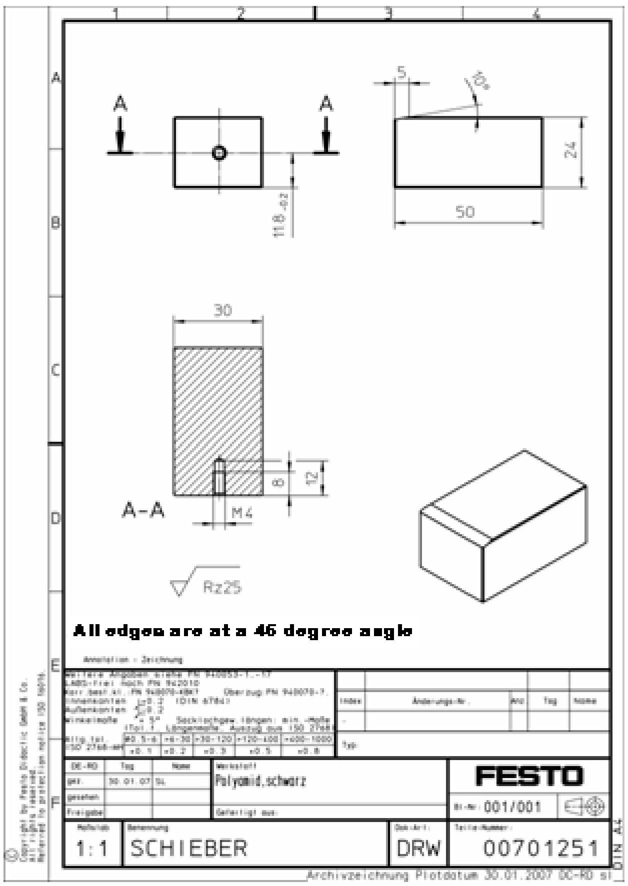



**Figure 1.2: Dimensional drawing of the slide from the stacking magazine**

# Engineering

**Assembly drawings show how each of a modules components make up the finished product. These drawings contain few dimensions, but do show the exact designations of the component parts (Figure 1.3).**

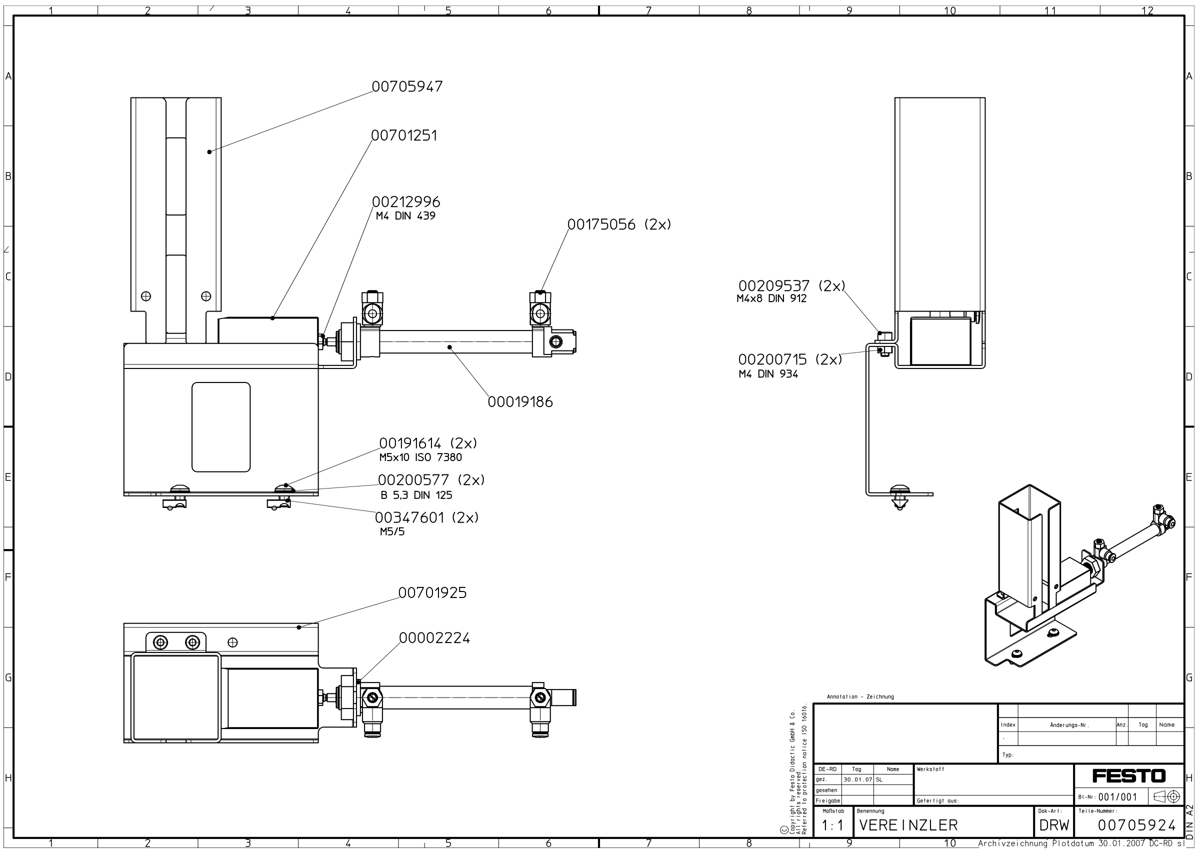



**Figure 1.3: Assembly drawing of the stacking magazine**

**The components are compiled in a parts list that provides information on how many of the respective parts are needed to manufacture the product (Table 1.1).**

# Engineering

| Number | Material number | Description |
|---|---|---|
| 1 | 00705947 | Gravity feed chute |
| 1 | 00701251 | Slide |
| 1 | 00701925 | Body |
| 1 | 00019186 | Pneumatic cylinder DSNU 10-50-PA |
| 2 | 00175056 | One-way flow control valve GRLA-M5-QS-4-LF-C |
| 2 | 00191614 | Tallow-drop screw M5 x1 0 ISO 7380 |
| 2 | 00200577 | Washer B 5.3 DIN 125 |
| 2 | 00347601 | T-head nut M5 |
| 2 | 00209537 | Socket head screw M4 x 8 DIN 912 |
| 2 | 00200715 | Nut M4 DIN 934 |
| 1 | 00002224 | Sealing ring |

Table 1.1: Example of a parts list (for Figure 1.3)

Each component has its own dimensional drawing that can be used as a basis for its manufacture. The only parts for which individual drawings are not produced are standard parts such as screws and ball bearings etc. Standard parts are identified in the parts list by their designation, which include a reference to the standard (e.g. ISO 7380).

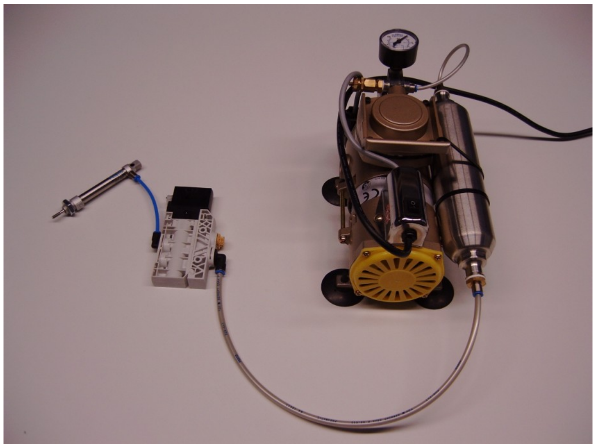
Engineers use standard parts whenever possible as they are inexpensive, can be bought in required quantities and meet the specified quality standards. This makes it easier for engineers to design the product and to repair it in the event of a malfunction.

## Circuit Diagrams

While technical drawings show the outer design of a product, circuit diagrams show how the electric, pneumatic or hydraulic components of a technical system or installation are connected. Standardized symbols are used to refer to the function of the component, regardless of their design or what they actually look like. Circuit diagrams are more abstract than technical drawings.

## Engineering

Figure 1.4 shows the circuit diagram for a pneumatic circuit.



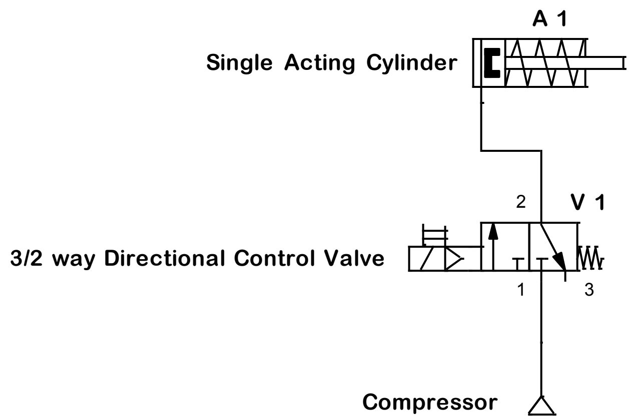



Figure 1.4: Components and how they are represented in a (pneumatic) circuit diagram

The drawing components, connections, etc. are numbered or labelled in order to reference the components on the machine.

# Engineering

## Flow charts and Programs

Most modern controllers are program controllers. This means that a computer program coordinates and directs control of the system. Special programming languages have been developed; Fortran (Formula Translation) for mathematical problems, Cobol (Common Business Oriented Language) for business programs, Ladder Diagram for logic control systems or Basic (Beginner's All-purpose Symbolic Instruction Code) as an easy-to-learn, all-purpose programming language.

The following is an example of how a basic program is developed. Before the actual programming can be started, the algorithm is developed in the form of a flow diagram. Figure 1.5 shows a flow diagram for the following control sequence:

- The status of pushbuttons 1 and 2 is checked.
- If both switches have a status 1 (on), then the cylinder is extended.
- In all other cases repeat all of the above.

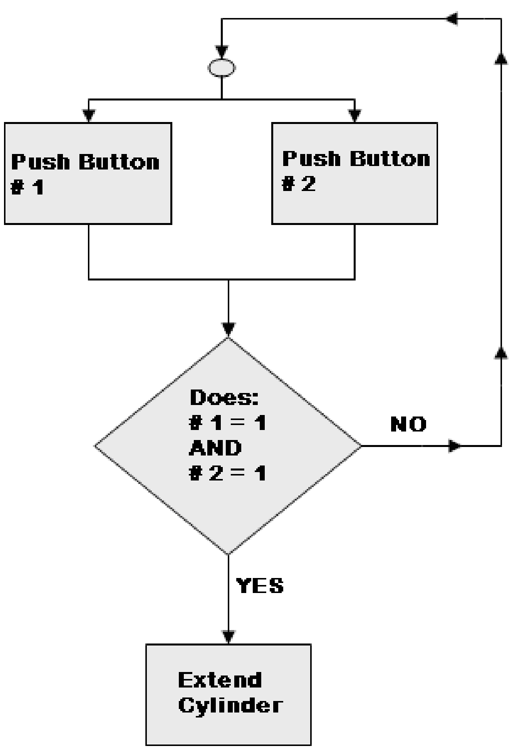



Figure 1.5: Flow diagram

# Engineering

A Basic program for the sequence shown in Figure 1.5 could go something like:

```
10      P1 = Pushbutton 1
20      P2 = Pushbutton 2
30      If (P1 = 1) and (P2 = 1) then advance cylinder, otherwise go to 10
```

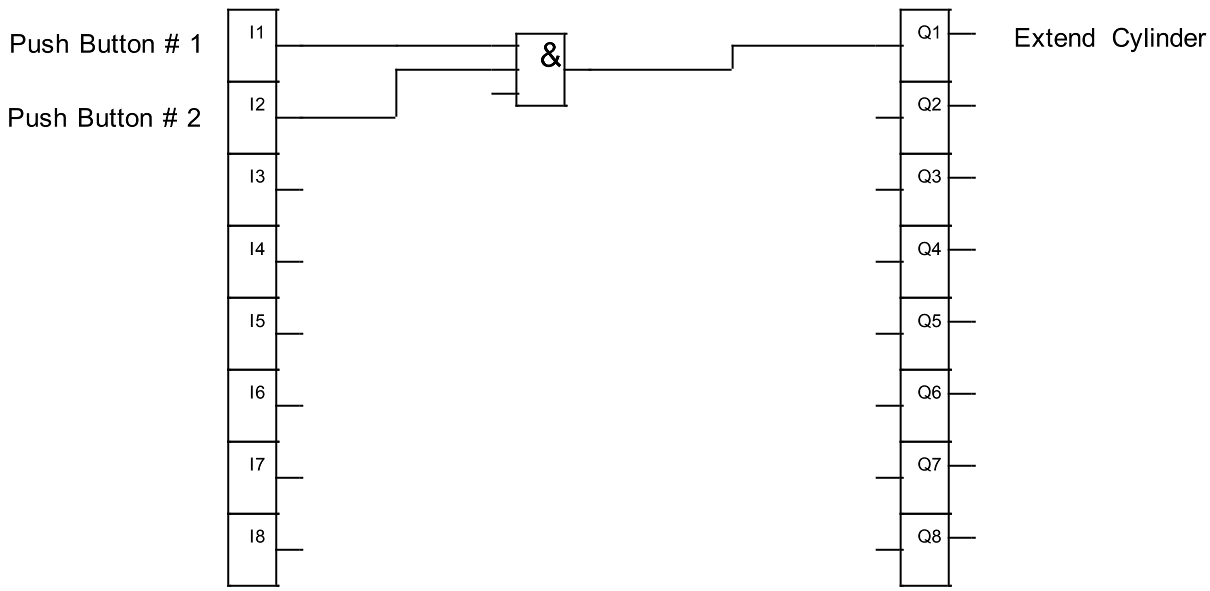
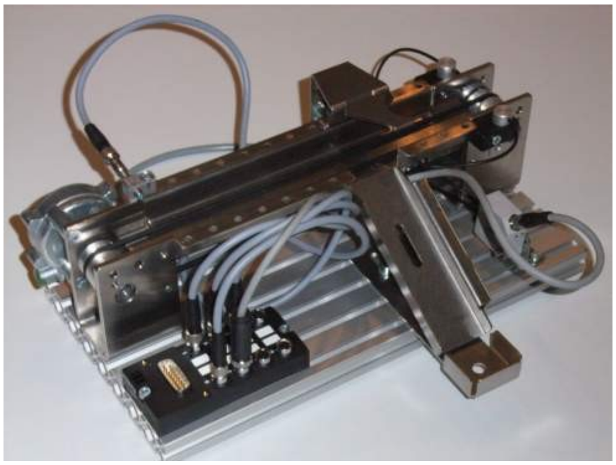



Figure 1.6: Logic program

## Technical Plans and Schematic Diagrams

A technical plan or schematic diagram is used to illustrate the function of a machine. An important characteristic of a plan or diagram is that it must portray the interaction and basic arrangement of the components and modules realistically. To illustrate key relationships, control components such as sensors can be labelled in the technical plan with the same designation as in the program or the circuit diagram. Figure 1.7 shows an example.

# Engineering



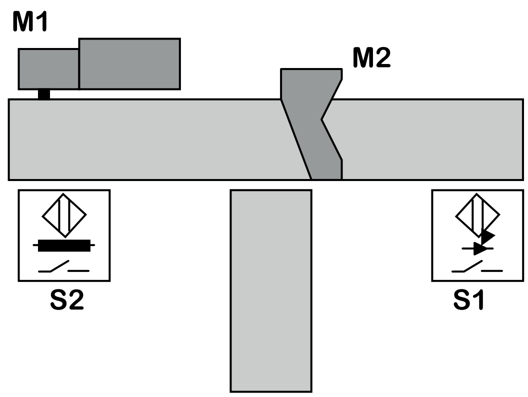



Figure 1.7: Picture and schematic diagram of the conveyor module

## Calculations and Simulation

Calculations are frequently required to ensure the operability of the machines under all circumstances. Examples of this are the calculation of force and torque for sizing drives or the calculation of current limits for sizing power lines.

Related to the topic of calculation is the use of simulation. Engineers try, wherever possible, to test and improve their designs via simulation before a (costly) prototype is built.

A good example of this is the FluidSIM® program that enables students to test and simulate their pneumatic, logic or electrical circuits before building them. If the circuit works, then it can also be used to control the actual model. In this case, the use of simulation enables several students to work simultaneously on one problem.

## Automation Technology as an Engineering Science

**Examples of engineering-related sciences include:**

- **Mechanical Engineering**
- **Electrical Engineering**
- **Production Engineering**
- **Structural Engineering**

**These sciences all have something in common. That is research, definition and application of engineering principles. What differentiates them is the subject matter and the orientation of the respective discipline.**

**Automation technology is a crossover discipline that uses knowledge and scientific methods from numerous other technical sciences. An automatic machine is an artificial system that makes decisions based on the conditions of inputs with respect to the state of the system. These decisions produce very specific outputs.**

**Automatic processes are comprised of three components. They are:**

- **Sensors to detect the status of the system**
- **Actuators to perform the actual “work” of the system**
- **Controllers to store the program and to make decisions**

# Automation Technology as an Engineering Science

## Key Milestones in the History of Automation Technology

When the term "automation technology" is used, one might picture industrial robots and computer controllers, but automation technology began with the utilization of the steam engine by James Watt in 1769. For the first time, a machine could replace man or horsepower.

The first steam engines were used to drain water from mines and to drive machine tools. These applications involved a single steam engine driving a number of machines via a complicated system of transmission shafts and leather belts mounted on the ceiling of the machine hall.

In 1820 the Danish physicist Oersted discovered electromagnetism. In 1834 Thomas Davenport developed the first direct current motor with commutator (reverser) and received the patent for it one year later. Nevertheless, it was not until 1866 that the electric motor became widely used. This was after Werner von Siemens invented the dynamo that provided a simple way of generating electrical current in large quantities. The electric motor replaced the steam engine as a driving component.

In 1913 Henry Ford introduced the first assembly line production system for the famous Model T (Figure 2.1). This resulted in much higher productivity, as production time for a car fell from 750 to just 93 hours. This was the basis for the series production of cars. This higher productivity enabled the Ford company to pay its workers a daily wage of 5 dollars for 8 hours of work in 1913. The price for a Model T fell to around 600 dollars. The automobile became available to a wider economic section of the population.

The science behind assembly line production was based on the work of Frederick Winslow Taylor on the division of labor. This was the principle of dividing the work to be performed into many “simple tasks” that unskilled workers were able to perform.

# Automation Technology as an Engineering Science

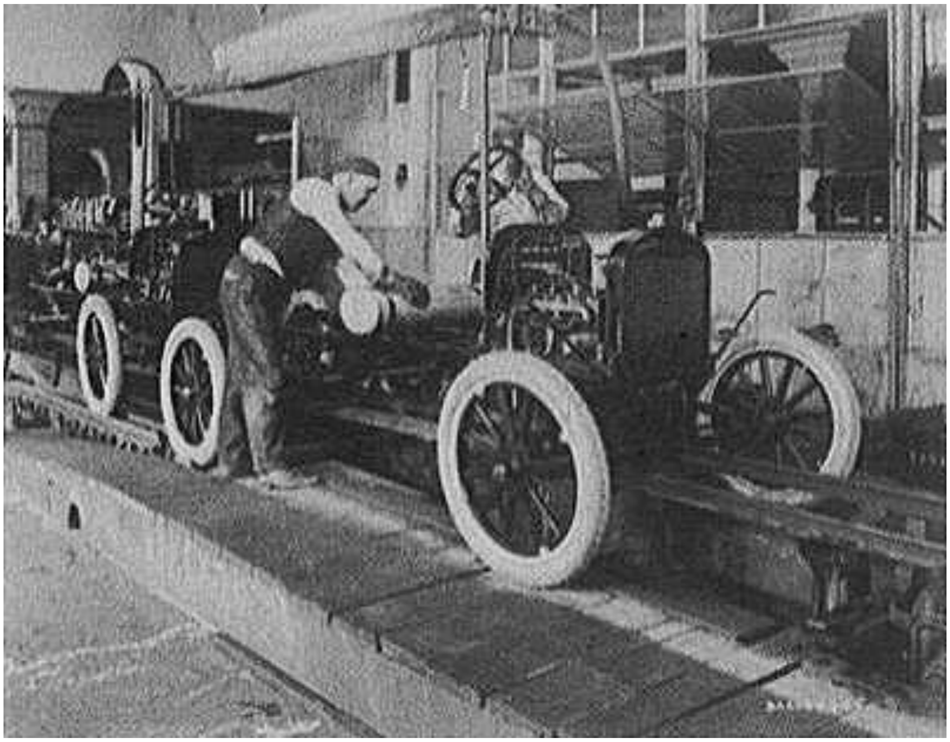


Figure 2.1: Assembly line production at Ford (1921)

In 1873 a patent was granted for an automatic machine that manufactured screws. This machine used "cam disks" to store the individual program sequences.

In 1837 Joseph Henry invented an electromagnetic switch that was called a relay . It was called a relay after the "relay stations" where Pony Express riders "switched" their tired horses for fresh ones.

They were initially used for signal amplification in morse code stations. Later they were used for building electrical controllers. This type of controller, where the relays are hard wired together, were called hard-wired programmed controllers, a name still used today. Relays could now be used to master complex control tasks, however the hard wiring meant that programming and troubleshooting was a time consuming process.

In 1959 Joseph Engelberger presented the prototype for an industrial robot that was used by General Motors in automobile production from 1961. The robot used hydraulic drives. It was not until later that industrial robots were fitted exclusively with electric motors.

## Automation Technology as an Engineering Science

In 1968 a team from Allen Bradley, under the leadership of Odo Struger, developed the first programmable logic controller (PLC). Now it was possible to simply change a program without having to rewire relays.

### Effects of Automation on People

One of the main reasons for the introduction of automated systems was the desire to produce goods for less cost than the competition. Automation technology helps in several ways:

- Fewer workers are needed for automated production.
- Production can run 24/7 (24 hours a day, 7 days a week) except for a few maintenance periods.
- Machines generally make fewer mistakes. This means the quality of product is consistently high.
- Production times are shortened. This means that more product can be shipped faster.
- Automation relieves people of boring, physically heavy or hazardous work.

There are also less positive effects associated with automation technology, such as:

- The loss of jobs. In particular those with low skill level requirements (one highly qualified service technician can take the place of 10 unskilled assembly workers).
- Production automation occasionally demands that employees make decisions. The complexity of the system might make it difficult to fully understand the consequences of those decisions.
- The investment a company makes in an automated system tends to increase each individual's responsibility for the success of the company as a whole.

# Electrical Engineering Basics

## Direct and Alternating Current

One of the most important foundations for automation technology is electrical engineering. Since most technical systems need electrical energy both to operate and to process incoming signals an overview of the basics of electrical engineering is provided below.

A simple electrical circuit consists of a supply voltage (or “source”), a consuming device (or “load”) and the connecting wires (or “conductors”) for transmitting the electrical energy (or “current”). Every electrical circuit is subject to the following simple rule: "from the source to the load and back".

In physical terms, within the electrical circuit are negatively charged particles, called electrons. These electrons move from the negative terminal of the supply voltage (or “source”) to the positive terminal via the conductor. Movement of the electrons is referred to as electrical current. An electrical current can only flow when the circuit is closed.

A distinction is made between direct and alternating currents:

- If the source provides voltage in one direction then the current flows in one direction. This is direct current (DC) or a DC circuit.
- If the source changes both the intensity and the direction of the applied voltage, then the current will also change direction. This is alternating current (AC) or an AC circuit.

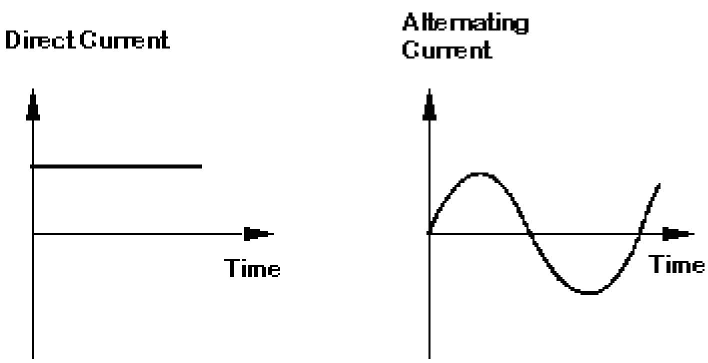



Figure 3.1: Symbols for direct and alternating current plotted over time

# Electrical Engineering Basics

Figure 3.2 shows a simple DC circuit consisting of a voltage supply, electrical cables, a control switch and a consuming device (a bulb in the example).

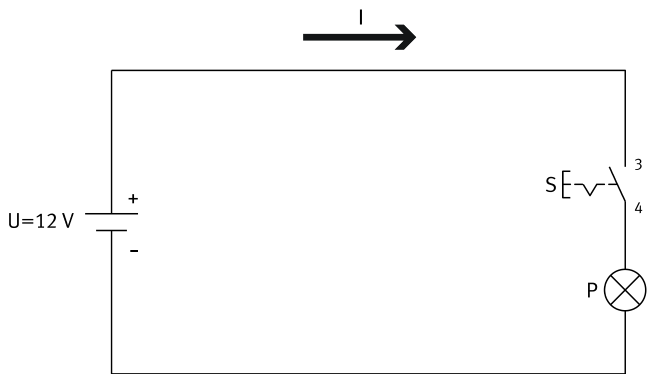



Figure 3.2: DC circuit

### Direction of Current Flow

When the switch is closed, current “I” flows through the load “P”. The electrons move from the negative terminal to the positive terminal of the voltage supply. Before the existence of electrons was discovered, the direction of current was defined as flowing from "positive" to "negative". This definition is still valid in practice today and is called the technical direction of current.

## Resistance and Power

## Electrical Conductor

The term electrical current refers to the movement of electrons. For a current to flow in a material, there must be sufficient free electrons present. Materials that meet this criterion are called electrical conductors. Copper, aluminium and silver are particularly good electrical conductors. Copper is the main conductive material used in control technology.

## Resistance

All materials, including electrical conductors, offer resistance to the electrical current. This is caused by the freely moving electrons colliding with the atoms in the conductive material. This results in their movement being impeded. Electrical conductors have low resistance. Materials with high resistance to the electrical current are called electrical insulators. Rubber and plastic-based materials are used to insulate electrical cables.

# Electrical Engineering Basics

## Ohm's Law

Ohm's law describes the relationship between voltage, current and resistance. It states that in a circuit with a given electrical resistance, the current changes in direct proportion to the voltage. In other words, if the voltage rises, the current will also rise and if the voltage drops, the current will also drop.

E (V)

I | R

| | | |
|---|---|---|
| E (or V) | = voltage | Unit: volt (V) |
| R | = resistance | Unit: ohm (Ω) |
| I | = current intensity | Unit: ampere (A) |

## Power

Electrical power can be defined in terms of work. The faster work is done, the greater the power required. Power is therefore work per unit of time.

In the case of a load in an electrical circuit, electrical energy is converted into kinetic energy (an electric motor), light (a simple light bulb) or heat (heater etc.) The faster the energy is converted, the higher the electrical power.

The electrical power of a load is also referred to as “consumption”.

$$P = I \times E$$

| | | |
|---|---|---|
| P | = power | Unit: watt (W) |
| E (or V) | = voltage | Unit: volt (V) |
| I | = current | Unit: ampere (A) |

# Electrical Engineering Basics

## Electrical Power of a Coil

The solenoid coil of a pneumatic valve (the 4/2-way solenoid valve in the handling station) is supplied with 24 V DC. The resistance of the coil is 60 Ω.

Calculate the solenoid coil's electrical consumption.

The current intensity is calculated using Ohm's law:

$$I = \frac{V}{R} = \frac{24\,V}{60\,\Omega} = 0.4\,A$$

The electrical consumption is the product of the current intensity and voltage:

$$P = V \cdot I = 24\,V \cdot 0.4\,A = 9.6\,W$$

The electrical consumption of the solenoid coil is 9.6 W.

## How a solenoid works

When current flows through an electrical conductor, a magnetic field builds up around it. This magnetic field grows in size if the current is increased. Magnetic fields exert an attractive force on work pieces made from iron, nickel or cobalt. This force increases as the magnetic field grows.

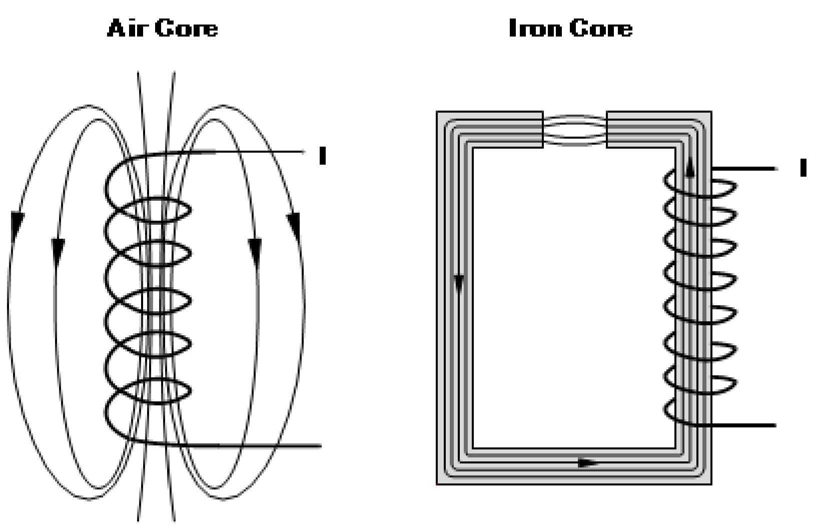



Figure 3.3: Electric coils with and without an iron core and their magnetic field lines

# Electrical Engineering Basics

## Structure of Solenoids

A solenoid has the following structure:

- The conductor is wound in the shape of a coil (air-core). As current flows through the coil a magnetic field is generated. The magnetic field is intensified by the multiple windings (or layers) of wires (see Figure 3.3).
- An iron core is placed in the coil. When current flows, the iron is magnetized. This provides a much stronger magnetic field than an air-core type coil.

Both of these features ensure that a solenoid exerts a strong force on ferrous materials even when the current intensity is low.

## Applications of Solenoids

In electro pneumatic control systems, “coils” are used to change the position of valves, relays or contactors. To explain how this happens, we will use the example of a spring-return directional control valve:
When current flows through the solenoid coil, the valve piston is actuated.
When the current flow is interrupted, a spring pushes the valve piston back into its initial position.

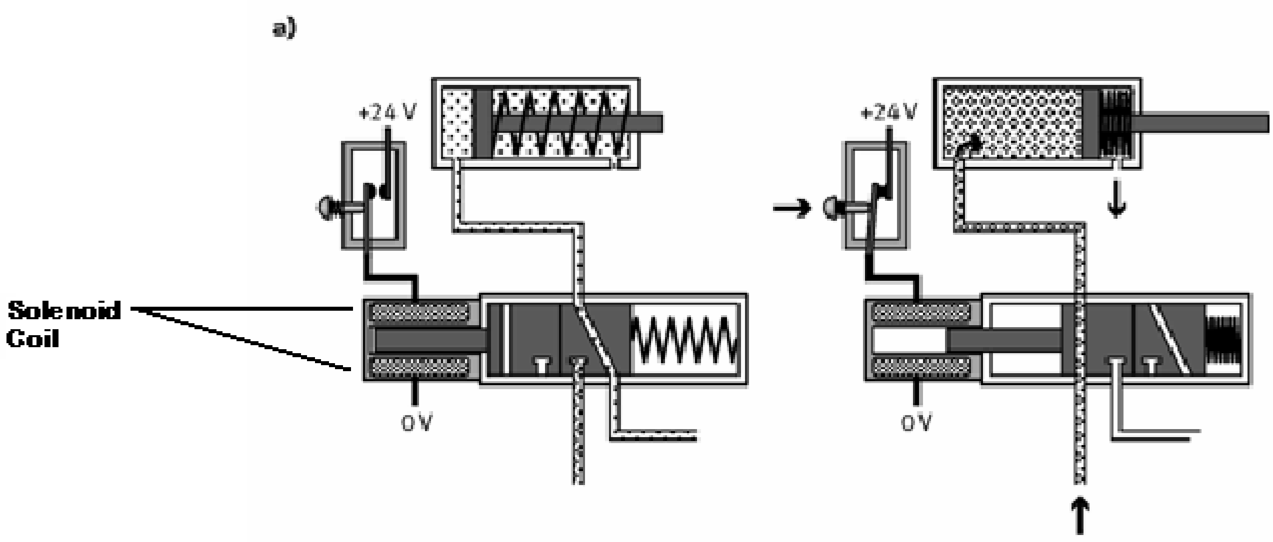



Figure 3.1: Operation of a solenoid valve

# Electrical Engineering Basics

## How Capacitors Work

A capacitor consists of two conductive plates separated by an insulating layer (also called dielectric material). When a capacitor is connected to a DC voltage supply (closing the pushbutton S1 in Figure 3.5), there is a brief flow of current, which electrically charges the two plates.

If the connection to the voltage supply is then interrupted (opening the pushbutton S1), the charge remains stored in the capacitor. The greater the capacitance of a capacitor, the more electrically charged particles it stores at the same voltage. The actual size specification for a capacitor is the capacitance C. It is defined as the relationship between the magnitude of charge Q stored in the capacitor and the voltage V applied to the capacitor:

$$C = \frac{Q}{V}$$

The unit of capacitance is the "farad" (F):

$$1\,F = 1\,\frac{As}{V}$$

When the electrically charged capacitor is connected to a load (closing the pushbutton S2 in Figure 3.5), current flows through the load until the capacitor is fully discharged.

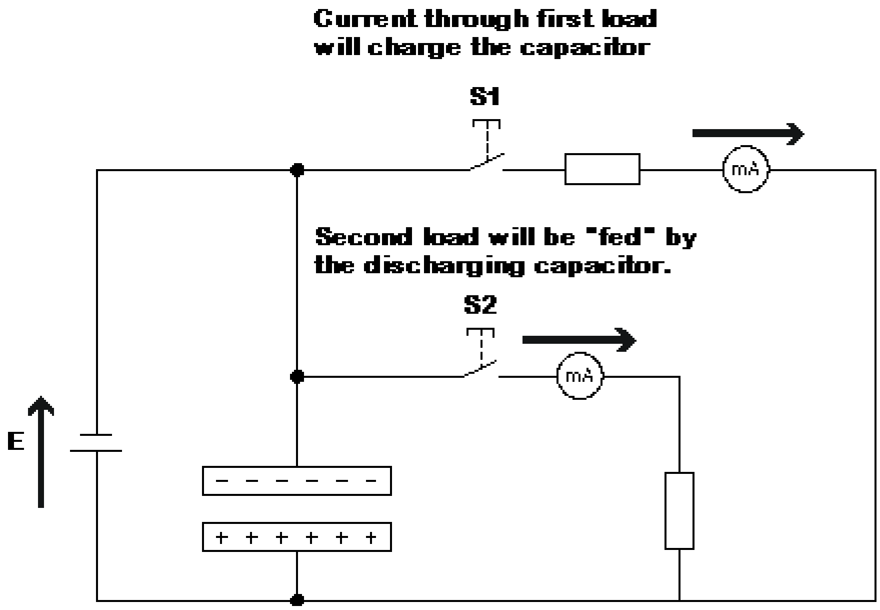



Figure 3.5: How a capacitor works

# Electrical Engineering Basics

## How a Diode Works

Diodes are electrical (semiconductor) components whose resistance differs depending on the direction in which the electrical current is flowing:

- When the diode is switched in the free-flow direction its resistance is very low, which means the electrical current can flow almost unimpeded.
- When it is switched in the blocked direction its resistance is extremely high, which means no current can flow.

When a diode is integrated in an AC circuit, the current can only flow in one direction. The electrical current is rectified (see Figure 3.6).
A diode's effect on the electrical current can be compared to the effect of a bicycle valve that allows air to enter a tIre but prevents it from escaping again.

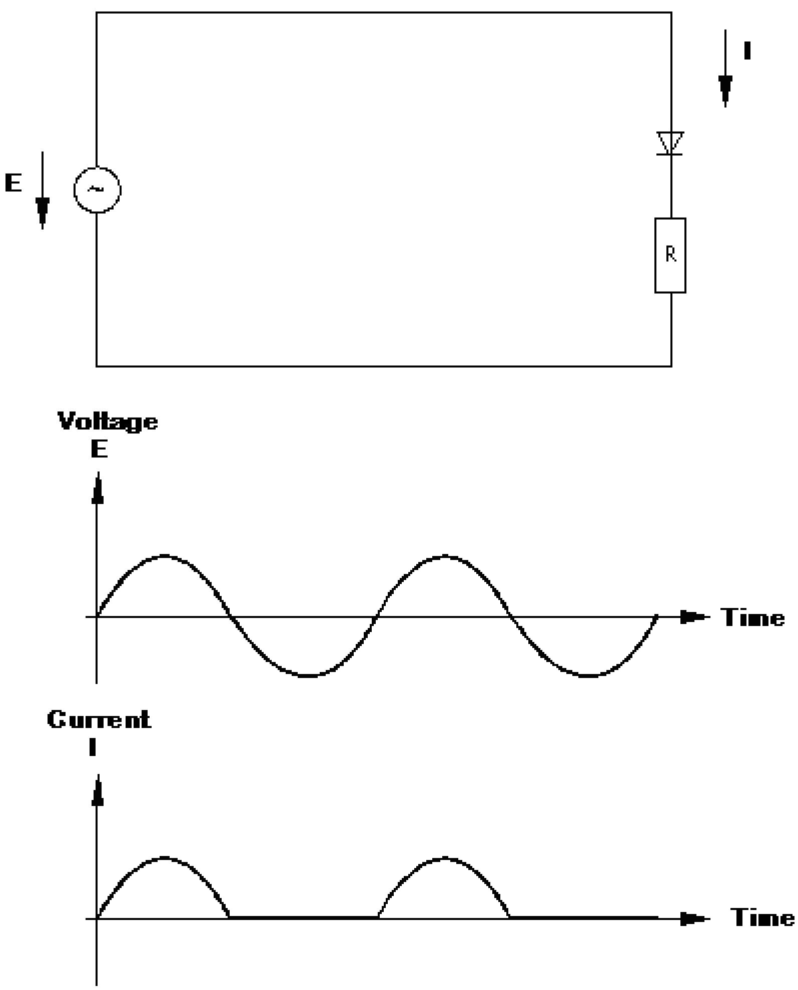



Figure 3.6: How a diode works

# Electrical Engineering Basics

## Construction and Operation of Switches

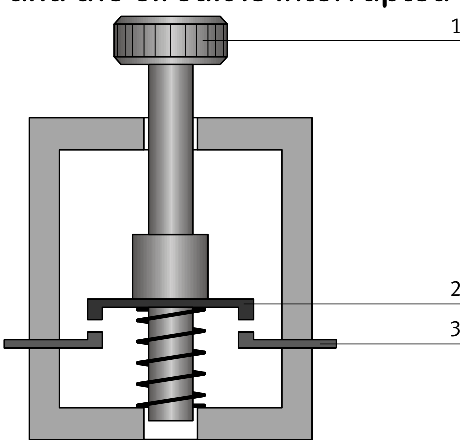
Switches are used to facilitate or to interrupt current flow in an electrical circuit. Depending on their design, switches can either be pushbutton or detented.

- In the case of a pushbutton, the chosen switching position is only maintained for as long as the pushbutton is actuated. Pushbuttons are used in doorbells, for example.
- In the case of a detented switch, both switching positions (ON/OFF) are mechanically latched. Each switching position is maintained until the switch is actuated again. Light switches in houses are an example of a latching switch in use.

Another type of classification for switches is their normal position. Switches are either normally open (N.O.) or normally closed (N.C.).

## Normally Open Contacts

In the case of a normally open contact , the circuit is interrupted (current can not flow) when the pushbutton is in its normal position. Pressing the pushbutton closes the circuit and current will flow. When the pushbutton is released, spring force returns it to its normal position and the circuit is interrupted once more.



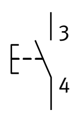




Figure 3.7: Sectional view and circuit symbol for a N.O. contact

# Electrical Engineering Basics

## Normally Closed Contacts

In the case of a normally closed contact (N.C.), the circuit is closed by spring force when the pushbutton is in its normal position. Pressing the pushbutton interrupts the circuit.

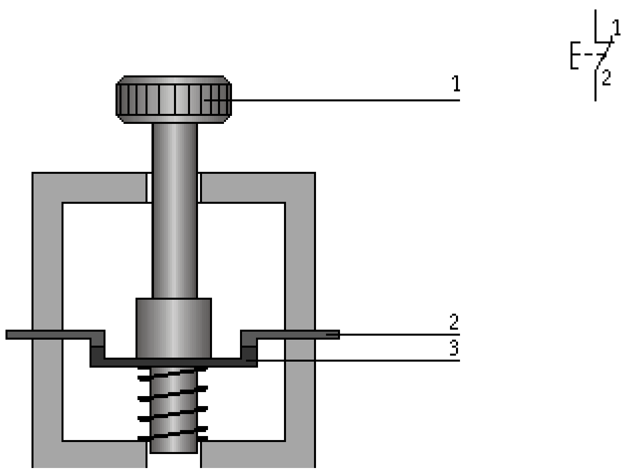



Figure 3.8: Sectional view and circuit symbol for a N.C. contact

## Changeover Switches

The changeover switch combines the functions of a N.C. contact and a N.O. contact in one device. They are used to close one circuit and open another one with a single switching operation. Both circuits are briefly interrupted during the changeover.

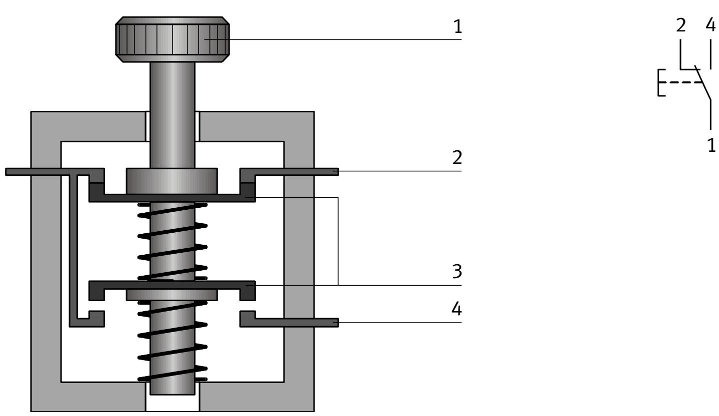



Figure 3.9: Sectional view and circuit symbol for a changeover switch

# Electrical Engineering Basics

## Relays and Contactors

Relays are used in electro pneumatic control systems to:

- Multiply signals
- Delay and convert signals
- Link information
- Separate the control and main circuits

They are also used in electrical control systems to separate DC and AC circuits.

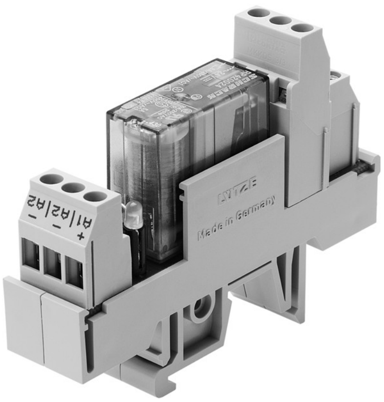



Figure 3.10: Relay

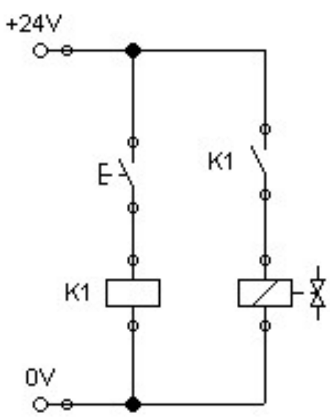
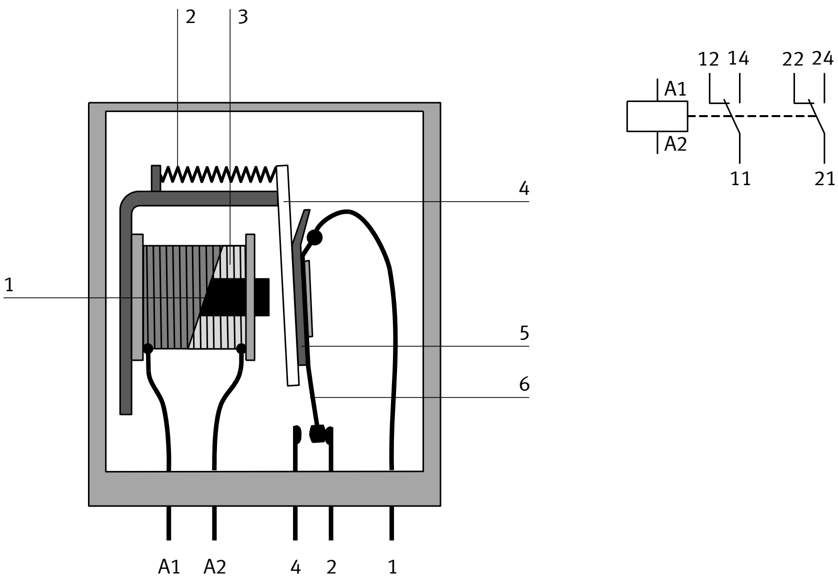



Figure 3.11: Circuit diagram for a basic relay circuit

# Electrical Engineering Basics

## Structure of a Relay

A relay is an electro-magnetic switch that uses one electrical signal to control another. It consists of a coil with an iron core (see (3)(1) in Figure 3.12), an armature as a mechanical actuating element (4), a return spring (2) and switch contacts (6). When a voltage is applied to the solenoid coil, an electromagnetic field is generated. This causes the movable armature to move towards the coil core. The armature acts upon the relay contacts that are either closed or opened, depending on the arrangement. If the flow of current through the coil is interrupted, a spring returns the armature to its initial position.




1-Coil Core
2-Return Spring
3-Relay coil
4-Armature
5-Insulation
6-Contact

Figure 3.12: Sectional view and circuit symbol for a relay

A relay coil can be used to switch one or more contacts. In addition to the relay type described above, there are other designs of electromagnetically-actuated switches for example the remanent relay, the time relay and the contactor.

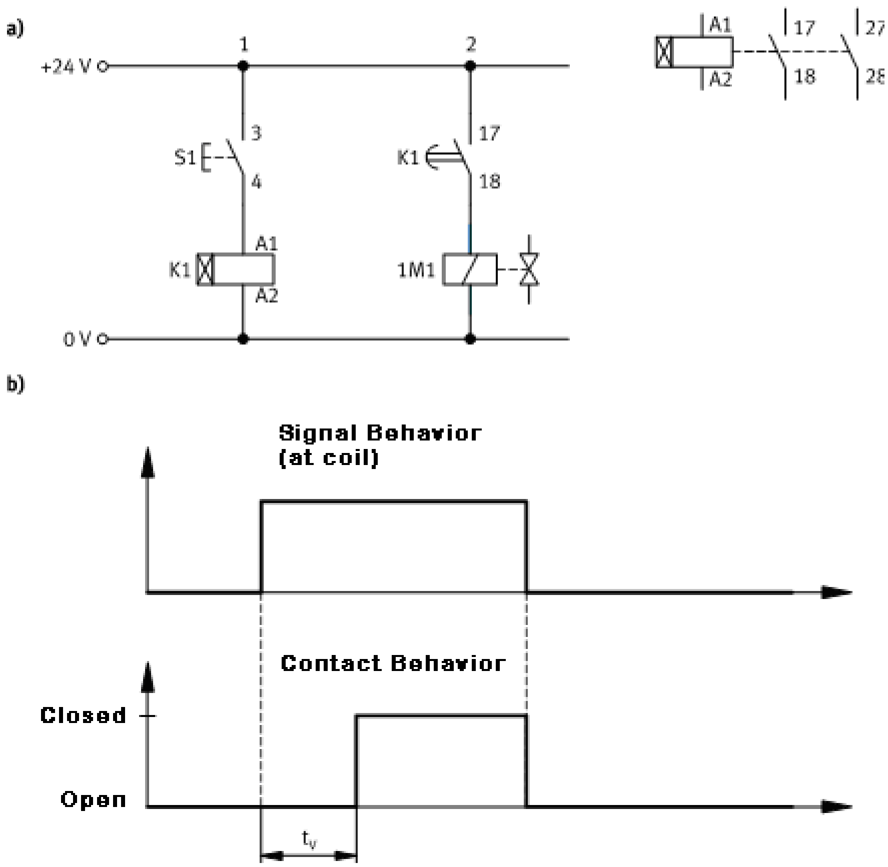
 

# Electrical Engineering Basics

## Time Relays

In the case of time relays, a distinction is made between relays that are delay-on and relays that are delay-off.

In a delay-on relay, the armature switches on after a preset delay ($t_d$) there is no switch-off delay. In a delay-off relay, the reverse happens. The contacts switch accordingly (see Figures 3.13/3.14). The delay time ($t_d$)can be set as required.

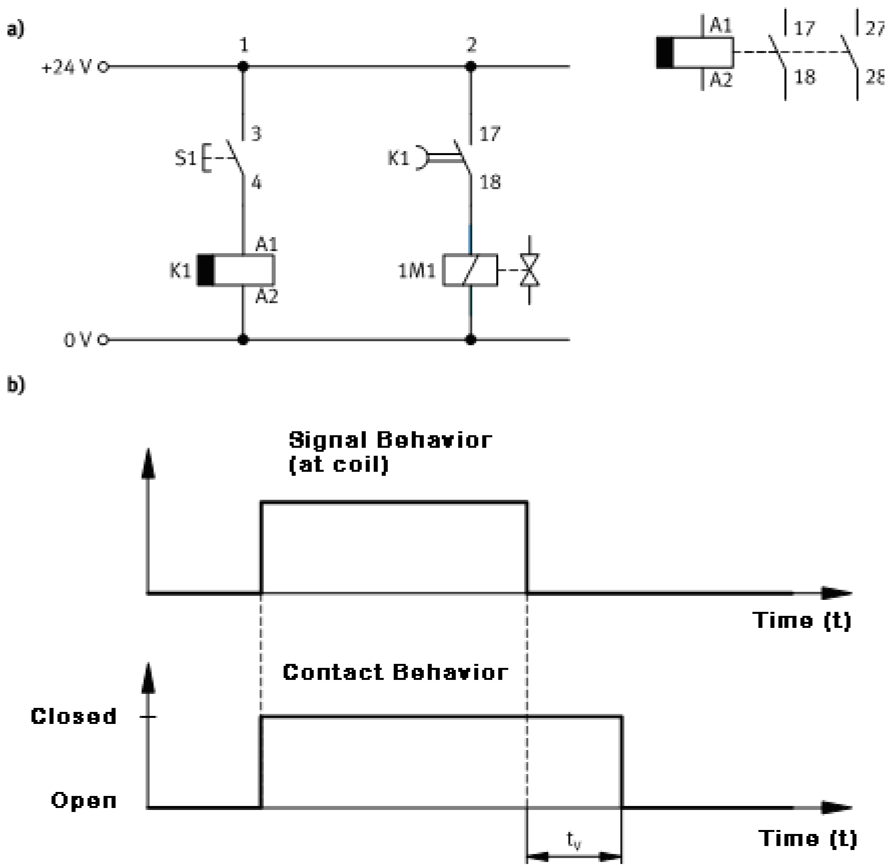



a) Electrical circuit diagram

b) Signal behavior

Figure 3.13: Delay-on relay

# Electrical Engineering Basics




a) Electrical circuit diagram

b) Signal behavior

Figure 3.14: Relay with switch-off delay

# Electrical Engineering Basics

## Function and Structure of the Power Supply Unit

The MecLab® controller includes a power supply unit (see Figure 3.15). The individual modules of the power supply unit have the following purposes:

1. The transformer reduces the operating voltage. Input voltage (at 115 VAC) is applied to the transformer inlet and is reduced to 24 VAC.
2. The rectifier converts the AC voltage into DC voltage. The capacitor at the rectifier outlet serves to smooth the voltage signal.
3. The voltage regulator keeps the electrical voltage constant.

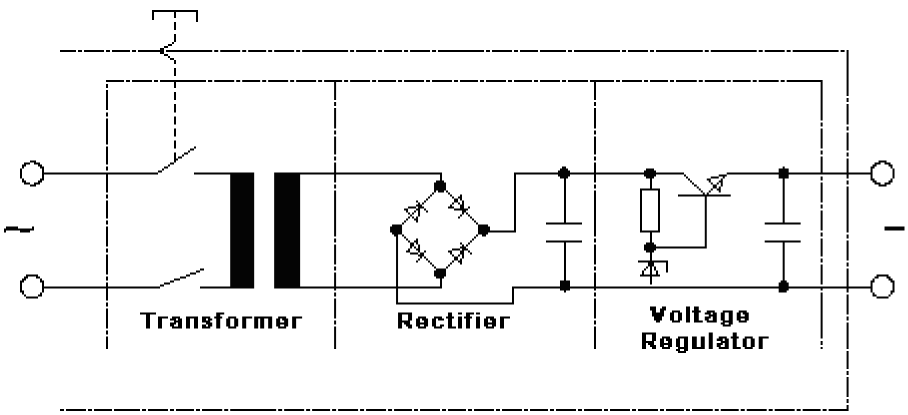



Figure 3.15: Modules in the power supply unit of an electro pneumatic control system

## Safety Information

Power supply units use high-voltage.
All Safety regulations for high-voltage systems must be observed.

Only authorized persons may work on the power supply unit .

# Electrical Engineering Basics

## Measurements in an Electrical Circuit

Measuring means comparing an unknown variable with a known variable (for example the length of a pneumatic cylinder compared to the scale on a measuring tape). A measuring device (a steel ruler) is used to make the comparison. The result (the measured value) consists of a numerical value and a unit (for example 12 in.).

Electrical current, voltage and resistance is measured with a device called a multimeter. Multimeters can be switched between different operating modes:

- AC voltage (alternating current)
- DC voltage (direct current)
- Current
- Resistance measurement.

Correct measurements are possible only if the correct operating mode is set and the measuring device has been placed correctly into the circuit.

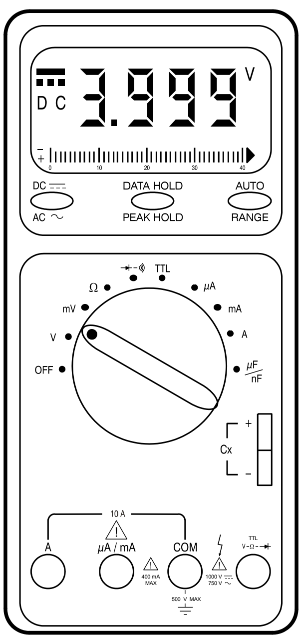



Figure 3.16: Multimeter

# Electrical Engineering Basics

## Safety information

- Before taking a measurement, ensure that the supply voltage is no more than 24 V.
- Measurements on control systems with a high voltage may only be performed by trained personnel.
- Failure to adhere to the correct procedure for measurements can be fatal.

## Measuring Procedures

Proceed in the following order when performing measurements in an electrical circuit:

1. Switch off the supply voltage to the circuit.
2. Set the required operating mode on the multimeter (current or voltage measurement, DC or AC voltage, resistance measurement).
3. When using pointer measuring instruments, check and if necessary adjust the zero point.
4. When measuring DC voltage/direct current, connect the measuring device to the correct terminal ("+" terminal of the measuring device to the positive terminal of the voltage supply).
5. Choose the largest measuring range.
6. Switch on the voltage supply to the circuit.
7. Monitor the pointer or display and gradually switch over to a smaller measuring range.
8. Read the display when the greatest pointer deflection occurs (smallest possible measuring range).
9. When using pointer instruments, always read the display by looking down onto it to avoid reading errors.

# Electrical Engineering Basics

## Voltage Measurement

For reading voltage, the measuring device is connected parallel to the load. The voltage drop across the load (voltage lost across the load) corresponds to the voltage drop across the measuring device. Each voltage measurement device (voltmeter) has its own internal resistance. To get the most accurate reading the voltmeter's internal resistance must be as great as possible.

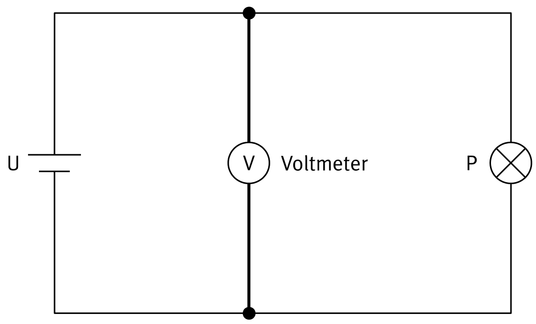



Figure 3.17: Voltage measurement

## Current Measurement

For current measurements, the full load current must flow through the measuring device. Therefore the measuring device must be connected in series with the load.

Each current measuring device (ammeter) has its own internal resistance. This additional resistance reduces the current flow. To get the most accurate reading an ammeter may exhibit a very small internal resistance.

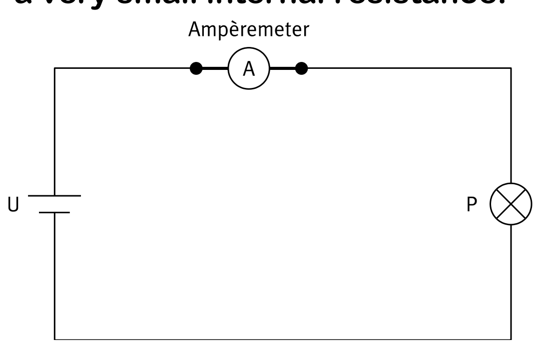



Figure 3.18: Current measurement

# Electrical Engineering Basics

## Resistance Measurement

The resistance of a load in a DC circuit can be measured either indirectly or directly.

- With indirect measurement, current and voltage are measured (Figure 3.19a). The resistance is then calculated using Ohm's law.
- With direct measurement, the load is isolated from the circuit (Figure 3.19b). The measuring device is switched to the "resistance measurement" operating mode and connected to the two terminals on the load. The resistance value is read directly on the measuring device.

If the load is defective (e.g. the solenoid coil of a valve is burnt out), the resistance measurement will either give an infinitely high value or the value zero (short circuit).

## Important

The resistance of a load in an AC or a DC circuit must be measured using the direct method. This means that the load must be isolated. There should be no current flow in the circuit.

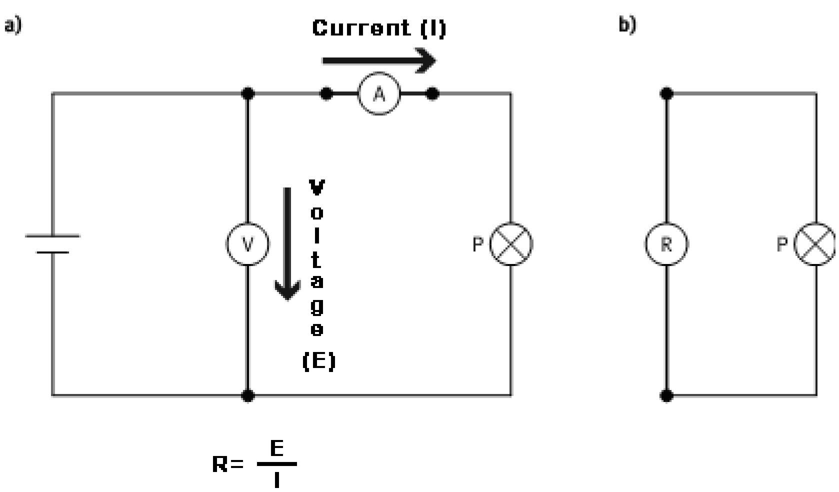



Figure 3.19: Resistance measurement

# Sensors

Sensors are used to acquire information and to send the information to a "decision maker". In many cases the "decision maker" is a Programmable Logic Controller (PLC).

Sensors are used in a variety of applications and have different designs and operating principles. They can be classified by:

- Operating principle (optical, inductive, mechanical, fluid, etc.).
- Measured variable (displacement, pressure, distance, temperature, ph value, luminous intensity, presence of objects, etc.).
- Output signal (analogue, digital, binary, etc.).

Sensors used most frequently in automation technology are those with digital outputs as they are more immune to interference than those with analog outputs. Controllers can use the signals from these sensors directly (as opposed to using analog sensors. The output signal from analog sensors must be converted by means of analog-digital converters).

The digital output type sensor that is most commonly used in industry are proximity sensors. This type of sensor determines the presence (or approach) of a work piece.

## Proximity Sensors

Proximity sensors are non-contacting and therefore have no external mechanical actuating force. As a result they have a long service life and are very reliable. A distinction is made between the following types of proximity sensor:

- Sensors with mechanical switch contact
  - Reed switches

- Sensors with electronic switch output
  - Inductive proximity sensors
  - Capacitive proximity sensors
  - Optical proximity sensors

# Sensors

## Magnetic Sensors

Reed switches are magnetically-actuated proximity sensors. They consist of two contact blades in a small glass tube filled with protective gas. The action of a magnet causes the contact between the two blades to close so that an electrical current can flow (Figure 4.1).

Reed switches have a long service life and a short switching time (approx. 0.2 ms). They are maintenance-free, but must not be used in areas with strong magnetic fields (e.g. in the vicinity of resistance welders or CAT scanners).

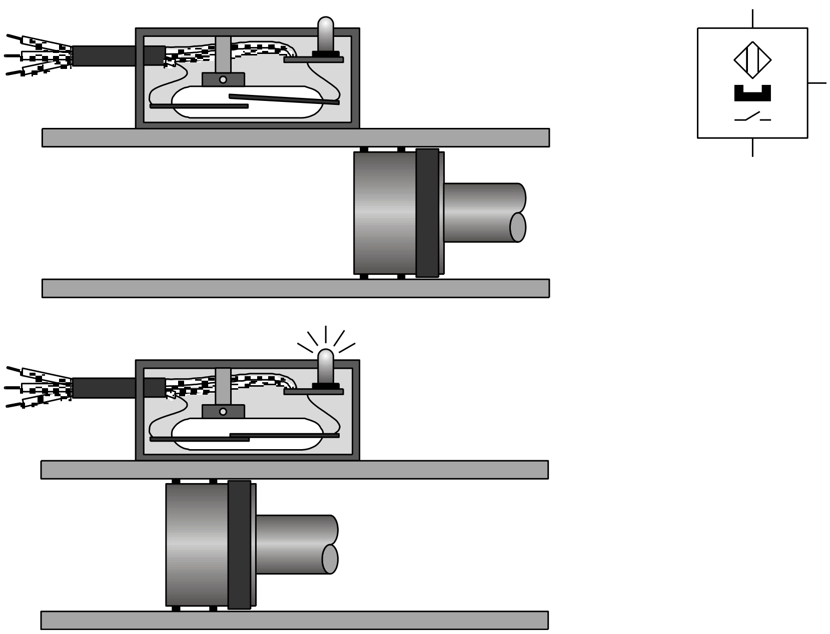


Figure 4.1: Schematic diagram and circuit symbol for a reed switch (N/O contact)


Figure 4.2: Reed switch

# Sensors

## Electronic Sensors

Electronic sensors include inductive, optical and capacitive proximity sensors. They normally have three electrical connections for:

- Supply voltage
- Return
- Output signal

Electronic sensors contain no moving parts. The output signal is either electrically connected with the supply voltage or to return (= output voltage 0 V).

There are two different designs of electronic proximity sensor:

- In the case of positive-switching electronic sensors, the output has a voltage of zero (OFF) when there is no part within the sensor's response range. The approach of a work piece results in the output being switched over (ON) so that supply voltage is applied.
- In the case of negative-switching sensors, supply voltage is applied to the output when there is no part within the sensor's response range. The approach of a work piece results in the output being switched over to a voltage of 0 V.

# Sensors

## Inductive Proximity Sensors

Inductive proximity sensors consist of an electrical resonant circuit (1), a flip-flop (2) and an amplifier (3) (Figure 4.3). When voltage is applied to the connections, the resonant circuit generates a (high-frequency) magnetic alternating field that escapes from the front side of the sensor.

Bringing an electrical conductor into this alternating field "attenuates" the resonant circuit. The downstream electronic unit, consisting of a flip-flop and amplifier, evaluates the resonant circuit's behaviour and actuates the output.

Inductive proximity sensors can be used to detect all materials with good electrical conductivity, for example graphite as well as metals.

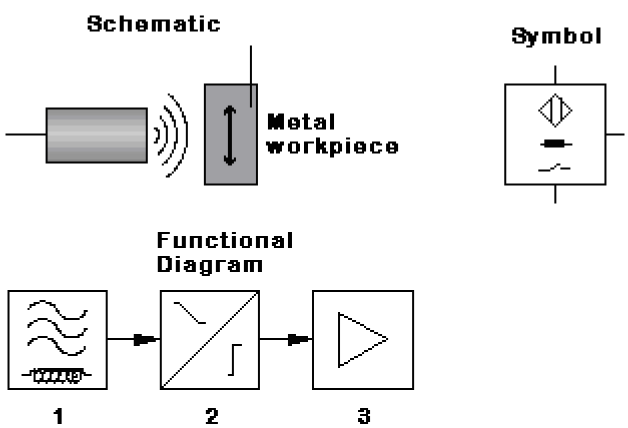



Figure 4.3: Basic representation, function and symbol for an inductive proximity sensor

(1) Resonant circuit
(2) Flip-flop
(3) Amplifier

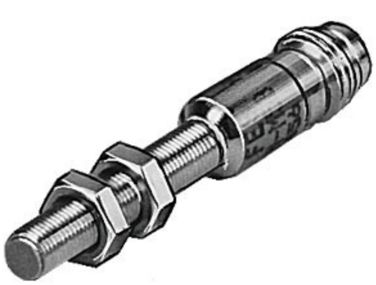


Figure 4.4: Illustration of an inductive sensor

# Sensors

## Capacitive Proximity Sensors

Capacitive proximity sensors consist of a resistor (R) and a capacitor (C) that form an RC circuit as well as an electronic circuit for evaluating the oscillation.

An electrostatic field is generated between the active electrode and the ground electrode of the capacitor. A stray field forms on the front side of the sensor. When an object is brought into this stray field, the capacitance of the capacitor changes (Figure 4.5).

The resonant circuit is attenuated and the downstream electronic unit actuates the output.

Capacitive proximity sensors not only respond to materials with a high electrical conductivity (e.g. metals), but also to all insulators with a high dielectric constant (e.g. plastics, glass, ceramic, liquids and wood).

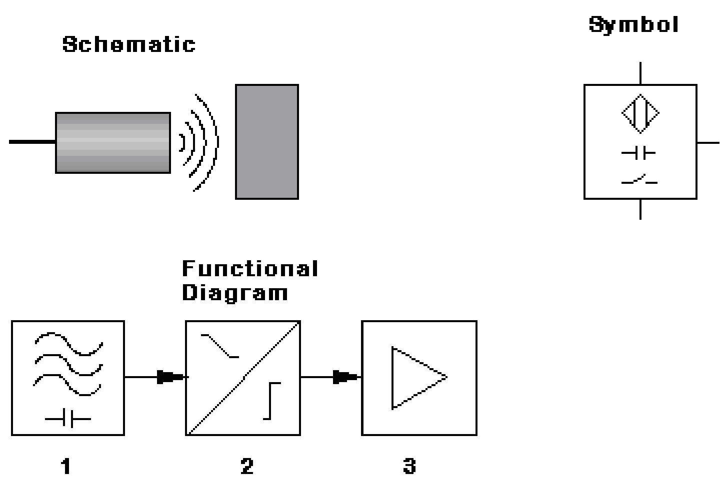



Figure 4.5: Basic representation, function and symbol for
a capacitive proximity sensor

(1) Resonant circuit
(2) Flip-flop
(3) Amplifier

# Sensors

## Optical Proximity Sensors

Optical proximity sensors consist of a transmitter and a receiver. They use optical (red or infrared light) and electronic components and modules to detect an object located between the transmitter and receiver.

Light emitting diodes (LEDs) are particularly reliable transmitters of red and infrared light. They are small, inexpensive, durable and easy to install. Red light has the advantage that it can be seen with the naked eye when aligning (adjusting) the sensor.

Photodiodes or phototransistors are used as the receiver component in optical proximity sensors.

There are three types of optical proximity sensor:

- Through-beam
- Retro-reflective
- Diffuse

## Through-Beam Sensors

Through-beam sensors consist of a transmitter and a receiver unit that are set apart from each other. The components are mounted in such a way that the beam of light emitted by the transmitter hits the receiver (e.g. phototransistor) directly (Figure 4.6). If an object, work piece or even a person enters the path between the transmitter and receiver, the light beam is interrupted and a signal is triggered that initiates a switching operation at the output (ON/ OFF).

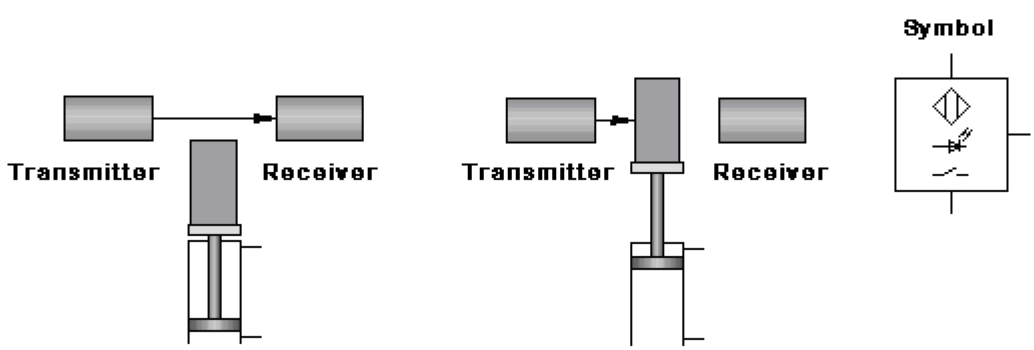



Figure 4.6: Schematic diagram and circuit symbol for a through-beam sensor

## Sensors

Figure 4.7: Fork light barrier

### Retro-Reflective Sensors

The transmitter and receiver of a retro-reflective sensor are arranged side-by-side in a housing. A reflector is located at a distance from the transmitter / receiver. The reflector reflects the light beam from the transmitter back to the receiver. It is mounted in such a way that the light beam emitted by the transmitter impinges almost entirely on the receiver. If an object, work piece or even a person enters the path between the transmitter and reflector, the light beam is interrupted and a signal is triggered that initiates a switching operation at the output (ON/OFF).

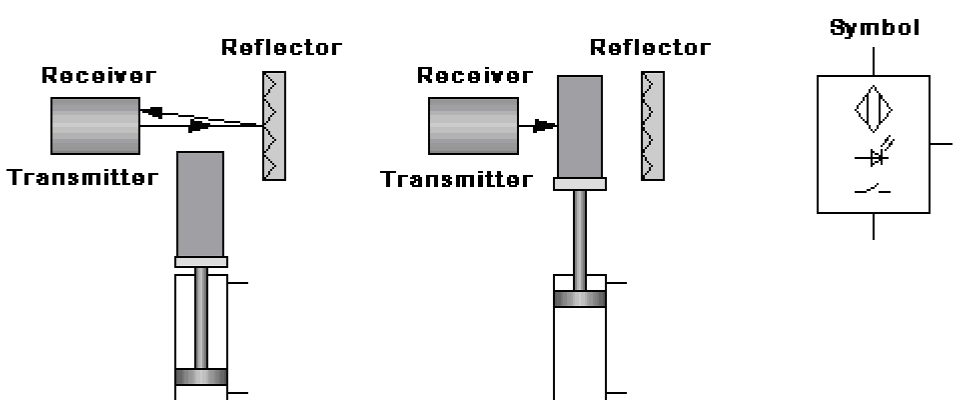



Figure 4.8: Schematic diagram and circuit symbol for a retro-reflective sensor

# Sensors

## Diffuse Sensors

Like the retro-reflective sensor,  diffuse sensors consist of both a transmitter and receiver. However, instead of using a reflector,  the diffuse sensor  uses the reflective property of the object or work piece that enters its transmission range. If the light (from the transmitter) hits a reflective body, it is "reflected"  back to the receiver and the sensor output is switched. This operational principle means diffuse sensors can only be used if the work piece or machine part to be detected is highly reflective (metallic surfaces, light reflecting colors).

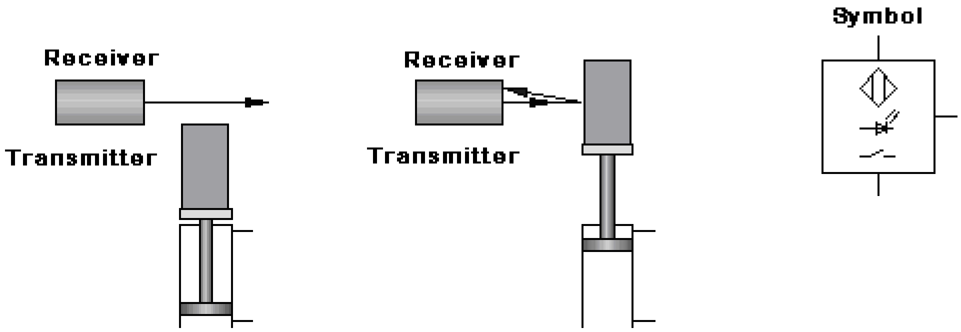



Figure 4.9: Schematic diagram and circuit symbol for a diffuse sensor

## Pressure Sensors

Pressure sensors come in different designs:

- Mechanical pressure switches with binary output signal
- Electronic pressure switches with binary output signal
- Electronic pressure sensors with analogue output signal

# Sensors

## Mechanical Pressure Switches with Binary Output Signal

**In a mechanical pressure switch, the pressure acts on a piston area. If the force exerted by the pressure exceeds the spring force, the piston moves and actuates the contacts of the switching elements.**

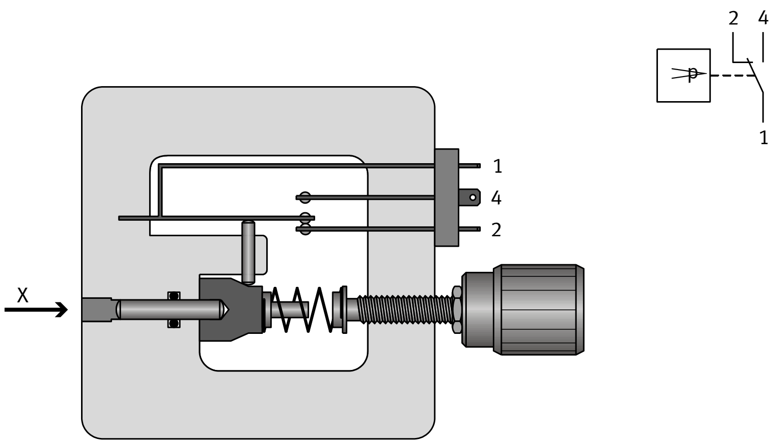



**Figure 4.10: Schematic diagram and circuit symbol for a piston pressure switch**

# Sensors

## Electronic Pressure Switches with Binary Output Signal

Typical examples of electronic pressure switches with binary output signal are diaphragm pressure switches that switch the output electronically instead of actuating a contact mechanically. Pressure or force-sensitive sensors are attached to a diaphragm for this purpose. The sensor signal is evaluated by an electronic circuit. As soon as the pressure exceeds a previously defined value, the output switches.


Figure 4.11: Electronic pressure switch and circuit symbol

# Fluid Power Basics (Pneumatics)

The term pneumatics comes from the Greek work "pneuma", meaning wind or breath. It refers to the use of compressed air systems in an industrial application. A modern pneumatic system consists of subsystems for:

- Generating compressed air (compressors)
- Distributing the compressed air (piping, pneumatic tubing)
- Controlling the compressed air (pressure regulators, directional control valves)
- Performing work (cylinders, rotary drives)

Compressed air is most often used to perform mechanical work including actuator movement and force generation.

Pneumatic drives serve to convert the energy stored in the compressed air into kinetic energy.

Normally cylinders are used as pneumatic drives. They are sturdy,  easily installed, inexpensive and are available in a variety sizes. Overall there is a large range of applications for pneumatics in industrial automation. The following table outlines additional advantages.

| Characteristics | Advantages |
|---|---|
| Quantity | Air is available in unlimited quantities. |
| Transport | Air is easily transported over large distances. |
| Storage ability | Compressed air can be stored (and in some cases, transported) in a reservoir. |
| Temperature | Compressed air is virtually insensitive to temperature fluctuations. This ensures reliable operation under extreme conditions. |
| Safety | Compressed air does not represent a hazard in terms of fire or explosion. |
| Cleanliness | Leaks of un-lubricated compressed air do not cause environmental hazards. |
| Setup | The components are easily installed. |
| Speed | Compressed air is known as a “speed multiplier”. It facilitates high piston speeds and fast switching times. |
| Overload protection | Pneumatic tools and operating elements can be loaded until they stall. |

# Fluid Power Basics (Pneumatics)

## Characteristics

Air is a mixture of gases containing approximately 78% nitrogen and 21% oxygen. It also contains traces of water vapor, carbon dioxide, argon, hydrogen, neon, helium, krypton and xenon.

To help in understanding the laws involved in fluid power, the associated variables are listed below.

## Basic Units

| Variable | Symbol | Units |
| --- | --- | --- |
| Length | l | Inches (in) |
| Mass | m | Pounds (lbs) |
| Time | t | Second (s) |
| Temperature | T | Farenheit (degrees °) |

## Derived Units

| Variable | Symbol | Units |
| --- | --- | --- |
| Force | F | Pounds (lbs) |
| Surface | A | Square Inches ($in^2$) |
| Volume | V | Cubic Foot ($ft^3$) |
| Volumetric flow rate | $q_V$ | Feet per second (ft/s) |
| Pressure | p | Pounds per square inch (PSI)<br>Bar (1 Bar = 14.5 PSI) |

## Newton's Law

Force = mass • acceleration

F = m • a

(in the case of free fall, “a” is replaced by gravitational acceleration g = 32 ft /s²)

# Fluid Power Basics (Pneumatics)

## Pressure

1 PSI corresponds to the pressure exerted by a vertical force of 1 pound on an area of 1 square inch.

The pressure on the earth's surface is referred to as atmospheric pressure ($p_{amb}$). This pressure is also known as reference pressure. The range above this pressure is called the excess pressure range ($p_e > 0$), while the range below is called the vacuum range ($p_e < 0$). The atmospheric pressure differential $p_e$ is calculated according to the formula:
$p_e = p_{abs} - p_{amb}$

This is illustrated in the following diagram:

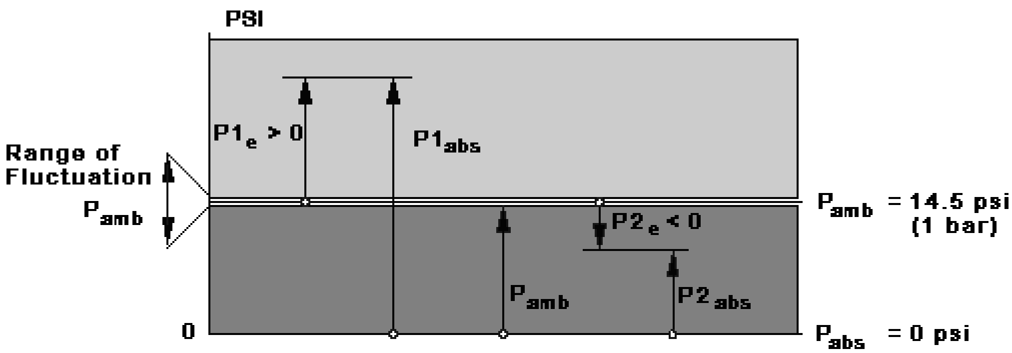



Figure 5.1: Air pressure

Atmospheric (or “ambient”) pressure changes depending on the geographical location and the weather. As a “rule of thumb” ambient air pressure is 14.7 psi.

Absolute pressure $p_{abs}$ starts with a reference of absolute zero (“0”) and is equal to the sum of atmospheric pressure (14.7psi) and any pressure that exceeds or is less than atmospheric. This means that if pressure readings are taken with an absolute pressure gauge (psia) any reading below 14.7 psia is regarded as a vacuum.

It is normal to refer to pneumatic specifications with respect to “standard conditions”. There are standard conditions for temperature and pressure. These are:

- Temperature: 0° C (Celsius). This is translated to 32° F (Farenheit). It is the freezing point of water.
- Pressure: 14.7 psi. Imagine a 1 square inch column going from the ground straight up and past the atmosphere. All of the air within this column weighs 14.7 pounds.

# Fluid Power Basics (Pneumatics)

## Properties of Air
Like all gases, air does not have a form. It takes the shape of its container and occupies all of the available space. It exerts pressure equally (and at right angles) on all surfaces.

## Boyle's Law
Air can be compressed. When it is compressed it exerts pressure. Boyle's law describes these properties as follows:

The volume of a fixed amount of gas is inversely proportional to the absolute pressure at constant temperature, or to put it another way, the product of volume and absolute pressure is constant for a fixed amount of gas.

V1 x P1 =  V2 x P2 = V3 x P3 = Constant

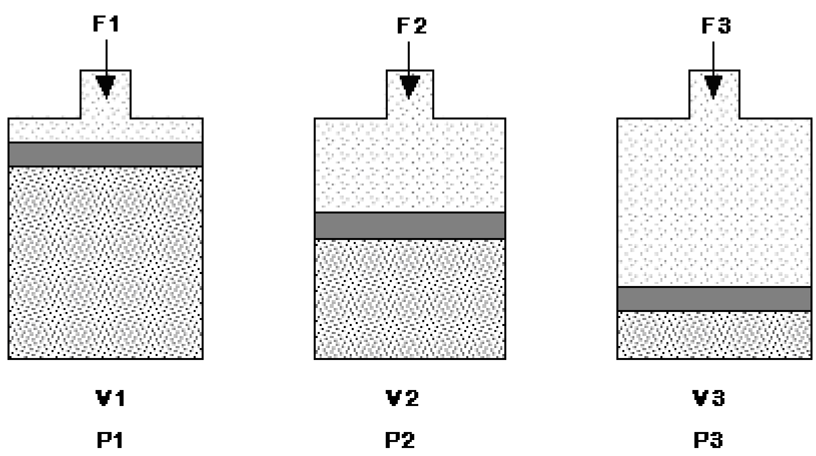



Figure 5.2: Boyle's law

# Fluid Power Basics (Pneumatics)

## Calculation Example

**Air is compressed to 1/7 of its volume at atmospheric pressure. What is the pressure if the temperature remains constant?**

**Solution**

$p_1 \cdot V_1 = p_2 \cdot V_2$

$p_2 = p_1 \cdot V_1 / V_2$ Note: $V_1 / V_2 = 1/7$

Where:
$p_1 = p_{amb} = 14.5$ psi = 1 bar

and

$p_2 = 1/7 = 101.5$ psi = 7 bar absolute

From this it follows that: $p_e = p_{abs} - p_{amb} = (101.5 - 14.5)$ psi = 87 psi (6 bar)

A compressor that generates an excess pressure of 87 psi (6 bar) has a compression ratio of 7:1.

# Fluid Power Basics (Pneumatics)

## Gay-Lussac's Law

Air expands by 1/273 of its volume at constant pressure, a temperature of 273 K and a rise in temperature of 1 K. Gay-Lussac's law states that the volume of a fixed amount of gas is proportional to its absolute temperature when pressure is constant.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$ V1 = volume at T1, V2 = volume at T2

Or $$\frac{V}{T} = \text{constant}$$

The change in volume $\Delta V$ is: $$\Delta V = V_2 - V_1 = V_1 \bullet \frac{T_2 - T_1}{T_1}$$

The following applies to V2: $$V_2 = V_1 + \Delta V = V_1 + \frac{V_1}{T_1}(T_2 - T_1)$$

The equations shown above only apply if the temperatures are used in K. The following formula must be used to convert to °C:

$$V_2 = V_1 + \frac{V_1}{273° C + T_1}(T_2 - T_1)$$

# Fluid Power Basics (Pneumatics)

## Calculation example

0.8 $m^3$ of air with a temperature of $T_1$ = 293 K (20 °C) is heated to $T_2$ = 344 K (71 °C). By how much does the air expand?

$$V_2 = 0.8m^3 + \frac{0.8m^3}{293K}(344K - 293K)$$

$$V_2 = 0.8m^3 + 0.14m^3 = 0.94m^3$$

The air expands by 0.14 m3 to 0.94 m3.

If the volume is kept constant during the heating process, the increase in pressure can be expressed using the following formula:

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}$$

Or

$$\frac{p}{T} = \text{constant}$$

# Fluid Power Basics (Pneumatics)

## General Gas Equation

**Fulfilling the basic laws is the general gas equation that states:
with a fixed amount of gas, the product of pressure and volume divided by the absolute temperature is constant.**

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2} = \text{constant}$$

**From this general gas law can be derived the above mentioned laws, when one of the three factors p, V or T remains constant.**

- **Pressure "p" constant > Isobaric change**
- **Volume "V" constant > Isochoric change**
- **Temperature "T" constant > Isothermal change**

# Fluid Power Basics (Pneumatics)

## Pneumatic Control System Components and Functions

**Compressor**
The most common type of compressor are the "screw" or "piston" compressors. They supply an output pressure of 105 – 120 psi (7 – 8 bar). This ensures that a working pressure of at least 90 psi (6 bar) is available at the cylinder, provided that there are no leaks, (points at which air can unintentionally escape) and line losses.

**Compressed air filters**
Compressed air filters are placed upstream of the compressed air system. They remove condensate and dirt particles. Properly filtered compressed air plays a major role in prolonging the service life of downstream components.

**Pressure regulator**
The pressure regulator is where the necessary pressure level for individual sub-systems is set. It compensates for fluctuations in the compressed air network. The set pressure remains constant as long as the pressure at the regulator input is at least 7psi (0.5 bar) above the required set point pressure.

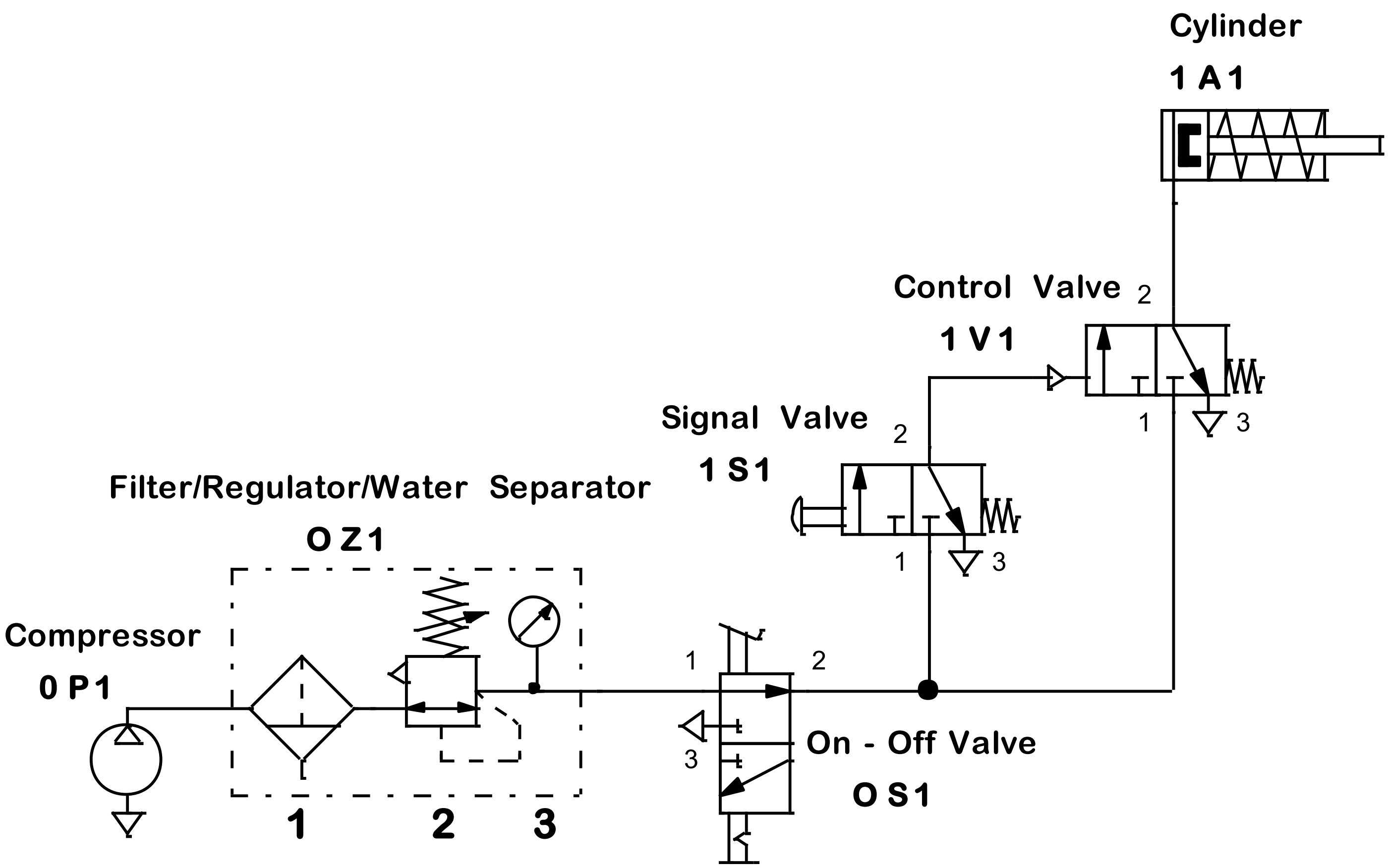
**On-off valves**
These separate individual compressed air networks.

**Control valves**
These are used to stop, start and change the direction of air flow to the operating elements at the required time. The safety and reliability of the system depend on the elements being correctly plumbed.

**Power valves**
These are also "control valves" but are adapted to the cylinder diameter and supply the cylinders with the necessary quantity of compressed air.

**Cylinders**
Pneumatic cylinders are actuators (which provide "work") with a long service life. The right cylinder dimensions can produce high speeds. For fault-free operation, the cylinders must be correctly sized and assembled.

# Fluid Power Basics (Pneumatics)




**1** Filter / Water Separator

**2** Regulator

**3** Gage

**Figure 5.3: Key components and modules in a pneumatic control system**

# Fluid Power Basics (Pneumatics)

## Functions and Features of Actuators (Pneumatic Cylinders)

### Single-Acting Cylinders

Single-acting cylinders perform work in one direction and are supplied with compressed air at one end. Once extended, a spring returns the cylinder to its normal position as long as an “exhaust path” has been provided for the air leaving the cylinder (see Figure 5.4). Some single acting cylinders use the load to retract. An air breather hole is provided in the cylinder bearing cap in order to prevent pressure build up.

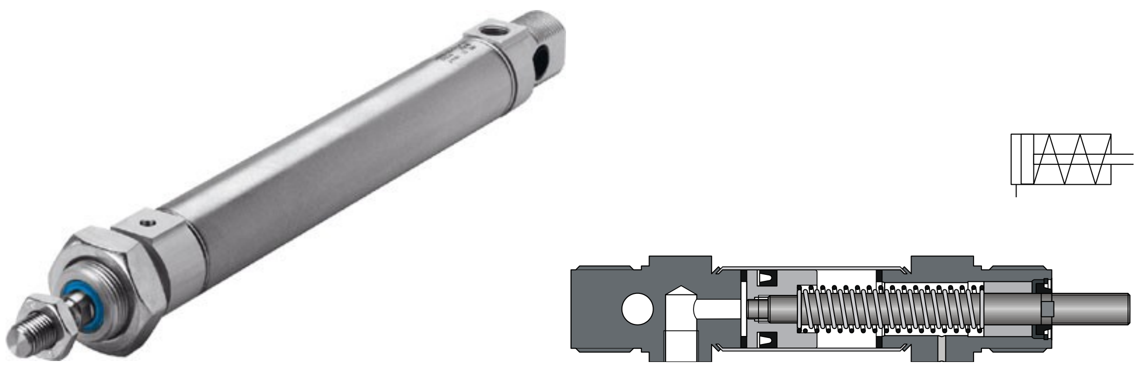


Figure 5.4: Picture, sectional view and circuit diagram of a single-acting cylinder

### Double-Acting Cylinders

Double-acting cylinders are supplied with compressed air at both ends. These cylinders can perform work in both directions. The force transferred to the piston rod is slightly greater for the extend stroke than for the retract stroke. This is because the surface area on the piston side air is greater than the surface area on the piston rod side (see Figure 5.5).

The double-acting cylinder has a port for each pressurized chamber. Before moving, the appropriate chamber (piston side or piston rod side) must first be exhausted.

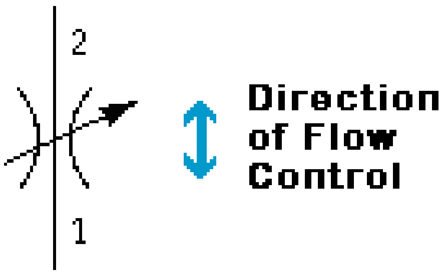

Figure 5.5: Picture, sectional view and circuit diagram of a double-acting cylinder

# Fluid Power Basics (Pneumatics)

## Speed Control for Single-Acting Cylinders

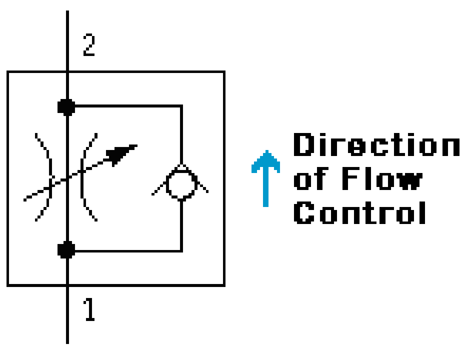
### Flow Control Valve

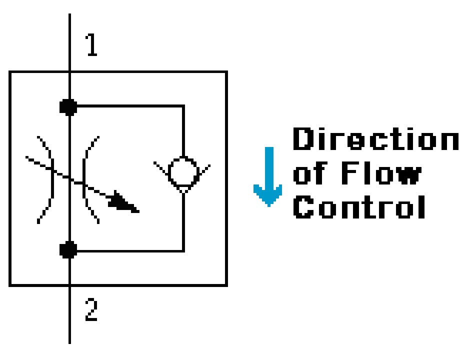
The flow of air can be restricted by using a “needle” valve. The restriction has the same effect on both directions of flow (supply and exhaust).




### One-Way Flow Control Valve

The setting at the one-way flow control valve is only effective in one direction because a “check valve” routes the air through the needle valve. When air flows in the opposite direction, it will bypass the needle valve through the check valve (since air takes the path of least resistance). The direction of flow control is indicated on the components by an arrow.



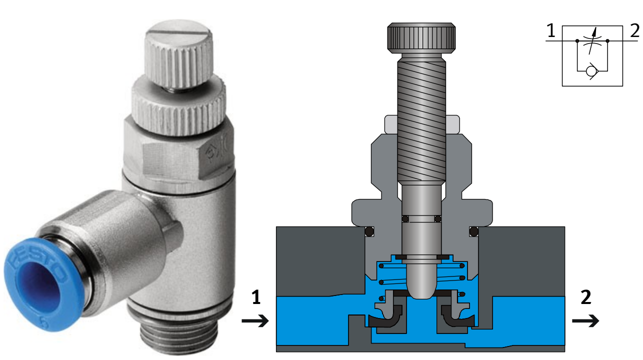
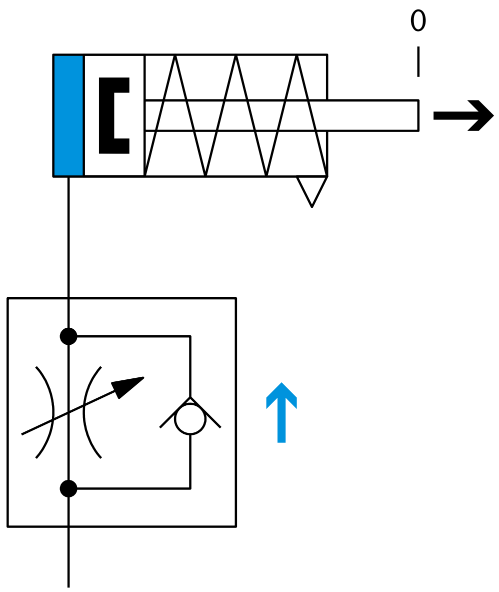



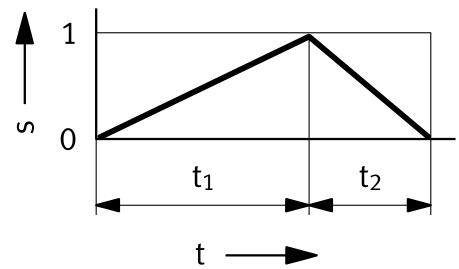

Figure 5.6: Picture, sectional view and circuit diagram of a one-way flow control valve

# Fluid Power Basics (Pneumatics)

## Forward Stroke

Air flow is reduced by means of a one-way flow control valve. The set speed is only effective in the forward stroke. The air is routed through the check valve on the return stroke.

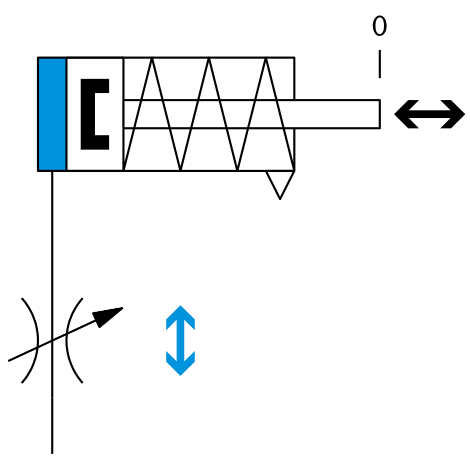


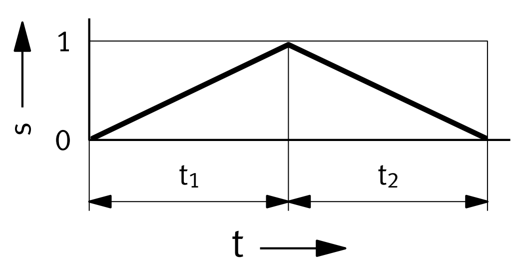




$t_1$ = adjustable, $t_2$ = constant (non-adjustable)

## Forward and Return Strokes

The flow control valve is at the port that supplies and exhausts the compressed air. The set speed is effective in the forward and return strokes.



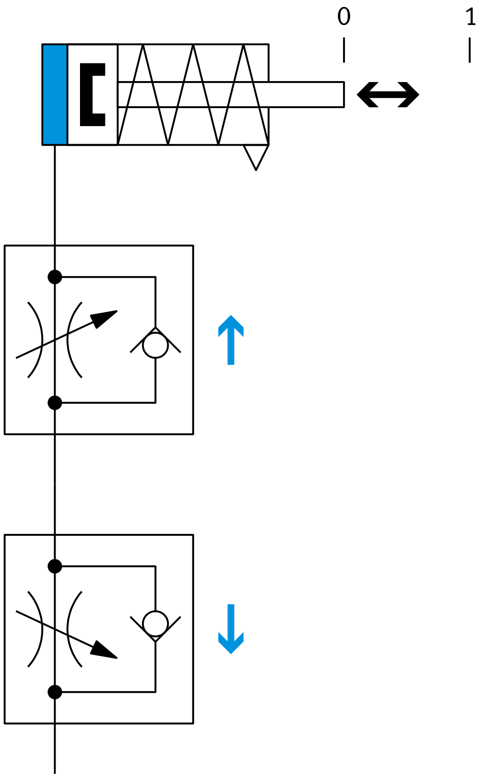



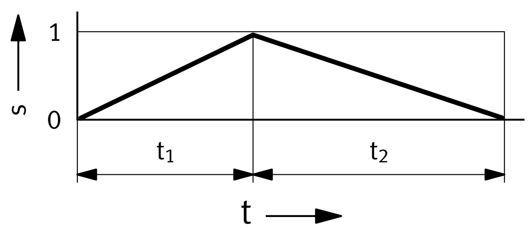

$t_1$ = $t_2$ = adjustable

# Fluid Power Basics (Pneumatics)

## Flow Control Using Two One-Way Valves

The speed can be set separately for the forward and return strokes.



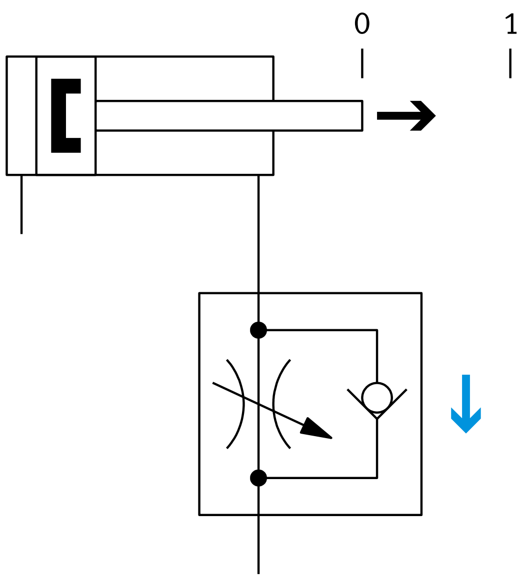

**$t_1$ = adjustable, $t_2$ = adjustable**

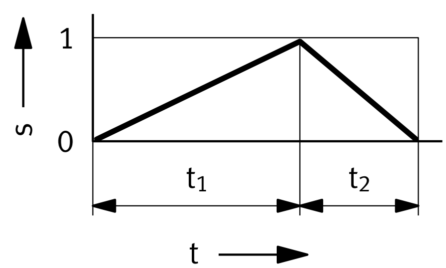
# Fluid Power Basics (Pneumatics)

## Flow Control for Double-Acting Cylinders

### Forward Stroke (Exhaust Air Flow Control)

The one-way flow control valve is at the port that exhausts the compressed air (exhaust air flow control). The escaping air is routed through the flow control valve. Exhaust air flow control is the method used most frequently with double-acting cylinders . This is commonly referred to as “meter out” flow control.  A “rule of thumb” for flow control is “When in doubt, meter out”.



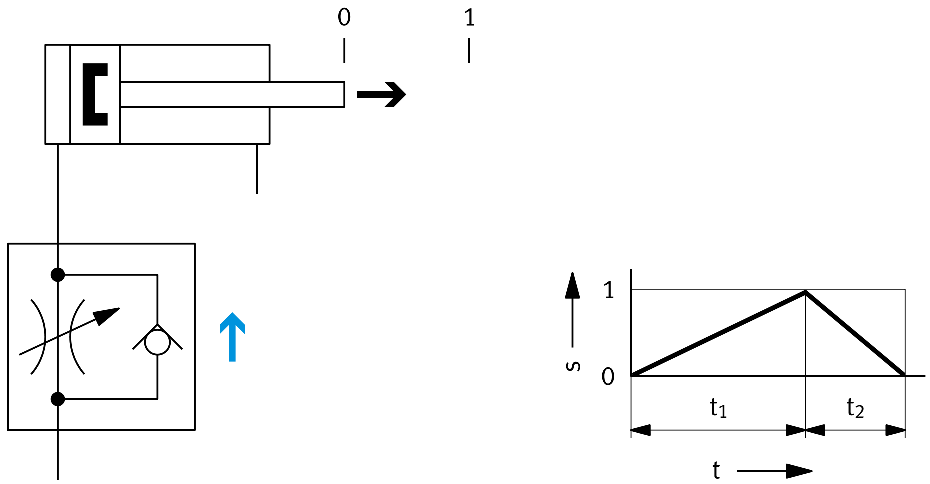

$t_1$ = adjustable, $t_2$ = constant (non-adjustable)

# Fluid Power Basics (Pneumatics)

## Forward Stroke (Supply Air Flow Control)

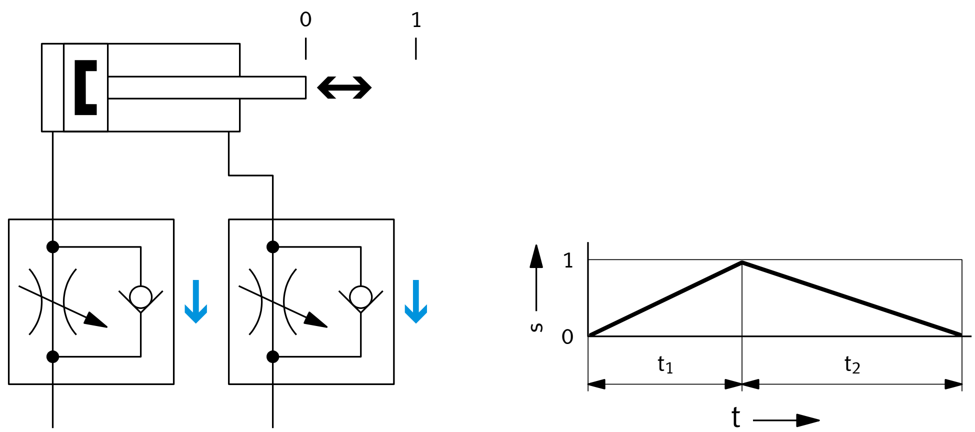
The one-way flow control valve is at the port that supplies the compressed air (supply air flow control-also known as “meter in”). The set speed is only effective in the forward stroke. A change in load at the piston rod can result in a change of speed. A tractive load (a load that tends to assist the movement of the cylinder) might accelerate the cylinder above the set value. This type of flow control is not suitable for cylinders that are mounted vertically.




$t_1$ = adjustable, $t_2$ = constant (non-adjustable)

## Forward and Return Strokes

Exhaust air flow control using two one-way flow control valves. The speed can be set separately for the forward and return strokes.




$t_1$ = adjustable, $t_2$ = adjustable

# Fluid Power Basics (Pneumatics)

## Directional Control Valves

Directional control valves start, stop and change the direction of air flow. The direction of flow is indicated by an arrow. Actuation can take place manually, mechanically, pneumatically or electrically. Automated systems generally use solenoid-actuated valves that form the interface between pneumatic and electrical control. They are switched by means of the output signals from the signal control section and shut off or open connections in the pneumatic power section. The main functions of electrically-actuated directional control valves include:

- Connecting or isolating the compressed air supply
- Extending and Retracting cylinders

Figure 5.7 and Figure 5.8 show two valve designs.

Figure 5.7: Manually-actuated 3/2-way valve with locking function

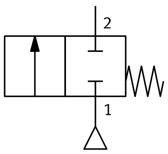
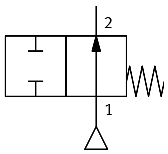
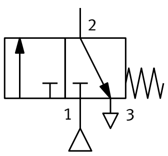
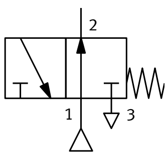
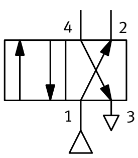
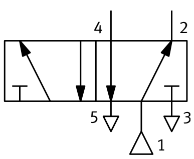
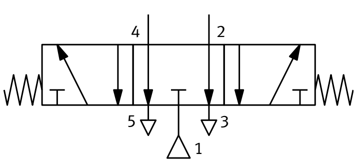
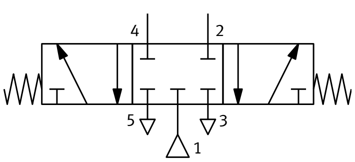
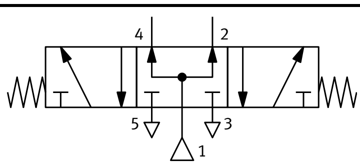
Figure 5.8: 4/2-way single solenoid valve with manual override

# Fluid Power Basics (Pneumatics)

## Valve Designations and Symbols

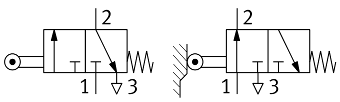
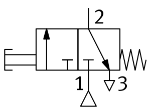
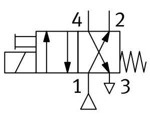
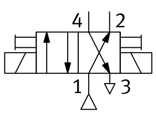
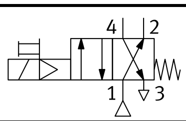
The following table shows the main designs of directional control valve.

| Symbol | Designation | Function |
|---|---|---|
|   | 2/2-way valve<br>– normally closed<br>– normally open | Valve with two switching positions and two ports |
|   | 3/2-way valve<br>– normally closed<br>– normally open | Valve with two switching positions and three ports |
|  | 4/2-way valve | Valve with two switching positions and four ports |
|  | 5/2-way valve | Valve with two switching positions and five ports |
|  | 5/3-way valve, mid-position exhausted | The piston of the cylinder drive exerts no force on the piston rod. The piston rod can move freely. |
|  | 5/3-way valve, mid-position closed | The piston rod comes to a stop, even if it is not at the defined stop. |
|  | 5/3-way valve, mid-position pressurised | The piston rod of cylinders with single-ended piston rod advances with reduced force. |

# Fluid Power Basics (Pneumatics)

## Pneumatic Valve Actuation Types

The following table provides an overview of the main actuation types of directional control valves.

| Symbol | Designation | Function |
|---|---|---|
|  | Roller lever valve, spring return, single solenoid | This valve is actuated by means of cylinder cams or similar. It is mainly used for sensing end positions. |
|  | Manually actuated, spring return, single solenoid | This valve is manually actuated and is returned by a spring when released. |
|  | Single solenoid valve with manual override, spring return | This valve is actuated by a solenoid and is returned by a spring as soon as the control current is switched off. |
|  | Double solenoid valve with manual override | This valve is actuated by solenoids and remains in its current position until the other solenoid is actuated. |
|  | Solenoid valve with pneumatic pilot control | This valve is actuated by a solenoid. The solenoid controls a pneumatic auxiliary circuit that actuates the valve spool. |

## Controlling a Single-Acting Cylinder

Figure 5.9a shows a solenoid-actuated valve that controls the movement of a single-acting cylinder drive. It has three ports and two switching positions.

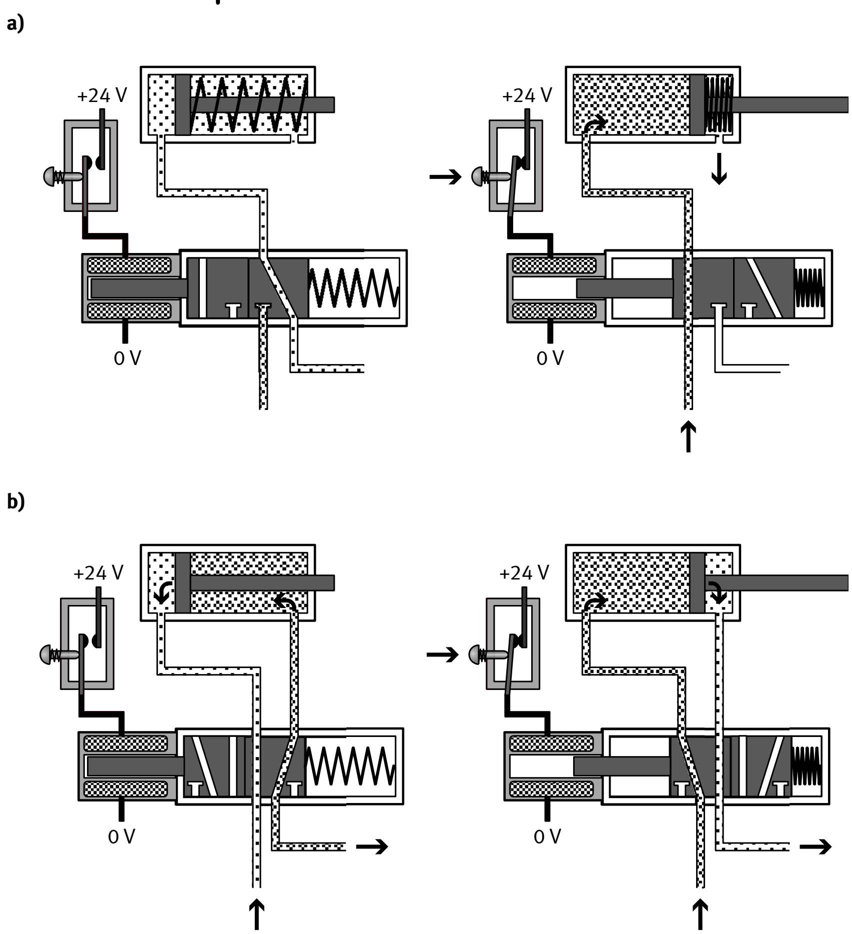
- When the solenoid coil of the directional control valve is de-energized, the cylinder chamber is exhausted via the directional control valve. The piston rod is retracted.
- When current is applied to the solenoid coil, the directional control valve switches and the cylinder chamber is pressurized. The piston rod advances.
- When current is no longer applied to the solenoid coil, the valve switches back. The cylinder chamber is exhausted and the piston rod retracts.

# Fluid Power Basics (Pneumatics)

## Controlling a Double-Acting Cylinder

The double-acting cylinder in Figure 5.9b is actuated by a directional control valve with five ports and two switching positions.

- When the solenoid coil is de-energized, the left-hand cylinder chamber is exhausted and the right-hand cylinder chamber is pressurized. The piston rod is retracted.
- When electrical current is applied to the solenoid coil, the valve switches. The left-hand cylinder chamber is pressurized and the right-hand cylinder chamber is exhausted. The piston rod advances.
- When current is no longer applied to the solenoid coil, the valve switches back and the piston rod retracts.




a) Single-acting

b) Double-acting

Figure 5.9: Controlling cylinders using solenoid valves

# Fluid Power Basics (Pneumatics)

## Pneumatic Drives

### Guided Cylinders, Rodless Linear Drives and Rotary Drives

Guided pneumatic cylinders are frequently used for special applications, particularly in handling technology (see Figure 5.11). Unlike conventional cylinders, the piston rod cannot be turned and subjected to additional forces. Depending on the design, they can either be plain-bearing guides for simple applications with low loading by external forces and limited accuracy or the more expensive, high-precision ball bearing guides that can absorb considerable force and torque.

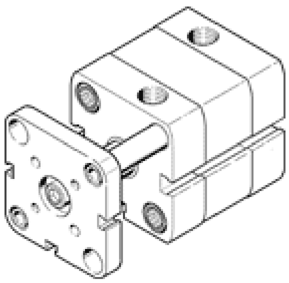


Figure 5.11: Guided pneumatic cylinder

Another class of drives are the rodless cylinders (see Figure 5.12). These have no piston rod and are therefore suitable for long stroke lengths.

A piston rod cylinder is at least twice as long as the cylinder when extended. Rodless cylinders are slightly longer than their cylinder stroke and are fitted with high-quality guides.

Figure 5.12: Rodless pneumatic drive

# Fluid Power Basics (Pneumatics)

**Pneumatic semi-rotary drives are used wherever a rotational or swivel motion is required.**

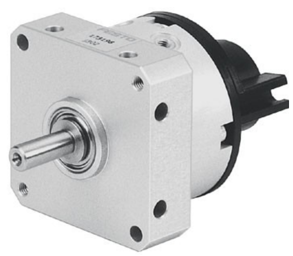
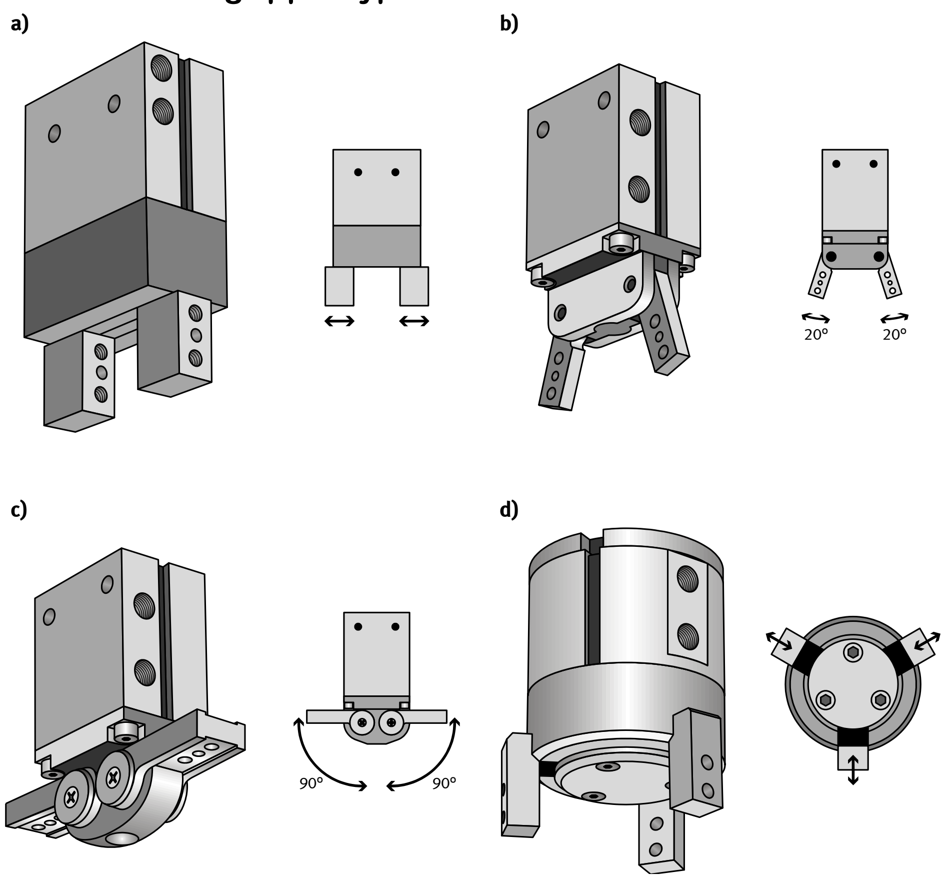


Figure 5.13: Pneumatic rotary drive

## Pneumatic Grippers

Pneumatic grippers are used for handling work pieces. The gripper is not normally used as shown. Handling “tools” are machined and attached to the gripper.The following illustrations show various gripper types.




a)Parallel gripper
b) Angle gripper

c) Radial gripper
d) Three-point gripper

Figure 5.14: Pneumatic grippers

# Fluid Power Basics (Pneumatics)

The following illustration (see Figure 5.15) shows a sectional view of an angle gripper driven by a double-acting cylinder (notice the "tool" being attached in 5.15b). It shows how gripper fingers (for cylindrical work pieces in this case) and proximity sensors are mounted on the gripper.

The choice of gripper type, size and jaw depends on the shape and weight of the work pieces.

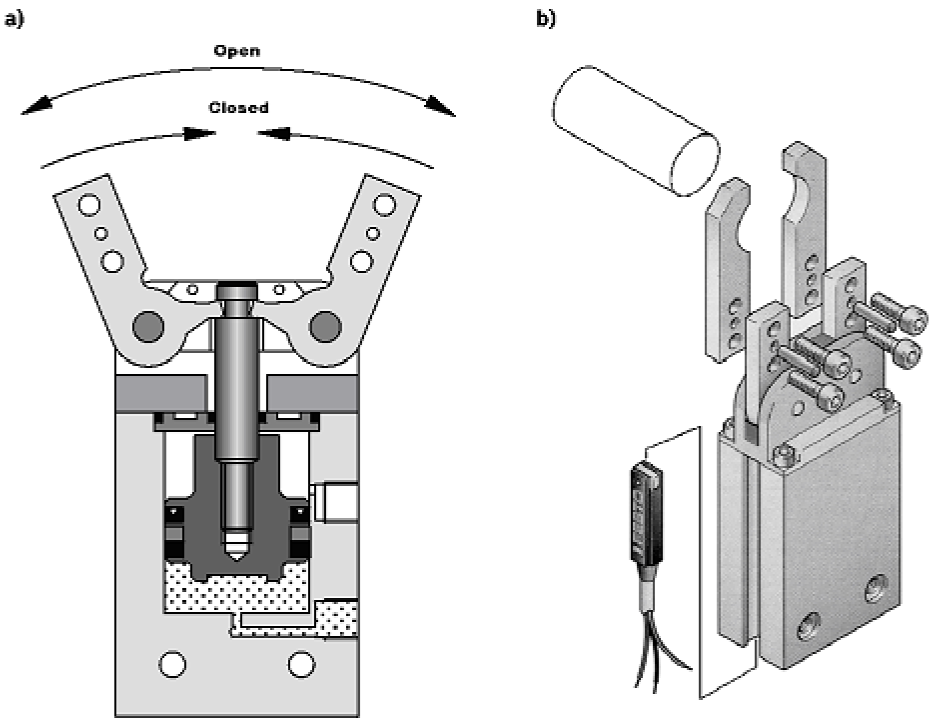



Figure 5.15: Drive principle, gripper jaw and proximity sensors for an angle gripper

Fluid Power Basics (Pneumatics)

## Pneumatic Circuit Diagram

The simplest way to control single and double-acting cylinders is by means of direct cylinder control. In this case the cylinder is controlled directly using a manually or mechanically-actuated valve.

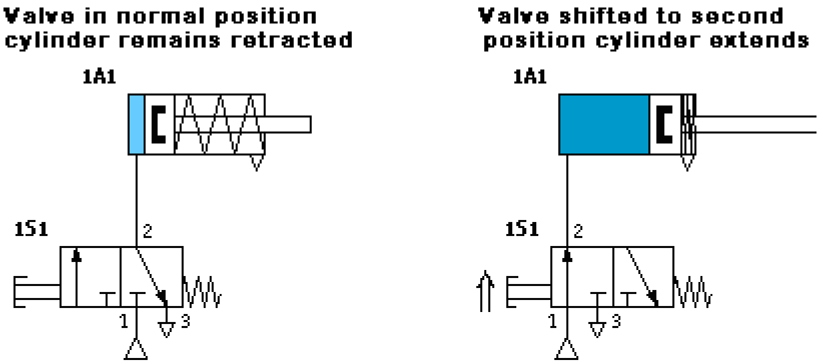



Figure 5.16: Circuit diagram for direct control via a manually-actuated 3/2-way valve

Normally, symbols for the individual components are drawn in the “nominal”, or, un-actuated condition. The novice may have difficulty understanding the concept of “switching positions”. For that reason (and departing from the standards) the switched position is also shown in some of the examples to make them easier to understand. The arrow beside the actuating element of the 3/2-way valve with pushbutton actuator indicates that this valve is actuated (Figure 5.16 on the right).

# Fluid Power Basics (Pneumatics)

## Circuit Diagram Symbols

The structure of pneumatic circuit diagrams and the arrangement of the circuit symbols as well as the designation and numbering of components are defined in ISO 1219-2. The circuit is drawn with the valves in the initial position (normal position). The operating section (cylinders with power valve) is shown at the top. The control section with the signal input components is underneath.

The elements are designated from bottom to top and from left to right (see Figure 5.17).

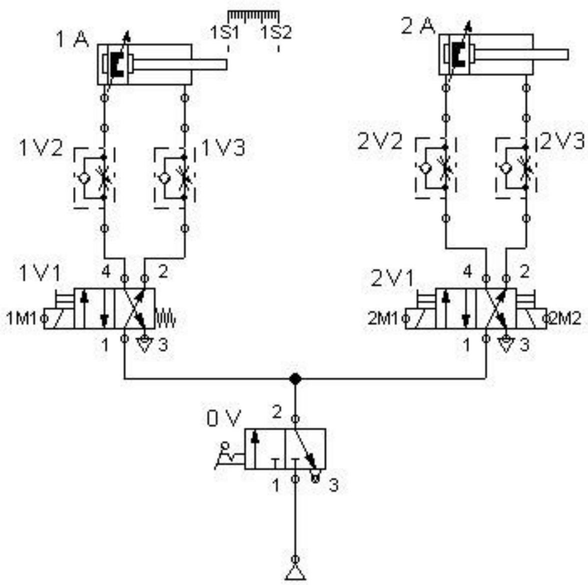



Figure 5.17: Designations in a pneumatic circuit diagram

# Fluid Power Basics (Pneumatics)

## Electro Pneumatic Circuit and Function

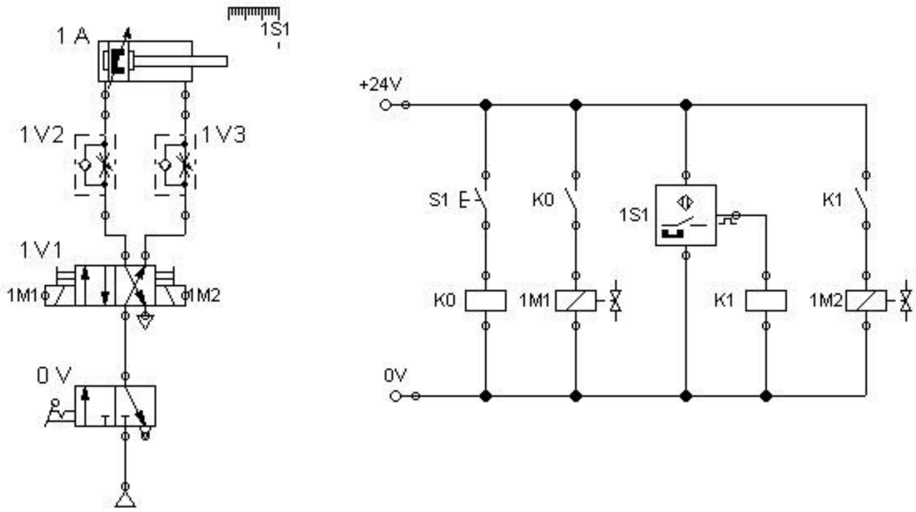



Figure 5.18: Electro pneumatic circuit

Function of the electro pneumatic circuit shown above:

- When pushbutton S1 is actuated, valve solenoid 1M1 is energized via a N/O contact of the relay K0 and cylinder 1A extends.
- When the cylinder is fully extended, the magnetic proximity sensor 1S1 energizes relay K1. A set of N/O contacts of K1 will close, energizing valve solenoid 1M2. The cylinder then retracts.

# Electric Drives

Unlike pneumatics, which are mostly used in the production environment as a simple and reliable drive technology, electric motors are used in washing machines, telephones, CD players, toys, food processors and fans. They are even used in automobiles for functions such as seat adjustment and opening/closing windows.

There are various types of electric motors specially designed for:

- Simple, low-cost DC drives used in battery operated devices.
- Three-phase, high power motors for use in industry.
- Dynamic servo drives for tooling machines or robots with high speed and precision requirements.
- Stepper motors for simple processes, for example, feed movements in tooling machines.

Electric motors can perform both turning (rotational) and linear (translational) movements. Drives have design requirements ranging from a few milliwatts to several megawatts or weighing a few ounces to several tons. However they are specified, electric drives are the most frequently used actuator used in engineering.

Almost all electric drives are based on the principle of electromagnetic force (or “Lorentz” force). The following sections describe the operational principle of a permanently excited DC motor since this motor type is relatively easy to understand and is very widely used.

## Fundamentals of DC motors

If an electrical conductor (wire) is passed through a magnetic field, a magnetic force (F) is generated on the wire. The direction of this force can be determined using the so-called "three-finger rule". We will assume that the magnetic field lines run from the magnet's north pole to its south pole and that the current in the wire flows from the power source's positive terminal to its negative terminal. The three fingers (thumb, index finger and middle finger) are aligned at right angles to each other so they form a Cartesian coordinate system.

# Electric Drives

When the thumb points in the direction of the flow of current (i.e. from the positive terminal to the negative terminal) and the index finger points in the direction of the magnetic field (north/south), the middle finger points in the direction of the active force. In Figure 6.1, the wire would therefore move forwards out of the magnetic field plane.

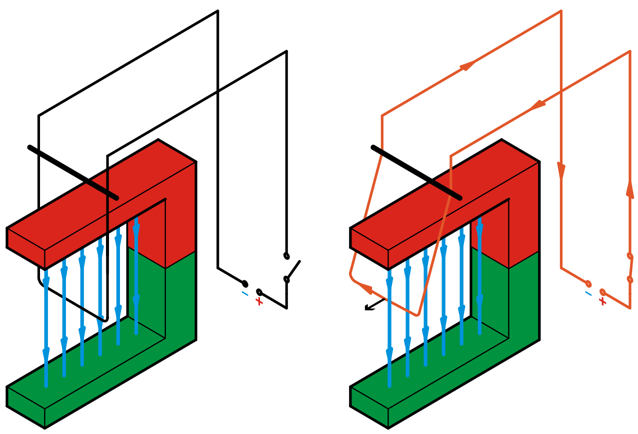


Figure 6.1: Lorentz force

The magnitude of the force depends on the strength of the magnetic field, the intensity of the current and the length of the wire in the magnetic field. The DC motor uses this force action to generate a rotation. To this end, a conduction loop is configured between the two magnetic poles (north/sound) so it can rotate (Figure 6.2).

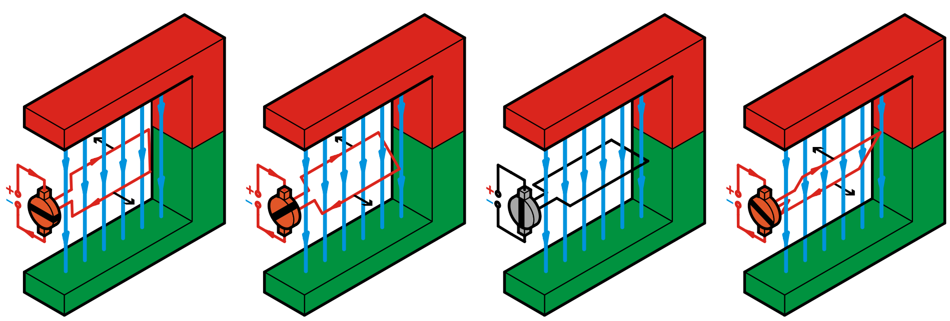


Figure 6.2: How a DC motor works

The current flows through the two halves of the conduction loop in opposite directions. This means that the force action on the two halves of the conduction loop is also opposed. A north and south pole are also established, that are attracted (north/south or south/north) or repelled (south/south or north/north) by the poles of the permanent magnet. Both forces generate a torque that keeps the conduction loop turning. The mechanical commutator (current converter) reverses the polarity of the current after a maximum of one half-revolution of the conduction loop and the process repeats itself.

## Electric Drives

The commutator is the important component since it generates rotation from each individual one-off event of the action of force on the conductor with current flowing through it. It consists of two metal half shells that are insulated from each other to which the current is transferred by means of carbon brushes.

Since DC motors normally generate low torques (Md) at high speeds (n), gear units are frequently placed upstream as a transmission component to reduce the output speed ($n_2$) by the transmission ratio i and increase the output torque ($Md_2$) by the same factor. The following rule applies:

$$i = \frac{n_1}{n_2} = \frac{Md_2}{Md_1}$$

Gear units come in a wide range of designs. Figure 6.3 shows a DC motor with worm gear unit where the drive shaft is turned 90° to the motor shaft.

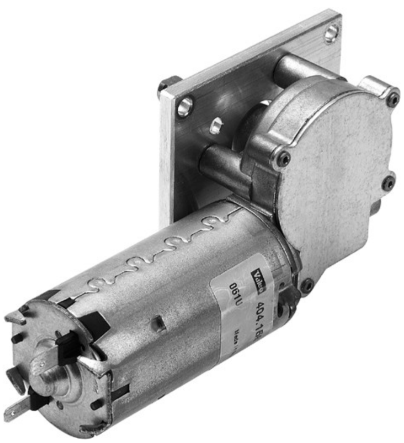


Figure 6.3: DC motor with gear unit

## Electric Drives

### Activating DC Motors

The DC motor begins to turn when it is connected to a power source. The direction of rotation depends on the polarity. Figure 6.4 shows the simplest method of activation, with the switch open (motor off) and with the switch closed (motor on).

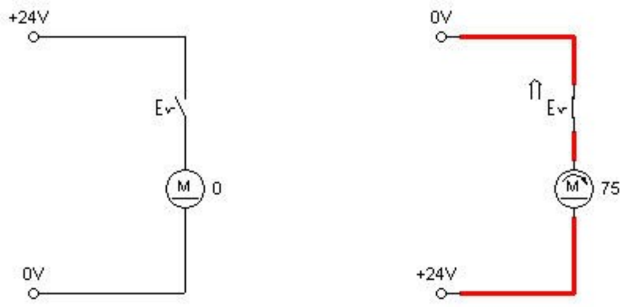



Figure 6.4: Activating a DC motor

Since electric motors need comparatively high currents, activation takes place via relays so as not to overload the switches. Figure 6.5 shows the corresponding circuit diagram.

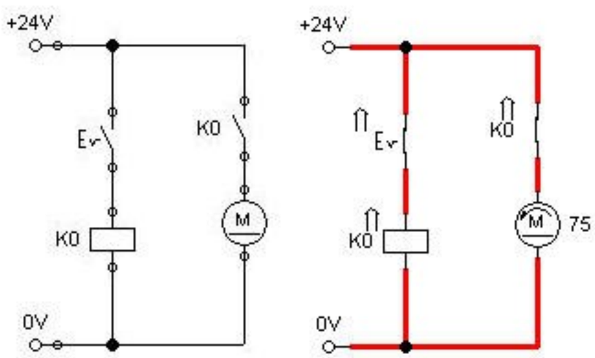



Figure 6.5: Activating a DC motor using relays

# Electric Drives

To reverse the direction of rotation of the motor, the direction of the current must be reversed by the motor (Figure 6.6).

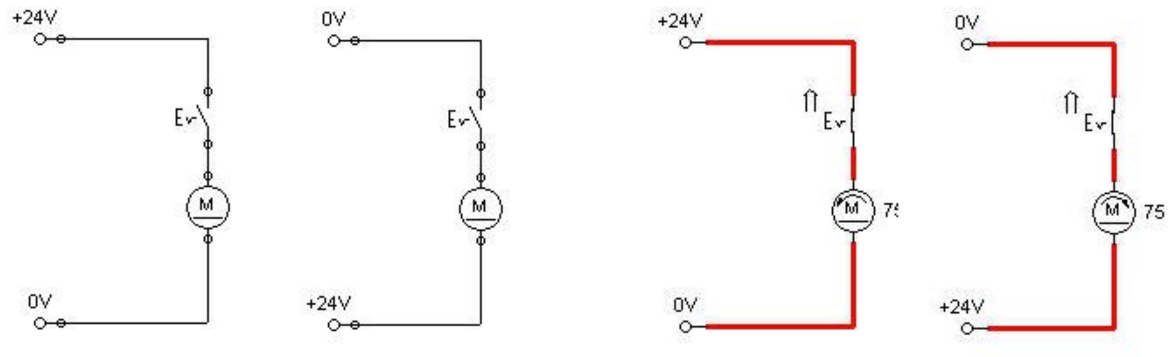



Figure 6.6: Reversal of the direction of rotation in a DC motor

Since it is not possible or practical to keep changing the motor wiring, a so-called pole reversal circuit is used in DC motors to reverse the direction of rotation (Figure 6.7).

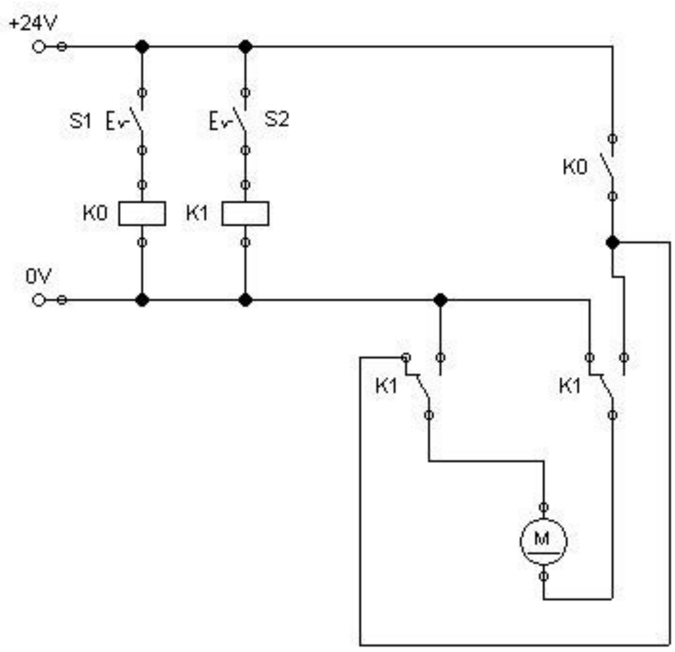



Figure 6.7: Pole reversal circuit

Here the motor is activated using two relays; the relay K0 switches the motor current on or off while the changeover relay K1 reverses the polarity of the motor current so that the motor runs forwards and backwards.

# Electric Drives

## Solenoids as Actuators

Another electric drive that is suitable for simple positioning tasks is the solenoid. Solenoids actuate the piston spools of solenoid valves, for example, and can be used in principle wherever small linear strokes are sufficient.

Figure 6.8 shows the operational principle. The solenoid essentially consists of a coil and an iron core. The coil generates a magnetic field when current flows through it and then exerts an attractive force on the iron core. This causes the iron core to be pulled into the coil. When the current is switched off, a spring pushes the iron core back out of the coil. A change in the direction of current does cause a change in the direction of the magnetic field, however this does not affect the attraction exerted on the iron core by the magnetic field.

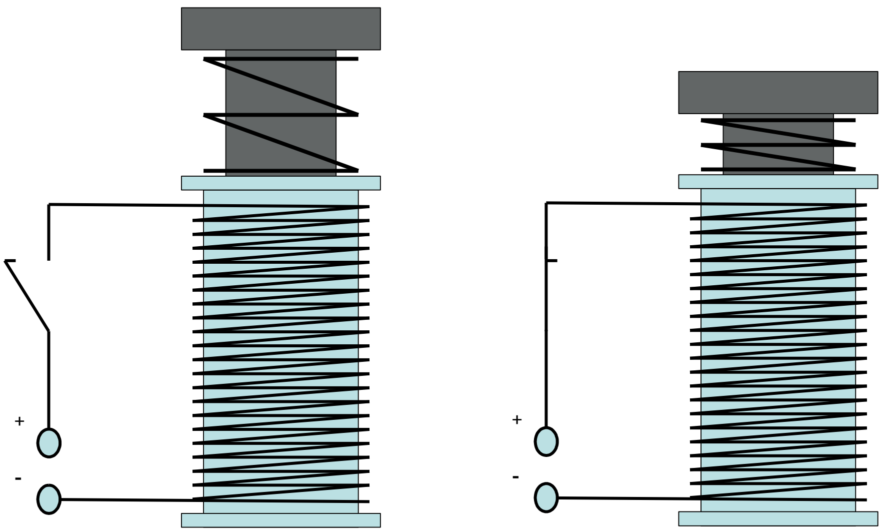



Figure 6.8: How a solenoid works

# Control Technology Basics

Control systems are a central element in automation technology along with actuators and sensors. The term control system is frequently used in the broad sense to describe devices used for:

- Open-loop control
- Closed-loop control
- Monitoring
- Data collection
- Communication
- Diagnostics

In the narrower sense, control within automation technology refers to influencing an energy or material flow by means of one or more signals in an open control loop (DIN 19226). Control systems are frequently used for processes that are performed in steps. Examples of these include:

- Opening a door when someone approaches
- Changing a traffic light to red after a specified time
- Turning a light on when a switch is pressed then automatically turning it off again after a specified time

Control systems such as these are characterised by an open-loop process, i.e. the input variable (x) is not influenced by the controlled output variable (y). The control system cannot react to possible disturbance variables. In bullet-point three (above), this means that the open-loop time control system for the corridor lighting switches the light off after the specified time whether or not the person who pressed the light switch and thereby initiated the process has reached the apartment door. Figure 7.1 shows an open control loop.

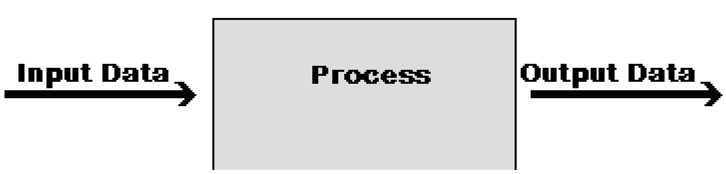



Figure 7.1: Open control loop

# Control Technology Basics

A closed-loop control system, on the other hand, continuously records the output variables (y) of the process, compares them with the input variables (x) and then automatically readjusts the process in the sense of an alignment of the output and input variables. It has a closed control loop and can react to disturbance variables. Closed-loop control processes are, for the most part, continuous processes where the output variable is to be maintained at a specific value. Examples of these include:

- Controlling water temperature in an aquarium
- Controlling the speed of a vehicle (cruise control)
- Controlling the rotational speed of an electric motor

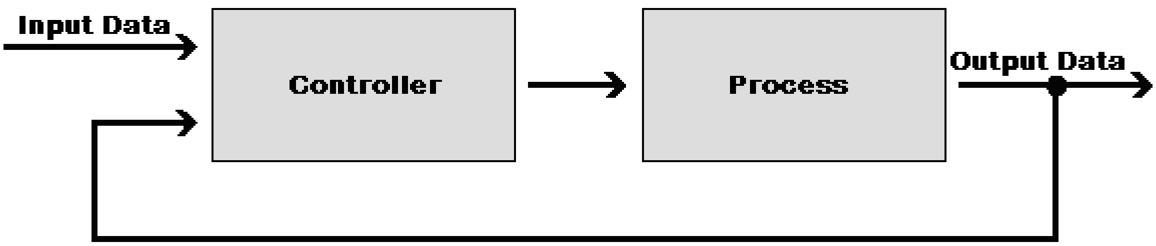



Figure 7.2: Closed loop control

Many terms are coined within automation technology for controller types with specific functions. Some examples of these include:

- Hard-wired programmed control systems
  Hard-wired programmed control systems function whereby the control logic or the "program" is realised by connecting relays. Contact control systems are an example of this. They are usually constructed from relays and are used for simple control tasks. A typical area of application of this type of control is the activation of electric motors.
- PLCs – Programmable logic controllers (see Figure 7.3)
  PLCs were developed to replace the less flexible contact control systems. They consist of a computer with special input and output modules. The program is not defined by linking individual relays but rather is stored in the controller memory, where it can be easily changed. PLCs mainly process binary signals.
  In the MecLab® learning media system, the actual PLC is replaced by a simulated PLC in the FluidSIM® software. In addition to programmable logic controllers, contact control systems can also be simulated in FluidSIM®.

# Control Technology Basics

- CNC – Computer numeric controllers
  These controllers are used to control machine tools such as drilling, cutting and turning machines, for example. The first automated machine tools used wooden patterns that were gauged to transfer their shape to the work piece. The wooden pattern was then replaced by a numeric model where the work piece coordinates are stored in the form of mostly binary numeric codes. The main purpose of the CNC controller is to translate the computer model of the work piece created using software into a motion sequence for the tool.
- RC – Robot controllers
  Robot controllers have been specifically designed for controlling industrial robots and are similar in structure to the CNC controllers.

## The Structure and Operation of a Programmable Logic Controller (PLC)

Since the PLC is the most frequently used and also the simplest controller, it is considered in more detail below.

Figure 7.3: Programmable logic controller (Festo)

# Control Technology Basics

The main component in a PLC is the microprocessor system. The programming of the micro-processor defines:

- Which controller inputs (I1, I2, etc.) are read in and in what order
- How these input signals are linked
- The outputs (O1, O2, etc.) to which the results of the signal processing are output

In the case of a PLC, the controller's behavior is not determined by the interconnection of electrical components (hardware), but rather by a program (software).

Figure 7.4 shows the basic structure of a PLC.

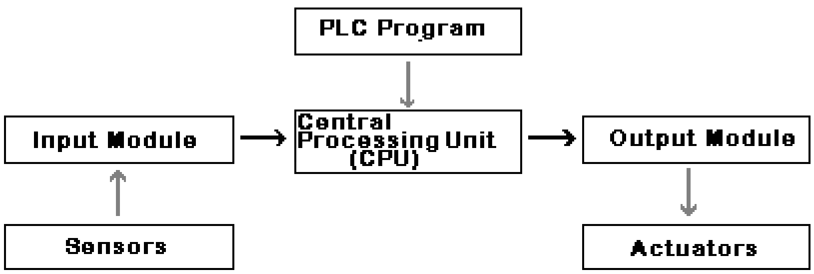



Figure 7.4: Components of a PLC

# Control Technology Basics

## Mathematical Fundamentals – Basic Logic Functions

### General Information

Basic logic functions form the basis of most controllers. Therefore an overview of the most important basic logic functions is provided below. Logic functions can be represented in tabular form, in the form of equations, using relay circuits (operations) or using logic symbols (see Section 7.2.6). Logic symbols are used in a PLC to create the program.

### Identity (YES function)

The pushbutton shown is an N/O contact. When it is unactuated, the lamp P1 does not light up. When, on the other hand, it is actuated, the lamp P1 lights up.

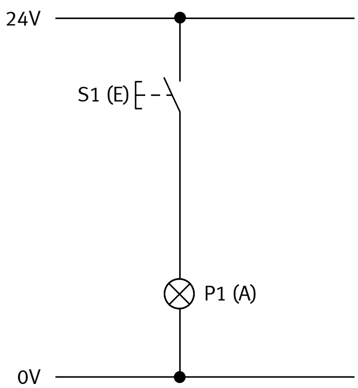



Figure 7.5: Circuit diagram (identity)

The pushbutton S1 acts as the signal input, the lamp is the output. The known facts can be recorded in a truth table:

| I | O |
|---|---|
| 0 | 0 |
| 1 | 1 |

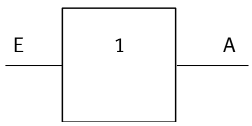
Truth table (identity)

The Boolean equation is therefore:

I = O

# Control Technology Basics

The logic symbol for identity is:




## Negation (NOT function)

The pushbutton shown is an N/C contact. When it is unactuated, the lamp P1 lights up. When, on the other hand, it is actuated, the lamp P1 switches off.

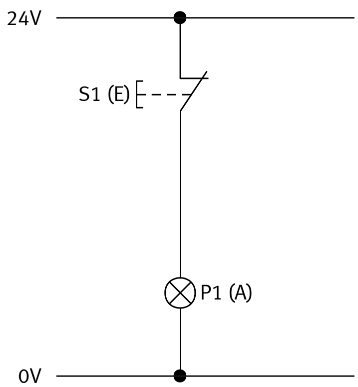


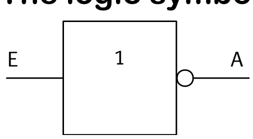

Figure 7.6: Circuit diagram (negation)

The pushbutton S1 acts as the signal input, the lamp is the output. The known facts can be recorded in a truth table:

The Boolean equation is therefore:

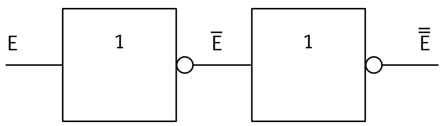
$\dot{I} = 0$ (reads: not I equal to O)

The logic symbol is:



If two negations are used in a series (negation of the negation), they cancel each other out.

$\overline{\overline{E}} = E$




Two linked NOT functions

## Conjunction (AND Function)

If two N/O contacts are connected in series, the activated lamp only lights up if both pushbuttons are actuated.

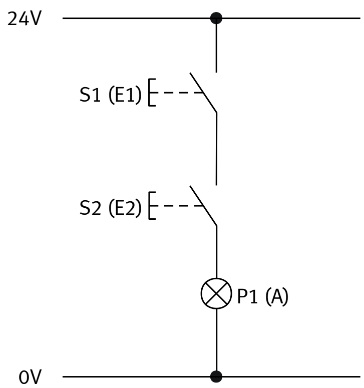



Figure 7.7: Circuit diagram (conjunction)

| I1 | I2 | O |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

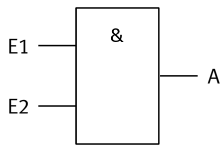
Truth table (conjunction)

The truth table describes the relationship. The output only becomes 1 if both input 1 and input 2 exhibit a "1" signal. This is described as an AND operation. It is expressed as follows as an equation:

$$I1 \wedge I2 = O$$

# Control Technology Basics

The logic symbol is:




The following arithmetic rules also apply to the AND operation:

$$a \wedge 0 = 0$$
$$a \wedge 1 = a$$
$$a \wedge \bar{a} = 0$$
$$a \wedge a = a$$

## Disjunction (OR Function)

Another basic logic function is the OR function. If two N/O contacts are switched in parallel, the lamp will always light up if at least one pushbutton is actuated.

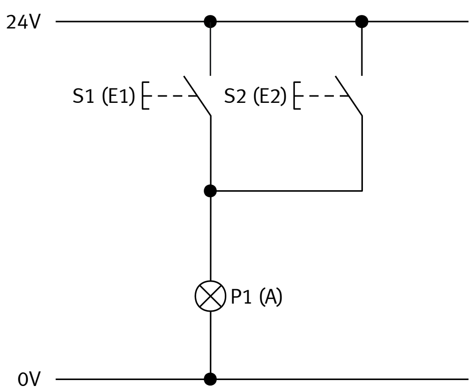



Figure 7.8: Circuit diagram (disjunction)

| I1 | I2 | O |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

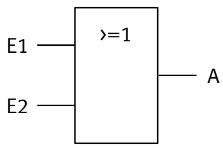
Truth table (disjunction)

# Control Technology Basics

**The OR operation is expressed as follows as an equation:**

$$I1 \vee I2 = O$$

**The logic symbol is:**




**The following arithmetic rules also apply to the OR operation:**

$$a \vee 0 = a$$
$$a \vee 1 = 1$$
$$a \vee a = a$$
$$a \vee \overline{a} = 1$$

# Control Technology Basics

## Additional Logic Operations

The realization of the NOT/AND/OR function using electro technical circuits has already been described. Each of the functions can naturally also be realised pneumatically or electronically. Boolean algebra also recognises further logic functions, an overview of which is given in the following table.

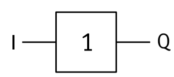
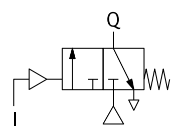
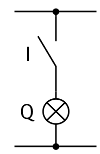
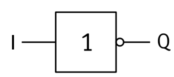
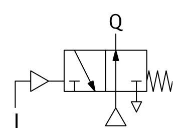
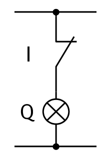
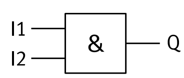
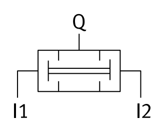
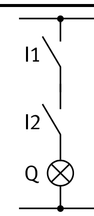
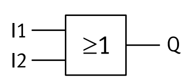
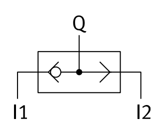
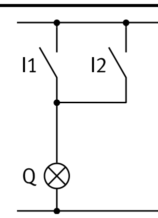
| Designation | Truth table | Equation | Symbol IAW EN 60617-12 | Symbol IAW ISO 1219-1 (Pneumatic) | Symbol IAW EN 60617-7 (Electric) |
|---|---|---|---|---|---|
| Identity | I Q<br>0 0<br>1 1 | **Q=IQ=I**<br>$Q=\bar{I}$ |  |  |  |
| Negation | I Q<br>0 1<br>1 0 | $Q=\bar{I}$ |  |  |  |
| Conjunction (AND) | I1 I2 Q<br>0 0 0<br>0 1 0<br>1 0 0<br>1 1 1 | $Q=I1\wedge I2$ |  |  |  |
| Disjunction (OR) | I1 I2 Q<br>0 0 0<br>0 1 1<br>1 0 1<br>1 1 1 | $Q=I1\vee I2$ |  |  |  |

Table 7.1: Logic operations

# Control Technology Basics

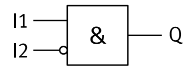
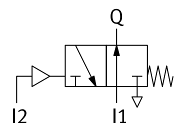
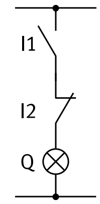
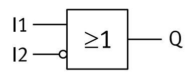
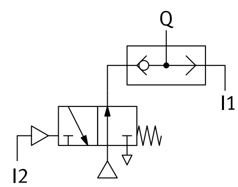
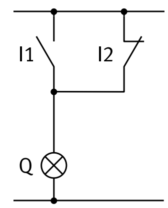
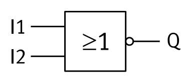
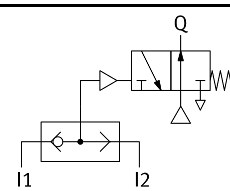
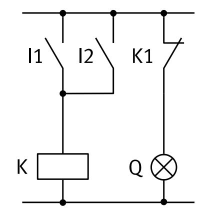
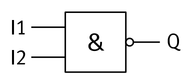
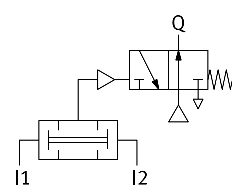
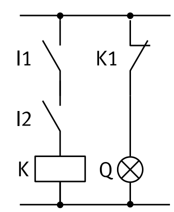
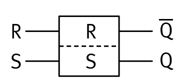
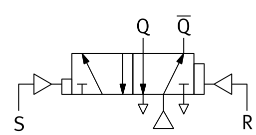
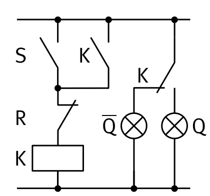
| Designation | Truth Table | Equation | Symbol IAW EN 60617-12 | Symbol IAW ISO 1219-1 (Pneumatic) | Symbol IAW EN 60617-7 (Electric) |
|---|---|---|---|---|---|
| **Inhibition** | I1 \| I2 \| Q<br>0 \| 0 \| 0<br>0 \| 1 \| 0<br>1 \| 0 \| 1<br>1 \| 1 \| 0 | $Q = I1 \wedge \overline{I2}$ |  |  |  |
| **Implication** | I1 \| I2 \| Q<br>0 \| 0 \| 1<br>0 \| 1 \| 0<br>1 \| 0 \| 1<br>1 \| 1 \| 1 | $Q = I1 \vee \overline{I2}$ |  |  |  |
| **NOR** | I1 \| I2 \| Q<br>0 \| 0 \| 1<br>0 \| 1 \| 0<br>1 \| 0 \| 0<br>1 \| 1 \| 0 | $Q = \overline{I1 \vee I2}$ |  |  |  |
| **NAND** | I1 \| I2 \| Q<br>0 \| 0 \| 1<br>0 \| 1 \| 1<br>1 \| 0 \| 1<br>1 \| 1 \| 0 | $Q = \overline{I1 \wedge I2}$ |  |  |  |
| **Memory** | S \| R \| Q \| $\overline{Q}$<br>0 \| 0 \| $q^{n-1}$ \| $\overline{q}^{n-1}$<br>0 \| 1 \| 0 \| 1<br>1 \| 0 \| 1 \| 0<br>1 \| 1 \| 0 \| 1 | |  |  |  |

Table 7.1: Logic operations (continued)

# Control Technology Basics

## Examples of Controller Structure

The section of an electro pneumatic controller that processes signals encompasses three functional modules. An example of its structure is shown in Figure 7.9.

- Signal input takes place by means of sensors or by means of pushbuttons or control switches. In Figure 7.9, two proximity sensors (1B1/1B2) are used for signal input.
- Signal processing usually takes place using a relay controller or programmable logic controller. There are other forms of signal processing, however these are of much less importance in automation practice. In Figure 7.9, signal processing is carried out by a relay controller (K1/K2).
- Signal output takes place using electromagnetically-actuated directional control valves (1M1/1M2).

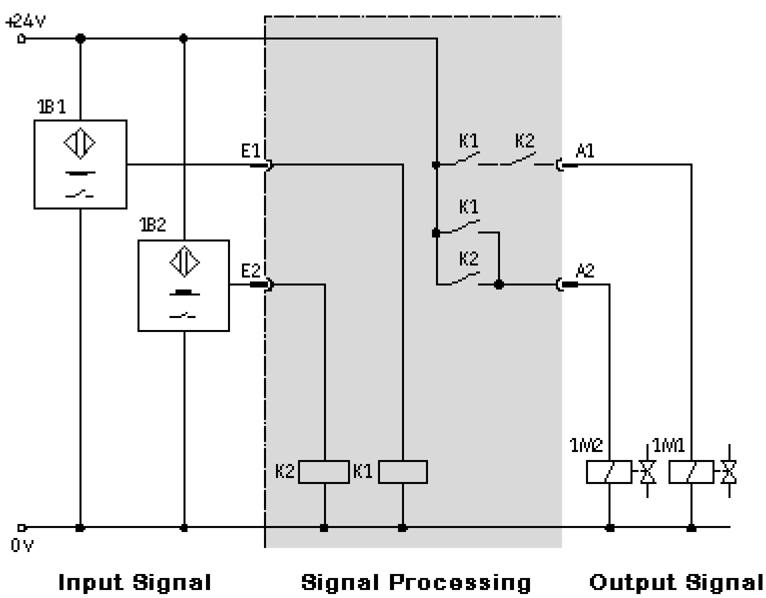



Figure 7.9: Signal control section with relay controller (schematic, circuit diagram not to standards)

# Control Technology Basics

**Functional description of the relay controller in Figure 7.9:**

- **The components for signal input, the inductive proximity sensors 1B1 and 1B2, are connected with the relay coils (K1, K2, etc.) via the controller inputs (I1, I2, etc.).**
- **Signal processing is realised through respective interconnection of a number of relay coils and relay contacts. In this case, the relay contacts to the output O1 are ANDed and the contacts to the output O2 are ORed.**
- **The components for signal output, directional control valve solenoid coils 1M1 und 1M2, are connected to the controller outputs (O1, O2, etc.). They are actuated via the contacts of the relays K1 and K2.**

# Control Technology Basics

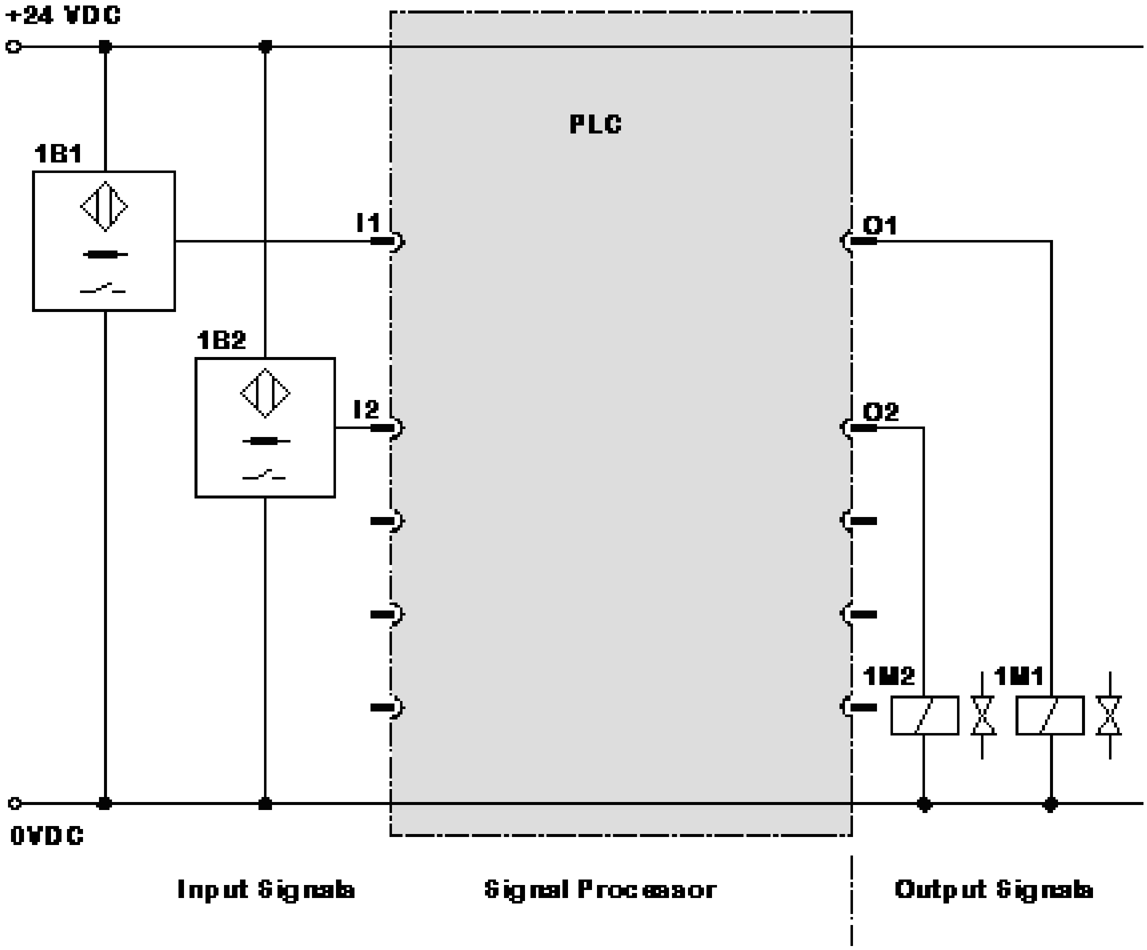



Figure 7.10: Signal control section of a programmable logic controller (PLC)

Figure 7.10 shows the signal control section of an electro pneumatic controller that uses a programmable logic controller for signal processing.

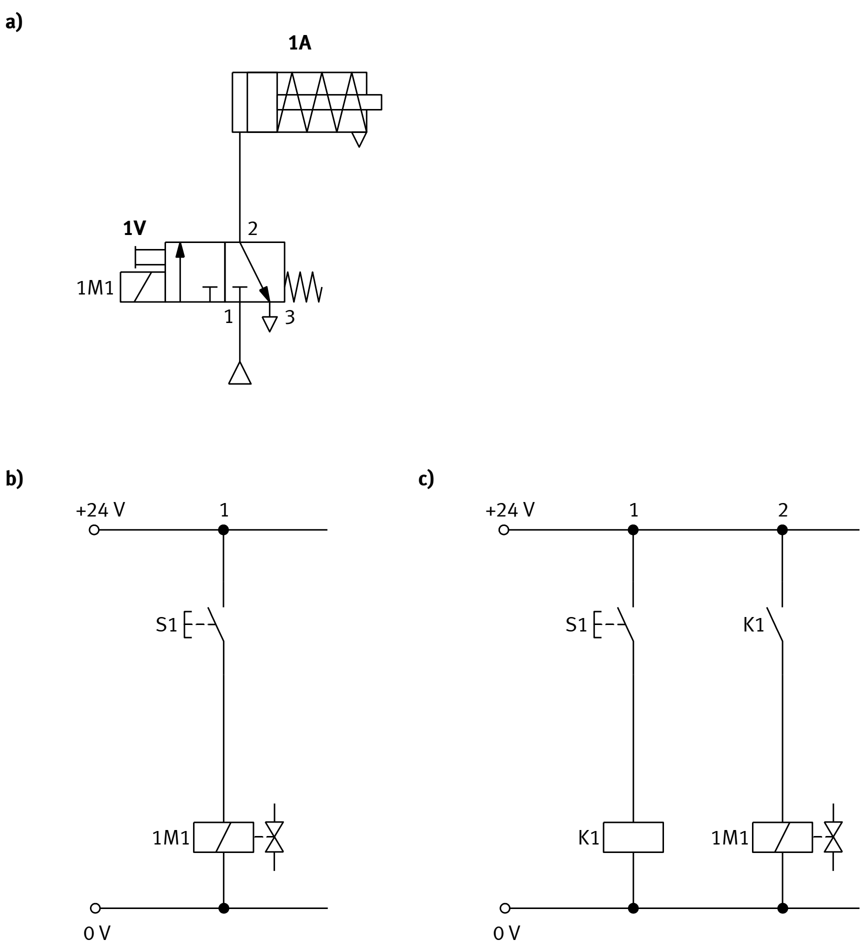
- The components for signal input (in Figure 7.10: the inductive proximity sensors 1B1 and 1B2) are connected with the inputs of the PLC (I1, I2).
- The programmable microprocessor system of the PLC handles all the signal processing tasks.
- The components for signal output (in Figure 7.10: directional control valve solenoid coils 1M1 and 1M2) are connected with the outputs of the PLC (O1, O2). Actuation takes place via an electronic circuit that is part of the microprocessor system.

# Relays

Relays can be used for all the signal processing requirements of an electro pneumatic controller. In the past, relay controllers were manufactured in large numbers. Their main advantages are their clear structure and easy to understand mode of operation. Since they are relatively reliable, relay controllers are still used today in industrial applications such as emergency-stop switchgears, for example. Increasingly, however, they are being replaced in signal processing by programmable logic controllers.

## Direct and Indirect Control Using Relays

The piston rod of a single-acting cylinder is to advance when the pushbutton S1 is actuated and retract again when the pushbutton is released. Figure 8.1a shows the accompanying pneumatic circuit diagram.




a) Pneumatic circuit diagram

b) Electrical circuit diagram for direct control

c) Electrical circuit diagram for indirect control

Figure 8.1: Circuit diagrams for the control model for a single-acting cylinder

# Relays

## Direct Control of a Single-Acting Cylinder

Figure 8.1b shows the electrical circuit diagram for direct control of a single-acting cylinder. When the pushbutton is actuated, current flows through the solenoid coil 1M1 of the 3/2-way valve. The solenoid exerts a pulling force, the valve switches to the actuated position and the piston rod advances. Releasing the pushbutton interrupts the flow of current. The solenoid is de-energised, the directional control valve switches to its normal position and the piston rod retracts again.

## Indirect Control of a Single-Acting Cylinder

With indirect control, when the pushbutton is actuated (Figure 8.1c), current flows through the relay coil. The contact K1 of the relay closes and the directional control valve switches. The piston rod advances.

Releasing the pushbutton interrupts the flow of current through the relay coil. The relay is de-energised and the directional control valve switches to its normal position. The piston rod retracts. The result is initially the same as with direct control. The more complex indirect control is used if:

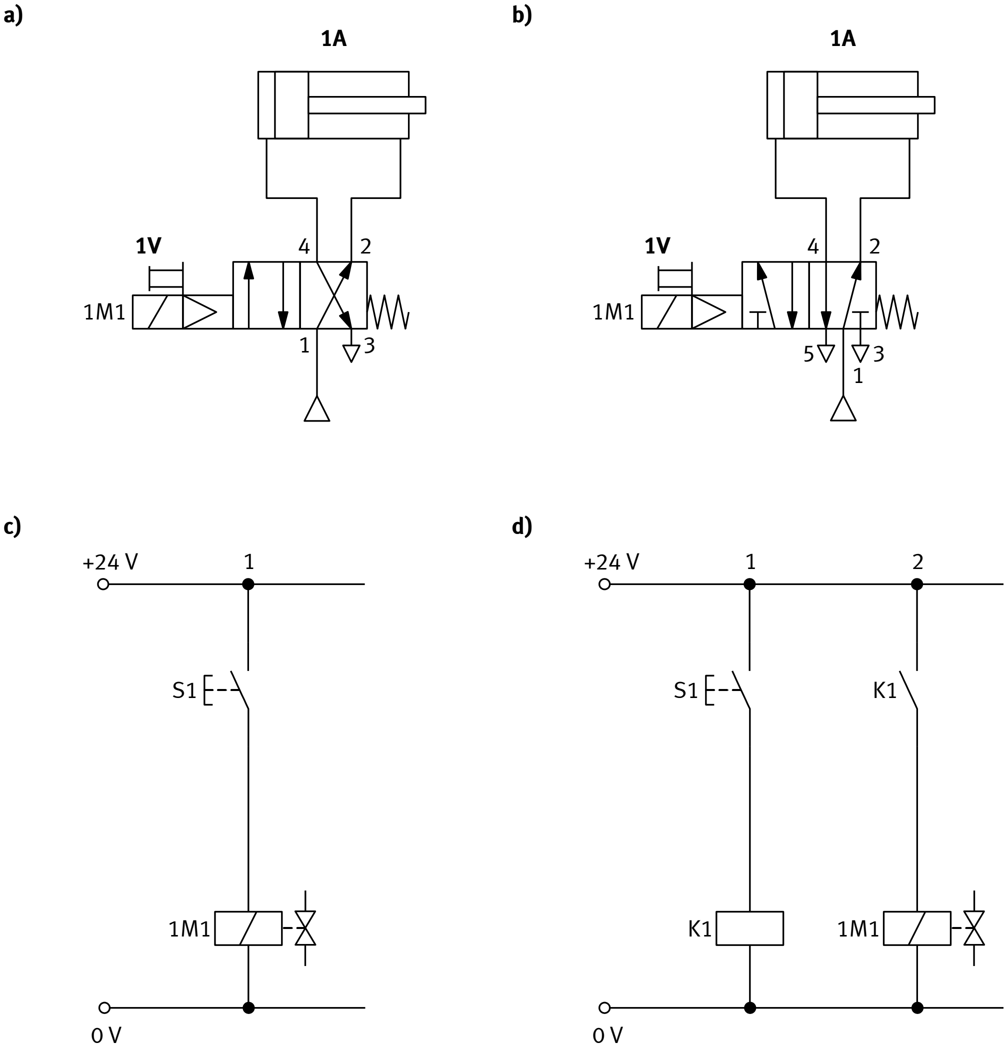
- The control circuit and main circuit are working with different voltages (e.g. 24 V and 115 V),
- The current through the coil of the directional control valve exceeds the permissible current for the pushbutton (e.g. current through the coil: 0.5 A; permissible current through the pushbutton: 0.1 A),
- One pushbutton or control switch is used to switch a number of valves,
- Extensive logic operations are required between the signals of the various pushbuttons.

# Relays

## Controlling a Double-Acting Cylinder

**The piston rod of a double-acting cylinder is to advance when the pushbutton S1 is actuated and retract when the pushbutton is released.**




a) Pneumatic circuit diagram with 4/2-way valve

b) Pneumatic circuit diagram with 5/2-way Valve

c) Electrical circuit diagram with direct control

d) Electrical circuit diagram with indirect control

Figure 8.2: Circuit diagrams for the control model of a double-acting cylinder

The electrical signal control section remains unchanged in comparison with the control model for the single-acting cylinder. Since two cylinder chambers have to be exhausted or pressurised, either a 4/2-way valve or a 5/2-way valve is used (Figures 8.2a and 8.2b respectively).

The designation 4/2-way or 5/2-way indicates the number of ports (4 or 5) and switching positions (2) offered by the valve.

# Relays

## Relay Logic Operations

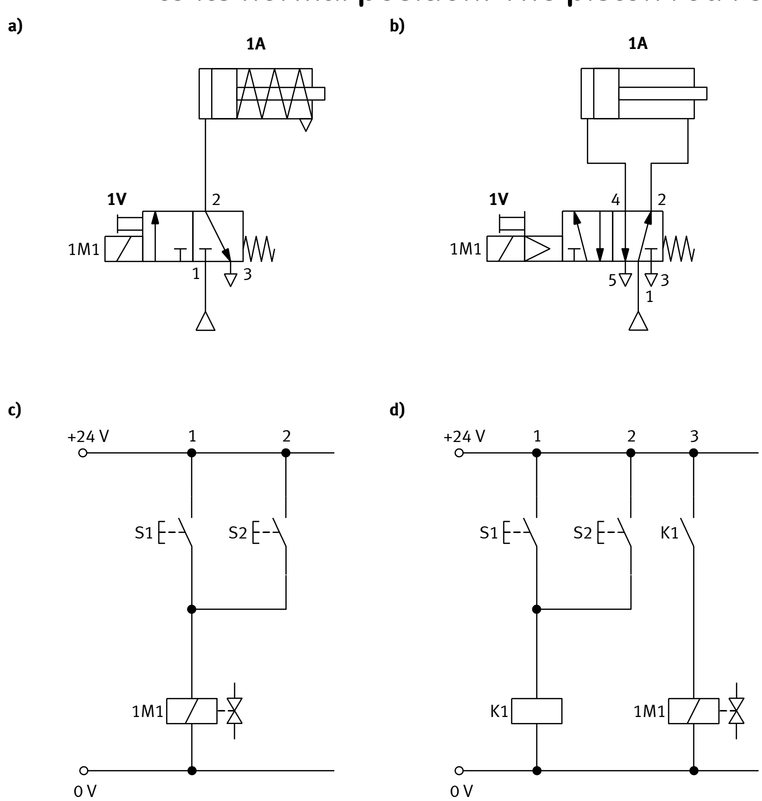
Signals from several control components frequently have to be combined to realise the pneumatic cylinder movements required for an application.

## Parallel Connection (OR Operation)

The advancing of a cylinder piston rod is to be triggered using one of two independent input components, the pushbuttons S1 and S2.

To this end, the contacts of the two pushbuttons are arranged in parallel in the circuit diagram
(Figures 8.3c and 8.3d).

- As long as neither pushbutton is actuated (S1 Ù S2 = 0), the directional control valve remains in its normal position. The piston rod is retracted.
- If at least one of the two pushbuttons is actuated (S1 Ú S2 = 1), the directional control valve switches to the actuated position. The piston rod advances.
- If both pushbuttons are released and thus opened (S1 Ù S2 = 0), the valve switches to its normal position. The piston rod retracts.




a) Pneumatic circuit diagram with single-acting cylinder

b) Pneumatic circuit diagram with double-acting cylinder

c) Electrical circuit diagram with direct Control

d) Electrical circuit diagram with indirect control

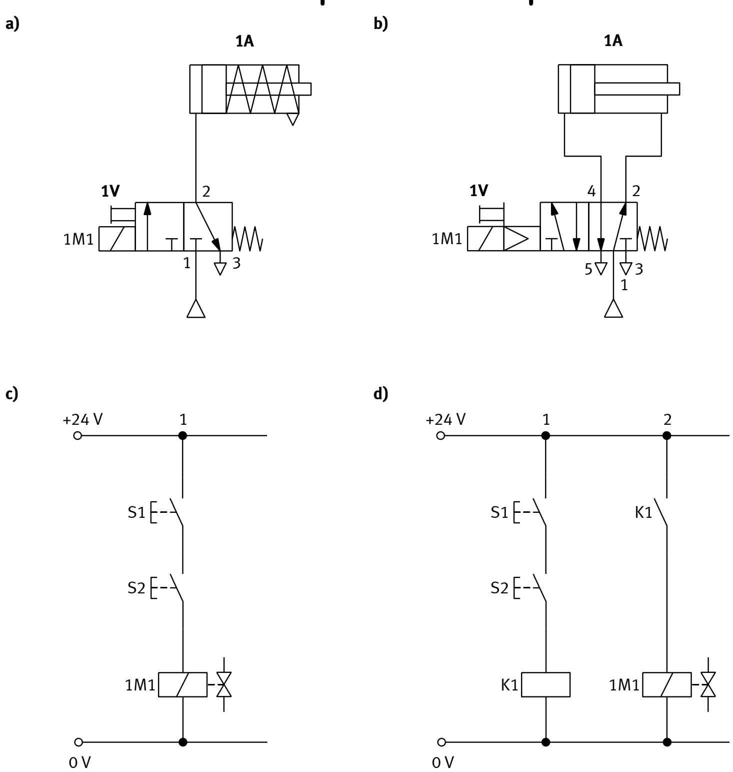
Figure 8.3: Parallel connection of two contacts (OR operation)

# Relays

## Series Connection (AND Operation)

The piston rod of a cylinder is only to advance if the two pushbuttons S1 and S2 are actuated. To this end, the contacts of the two pushbuttons are arranged in series in the circuit diagram (Figures 8.4c and 8.4d).

- As long as neither pushbutton or just one of the two pushbuttons is actuated (S1 Ú S2 = 0), the valve remains in its normal position. The piston rod is retracted.
- If both pushbuttons are actuated simultaneously (S1 Ù S2= 1), the directional control valve switches. The piston rod advances.
- If at least one of the two pushbuttons is released (S1 Ú S2 = 0), the valve switches to its normal position. The piston rod retracts.




a) Pneumatic circuit diagram with single-acting cylinder

b) Pneumatic circuit diagram with double-acting cylinder

c) Electrical circuit diagram with direct control

d) Electrical circuit diagram with indirect control

Figure 8.4: Series connection of two contacts (AND operation)

## Relays

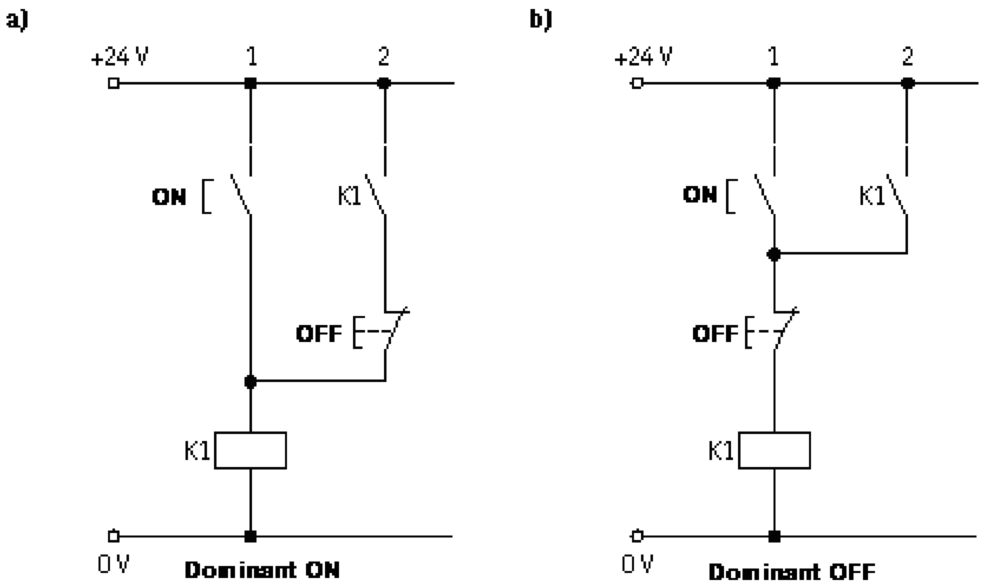
### Signal Storage Using Relays and Double Solenoid Valves

In the circuits discussed so far, the cylinder extends only as long as the pushbutton is pressed. If the button is released the cylinder will retracts without having reached the extended position.

### Signal Storage by Means of a Relay Circuit with Self-Latching Loop

In most cases, the application will call for the cylinder to fully extend even when operator presses the pushbutton briefly. To this end, the directional control valve must remain in the intended position even after the pushbutton is released, in other words the actuation of the pushbutton must be stored.

When the "ON" pushbutton in the circuit in Figure 8.5a is actuated, the relay coil is energized. The relay pulls in and the contact K1 closes. After the "ON" pushbutton is released, current continues to flow through the coil via the contact K1 and the relay remains in the actuated position. The "ON" signal is stored. This is called a “latching” relay circuit.




a) Dominant ON

b) Dominant OFF

Figure 8.5: Latching circuit using relays

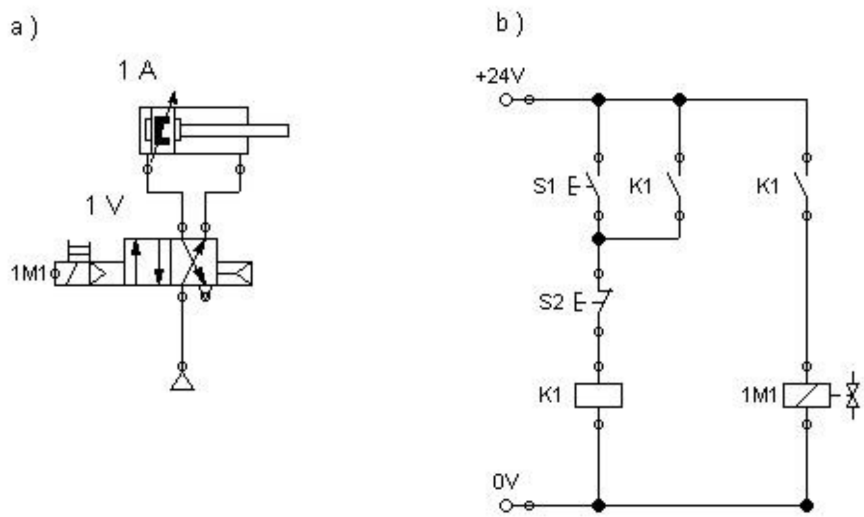
Pressing the "OFF" pushbutton interrupts current flow and the relay de-energizes. If the "ON" and "OFF" pushbuttons are pressed at the same time, the relay coil is energized. This is called a dominant ON circuit.

If both buttons are pressed in the circuit in Figure 8.5b the relay coil is not energized. This is called a dominant  OFF circuit.

# Relays

## Manual Cylinder Operation Using Latching Relays

The piston rod of a cylinder is to advance when the pushbutton S1 is actuated and retract when the pushbutton S2 is actuated. A relay with self-latching loop is to be used to store the signal.




a) Pneumatic circuit diagram with double-acting cylinder

b) Electrical circuit diagram

Figure 8.6: Manual forward and return stroke control with signal storage by means of a latching relay

When the pushbutton S1 is actuated, the relay goes into the self-latching loop (Figure 8.6b). The directional control valve is actuated via a further relay contact. The piston rod advances. If the self-latching loop is interrupted by the pushbutton S2 being actuated, the piston rod retracts.

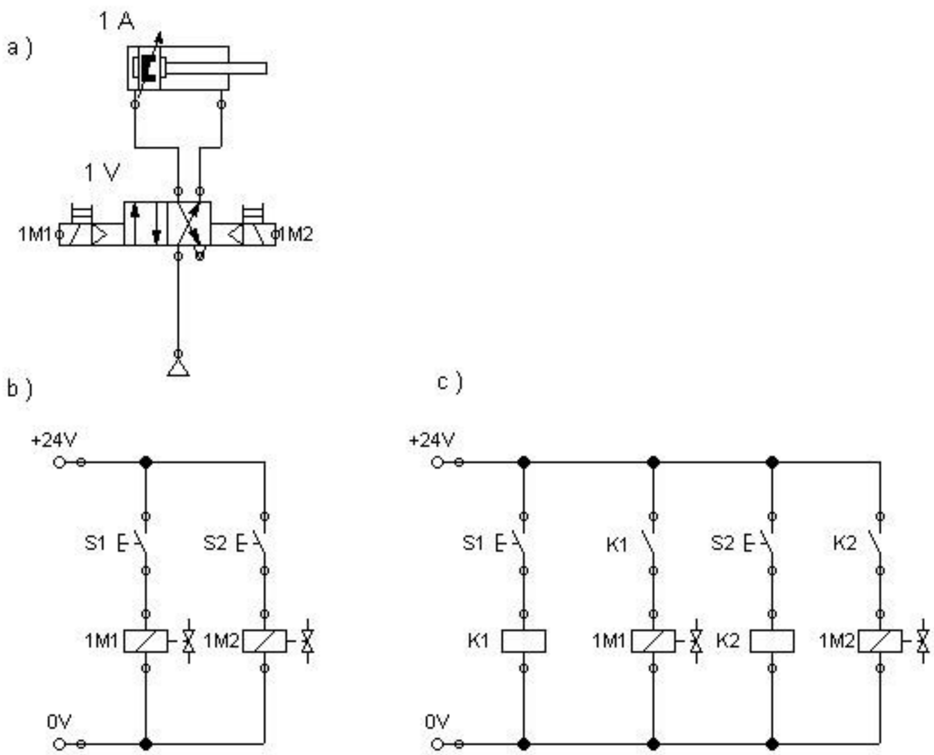
Since the circuit is a dominant resetting relay circuit, actuating the two pushbuttons results in the piston rod retracting or remaining in the retracted end position.

# Relays

## Signal Storage Using a Double Solenoid Valve

A double solenoid valve is a component that retains its switching position even if the associated solenoid coil is no longer energised. This means it can fulfil the function of a memory.

The piston rod of a cylinder is to be controlled by briefly actuating two pushbuttons (S1: advance, S2: retract).




a) Pneumatic circuit diagram with double-acting Cylinder

b) Electrical circuit diagram with direct control

c) Electrical circuit diagram with indirect control

Figure 8.7: Manual forward and return stroke control with signal storage by means of a double solenoid valve

The two pushbuttons act directly or indirectly on the coils of a double solenoid valve (Figures 8.7b and 8.7c respectively).

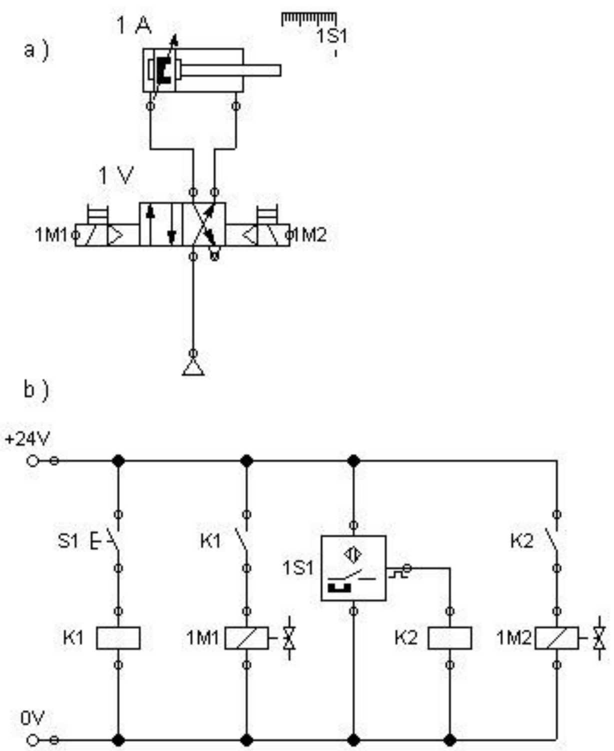
Actuating the pushbutton S1 causes an attractive force to be exerted on the solenoid coil 1M1. The double solenoid valve switches and the piston rod advances. If the pushbutton is released during the advancing operation, the piston rod still keeps moving to the advanced end position since the valve retains its switching position.

Actuating the pushbutton S2 causes an attractive force to be exerted on the solenoid coil 1M2. The double solenoid valve switches again and the piston rod retracts. Releasing the pushbutton S2 has no effect on the movement.

# Relays

## Automatic Return Using Double Solenoid Valves

**The piston rod of a double-acting cylinder is to advance when the pushbutton S1 is actuated. After it reaches the advanced end position, the piston rod must automatically retract. To this end, a magnetic proximity sensor S1 that controls (reverses) the solenoid valve via the relay K2 is mounted at the advanced end position. Figure 8.6b shows the circuit diagram for the return stroke control model. The piston rod advances when the pushbutton S1 is actuated. When the piston rod reaches the advanced end position, the solenoid coil 1M2 can receive (draw) current via the limit switch 1S2 and the piston rod retracts.**




**a) Pneumatic circuit diagram**

**b) Electrical circuit diagram with indirect control**

**Figure 8.8: Automatic return stroke control with signal storage by means of a double solenoid valve**

# Relays

## Signal Storage Comparison Using Latching Relays and Double Solenoid Valves

Signal storage can take place in the power section of the controller by means of a double solenoid valve or in the signal control section by means of a relay with self-latching loop. The different circuits behave differently in the event of simultaneous set and reset signals as well as in the event of a power failure or defect such as a wire break, for example (Table 8.1).

| Situation | Storage Using a Double Solenoid Valve | Storage Using Latching Circuit and Single Solenoid Valve (Spring Return) | |
|---|---|---|---|
| | | Dominant setting | Dominant resetting |
| Set and reset signals together | Valve position unchanged | Valve is actuated | Valve switches to normal position |
| Failure of the electrical power supply | Valve position unchanged | Valve goes to normal position | Valve switches to normal position |

Table 8.1: Comparison of signal storage by means of latching circuit and double solenoid valve

# Relays

## Timed Circuits Using Delay Relays

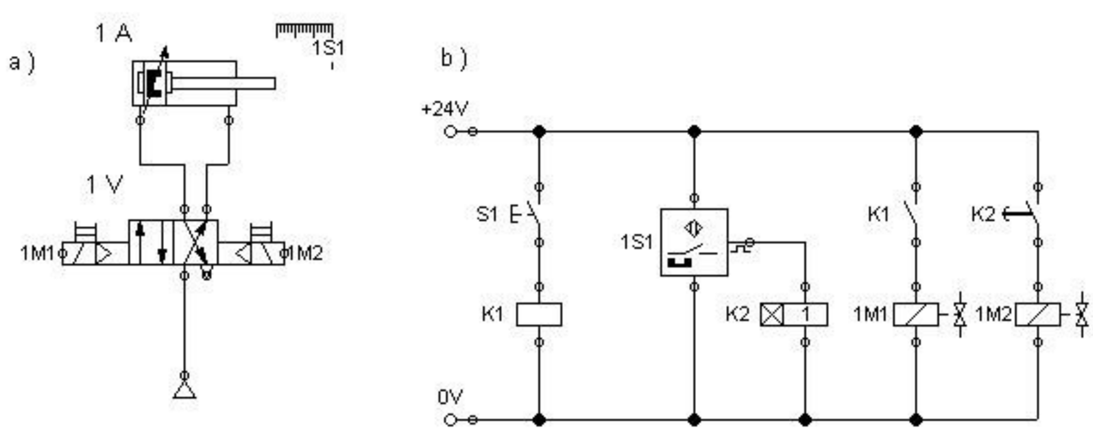
Many applications within automation technology require the piston rod of a pneumatic cylinder to remain in one position for a defined period of time. An example of such an application is the drive for a pressing device that presses two work pieces together until the adhesive has set and both parts are firmly stuck together.

Tasks such as this use relays with a switch-on or switch-off delay. These are relays that can trigger or interrupt a switching operation via a predefined time delay.

## Timed Control of a Cylinder

The piston rod of a cylinder is to advance after the pushbutton S1 is briefly actuated, remain in the advanced end position for 10 seconds and then automatically retract.

Figure 8.9b shows the electrical circuit diagram for delayed retraction. The piston rod advances when the pushbutton S1 is actuated. If the advanced end position is reached, the limit switch 1S1 closes. Current flows through the coil of the relay K2. The contact K2 remains open until the set delay time (1 second in this case) has expired. It is then closed and the piston rod retracts.




a) Pneumatic circuit diagram

b) Electrical circuit diagram

Figure 8.9: Delayed retraction (relay with switch-on delay, storage by means of a double solenoid valve)

# Programmable Logic Controllers (PLCs)

## General Information

These days complex control tasks are mainly handled using programmable logic controllers (PLCs). With this type of controller, the program is not realised through the linking of individual relays but rather using appropriate software. PLCs mainly process binary signals.

Their advantages over contact controllers or hard-wired programmed controllers are:

- Uses a few logic blocks instead of many relays
- Less wiring
- More flexible when it comes to changing the programs quickly and effectively
- Faults are easier to find
- Much more cost-effective

The MecLab® learning system uses a PLC simulated in the FluidSIM® software instead of an actual PLC. The programming of this PLC is essentially the same as for a standard PLC such as the Siemens "LOGO!" controller shown in Figure 9.1.

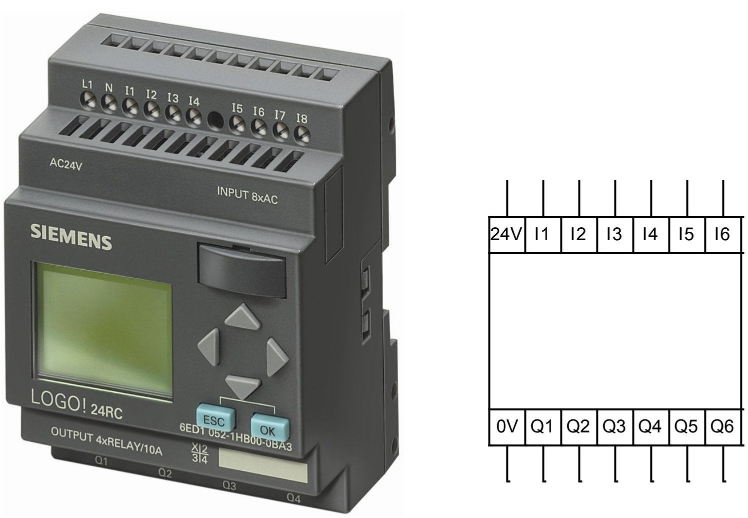



Figure 9.1: Picture of the "LOGO!" PLC from Siemens and the corresponding symbol in FluidSIM®

# Programmable Logic Controllers (PLCs)

## Logic Symbols in the FluidSIM® Control Software

Using controllers in an application makes sense if the sequences happen at the right time, at the right position and in the correct order. The user must have reliable hardware, software that enables sequences to be planned and controlled (with a simple user interface).

In this case we will use the FluidSIM® software. It offers three options for developing a control system:

- Pneumatic circuits
- Electrical circuits
- Logic circuits

All of these circuit types can be combined together . Simulation mode enables controller functions to be put to the test before they are used on the actual module. This advance testing of solutions on a computer can prevent damage to the system.

The following table provides an overview of the most important logic symbols available in FluidSIM®.

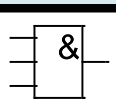
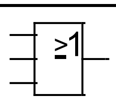
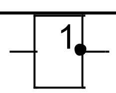
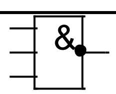
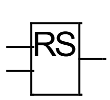
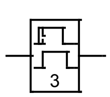
| Symbol | Designation | Function |
|---|---|---|
|   | AND | Switches the output to 1 when all inputs are 1. Unassigned inputs are always 1. |
|   | OR | Switches the output to 1 when at least one input is 1. Unassigned inputs are always 0. |
|   | NOT | Inverts the input. |
|   | NOT AND (NAND) | Switches the input to 0 when all inputs are 1. Unassigned inputs are always 1. |
|   | Latching element | Switches the input to 1 when the upper input is set to 1. The output is only reset to 0 when the lower input is set to 1. |
|   | Switch-on/off delay | When the input is set to 1, the output is set to 1 after the first set time has elapsed and reset to 0 after the second set time has elapsed. |

Table 9.1: Logic symbols in FluidSIM®

# Programmable Logic Controllers (PLCs)

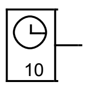
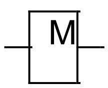
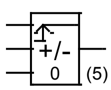
| Symbol | Designation | Function |
|---|---|---|
|   | Time delay clock | The output is set to 1 after the switch-on time has elapsed and reset to 0 after the switch-off time has elapsed. The process can be repeated. |
|   | Label | The output assumes the value of the input. This is necessary because some logic blocks cannot be connected with the output of another logic block. |
|   | Counter | Counts how often the value 1 was applied at the middle input. The output is set to 1 after a preset number of counting pulses is reached. The direction of counting (forwards/backwards) can be set using the lower input and the counter can be reset using the |

Table 9.1: Logic symbols in FluidSIM® (continued)

## Programming a Logic System Using a PLC

## Example 1: Self-Latching Loop

Figure 9.2 shows a circuit with double-acting cylinder and 4/2-way single solenoid valve. A PLC program is to be created for it that enables the piston rod to advance when a pushbutton T1 is pressed. The piston rod should retract when the forward end position has been reached. The forward end position is detected via proximity sensor 1S1.

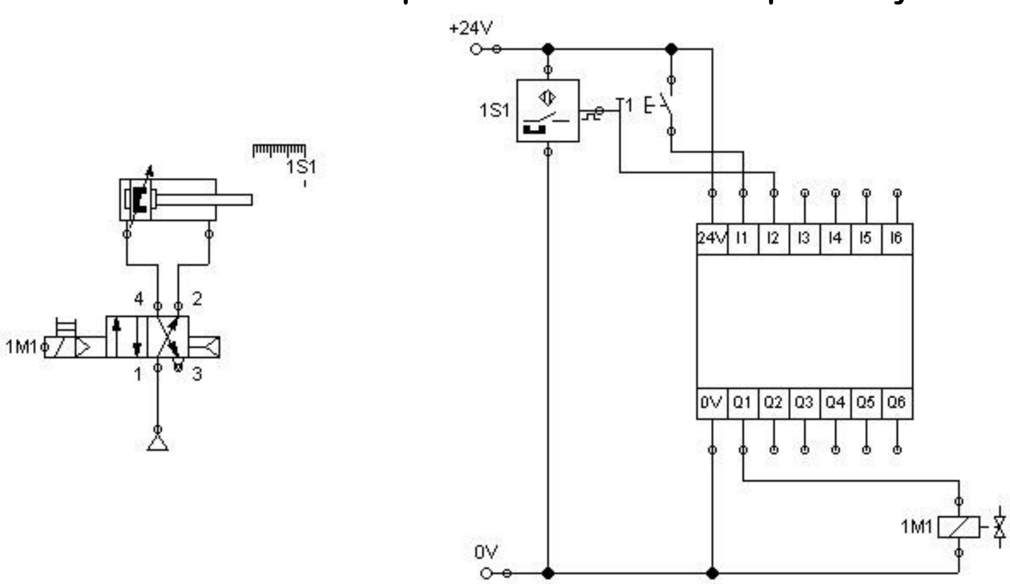



Figure 9.2: Pneumatic circuit diagram with solenoid valve and proximity sensor

# Programmable Logic Controllers (PLCs)

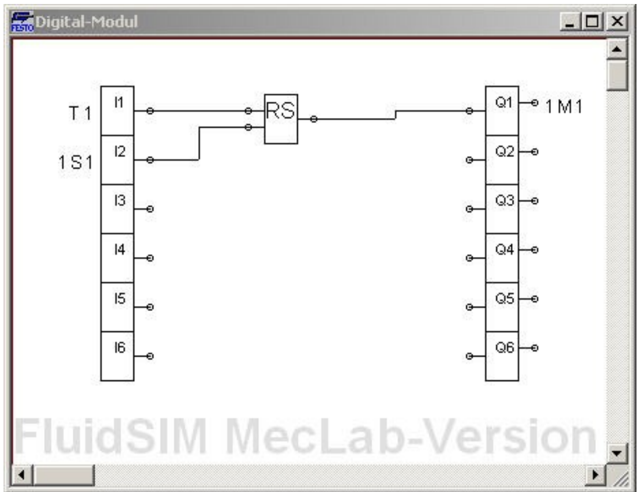



Figure 9.3: PLC program for Figure 9.2

Figure 9.3 shows the accompanying PLC program. The pushbutton T1 is connected to the input I1 of the PLC. This activates a latching element that switches on the valve solenoid 1M1 connected to the output Q1 of the PLC.

When the piston of the cylinder 1A (see Figure 9.2) reaches the forward end position, the sensor 1S1 connected to the input I2 of the PLC is activated. The latching element and thus also the output Q1 are reset. The valve returns to its normal position and the cylinder piston rod retracts.

## Example 2: AND Operation, Timer

Figure 9.4 shows a modified pneumatic circuit. The cylinder is equipped with two proximity sensors, one at the forward end position and one at the retracted end position. A program is to be developed that lets the cylinder advance when it is in the retracted end position and the pushbutton is actuated. The piston rod should advance fully, stay in that position for exactly 3 seconds and then retract again.

# Programmable Logic Controllers (PLCs)

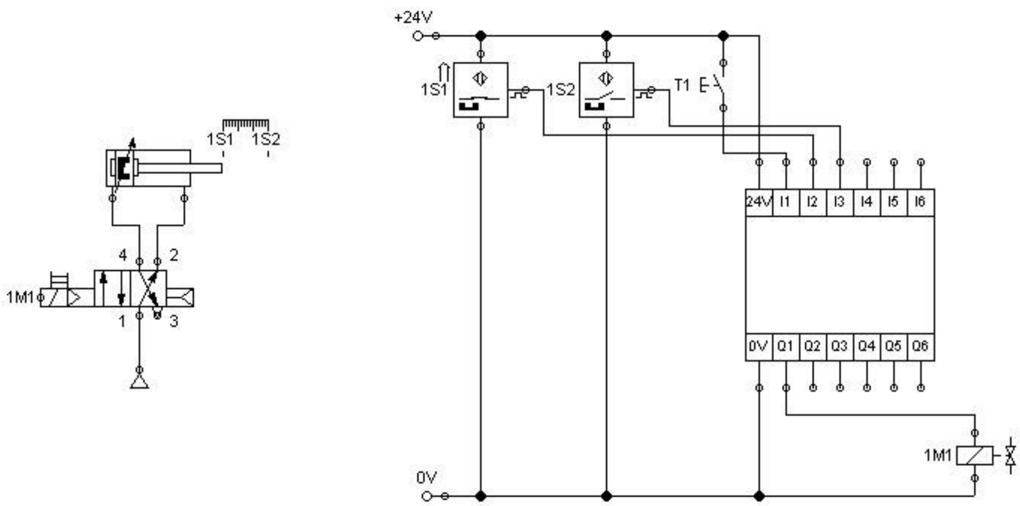



Figure 9.4: Cylinder with two proximity sensors

Figure 9.5 shows the accompanying PLC program. The inputs I1 and I2, to which the start button and the proximity sensor 1S1 are connected, have been linked using an AND operation (the high element sets the third, unused input to 1 also). If the cylinder is in the retracted end position and the pushbutton is actuated, all inputs of the AND operation are set to 1. The output of the AND operation as well as the required input of the latching element is likewise set to 1 and the cylinder advances.

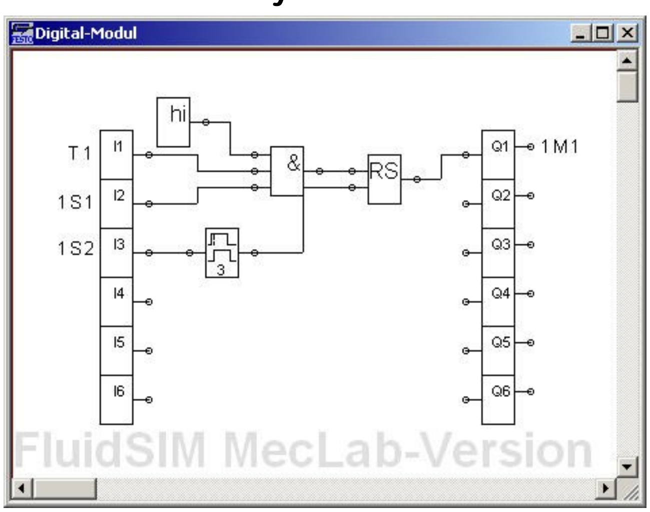



Figure 9.5: PLC program for Figure 9.4

When the cylinder reaches its forward end position, this activates the proximity sensor 1S2 that sets the input of the timer to 1. The output of the delay element is set to 1 after the set delay time expires, resetting the latching element. Current is no longer applied to the valve solenoid 1M1 and the cylinder retracts again.

# Programmable Logic Controllers (PLCs)

## Programming Control Systems Using the Sequencing Method

The logic control systems described in the previous section are adequate for simple control problems. If, however, operations where complex steps are to be performed in sequence are to be controlled, this simple type of programming usually no longer suffices. Sequencing technology was developed for this application. With sequencing, the execution of one step is a condition for the next step. The information collected is buffered via latching elements.

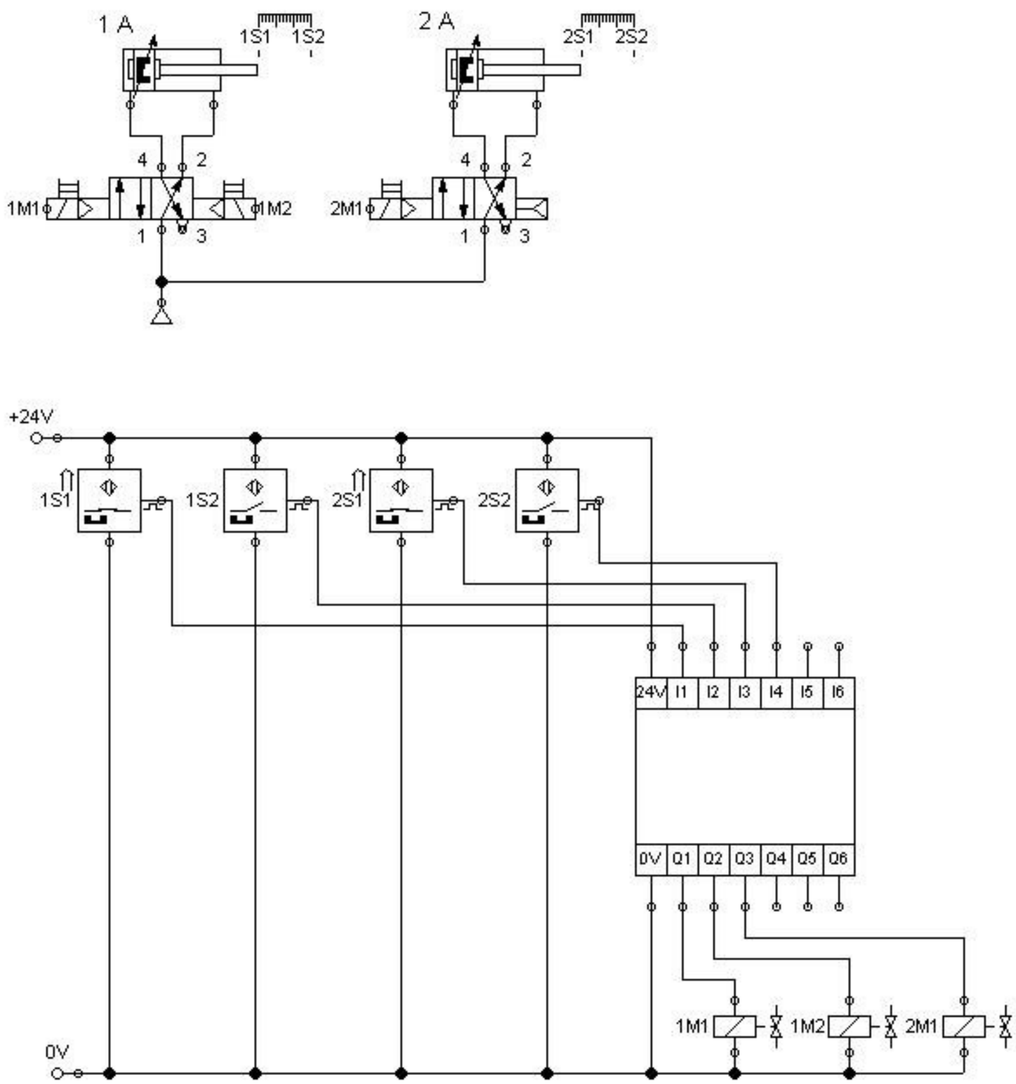



Figure 9.6: Circuit with two double-acting cylinders

Figure 9.6 shows a circuit diagram for two cylinders with two proximity sensors each for checking the end position.

# Programmable Logic Controllers (PLCs)

Figure 9.7 shows the accompanying PLC program. The sequence can be described as follows:

- When the proximity sensors 1S1 and 2S1 are activated (both cylinders in their initial position), the latching element is activated via the AND operation. This energises the valve solenoid 1M1 and the cylinder advances (step 1).
- Once the cylinder 1A has reached its forward end position, the second AND operation activates the second latching element. This activates the valve solenoid 2M1 and the cylinder 2A advances (step 2).
  Step 2, however, can only be realised if step 1 has been executed since the output of the first latching element is connected to an input of the AND operation of the second circuit. When step 2 is executed, it resets step 1 via the label by resetting the latching element.
- Once step 2 has been executed and both cylinders have reached their forward end positions, step 3 is activated. This resets step 2, activates the valve solenoid 1M2 and de-energises the valve solenoid 2M1. Both cylinders return to their normal positions and the cycle begins again.

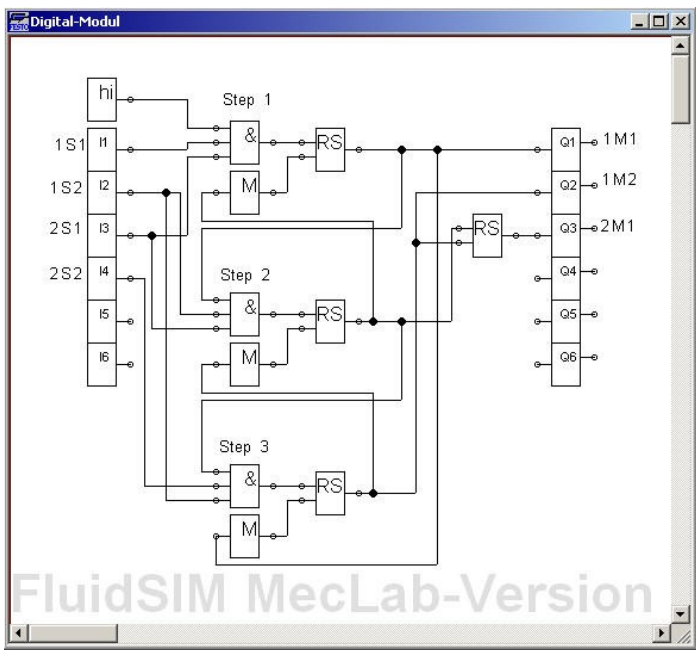



Figure 9.7: PLC program with sequencing

Note that the execution of each step is a condition for the execution of the next step and resets the preceding step. Any number of sequences can be combined in principle using this technique, enabling very complex operations.