fischertechnik® fischer®

Pneumatics

Most of the models can be built with Start 100.

A suitable compressed-air source is recommended on page 16.

Pneumatique

La boîte Start 100 permet de construire pratiquement tous les modèles.

L'acquisition d'une bonne source d'air comprimé est vivement conseillée (voir page 16).

Pneumatika

De meeste modellen kunnen met de bouwdoos Start 100 worden gebouwd.

Een adequate luchtverzorging is aan te bevelen (zie ook blz. 16).

Pneumatics

fischertechnik

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Contents

Foreword

Mechanisation – automation – cybernetics – industrial robots – transfer lines... these key words of modern production technology are familiar to us all whether we are directly concerned with technology or if we are merely newspaper readers, radio listeners or TV viewers with an interest in industry and business. And in this connection who does not first think of computers, microprocessors, integrated circuits and the countless achievements of electrical engineering and electronics? It is as if present-day technology, as we experience it in our everyday life, were essentially moulded by electrical and electronic equipment and processes, and as if they were the sole foundation of technological progress.

The spectacular developments in the field of electronics in particular have pushed other fields of present-day technology into the background; in many cases the processes and equipment of these fields are unknown outside the specialised circles directly concerned with them. This applies, for instance, to a field of technology which is of outstanding importance for modern production methods in particular, although in principle it requires no electricity. Here we have in mind pneumatics.

Without pneumatic systems, automation would be quite inconceivable; its present advanced state of development depends very largely upon the creation of pneumatic control and regulation devices. Nevertheless, pneumatic devices and methods have not aroused nearly as much public interest as those of electronics, although they are no less fascinating and it is certainly worthwhile making a detailed study of them. Until now, however, there has been a complete lack of experimental material for young people avid for knowledge, interested modelmakers or people wishing to educate themselves in the domain of technology, because teaching and learning systems have hitherto existed only in the professional training sector; for the above purposes they would have been inconvenient and above all too expensive.

fischertechnik Pneumatics now offers a system which enables all who are interested to penetrate the secrets of pneumatics at a reasonable cost. With relatively few, carefully selected components almost all important pneumatic circuits can be built, studied and reliably operated. Furthermore, fischertechnik Pneumatics is fully integrated into the fischertechnik system of kits so that it is possible not only to construct circuits but also to demonstrate their use in appropriate models. As a result, their rationale and mode of operation is made directly understandable on the basis of their intended purpose.

The models have been chosen in such a way that systems which operate purely statically (i.e. with hardly any visible movements) do not stand in isolation; instead, as far as possible application which have interesting movements or are otherwise entertaining have been chosen, so that those who are not directly interested in the construction of the pneumatic systems can make perfectly operating models simply by adding a few parts.

This instruction book is divided into two sections:

The 1st section deals with the *principles* of pneumatics and presents the various components. In the 2nd part the most important *basic pneumatic circuits* are presented. At the same time the reader is made familiar with graphic symbols and circuit diagrams. These are based on the appropriate standard symbols, but a somewhat less abstract form has been adopted in order to make the diagrams more readily understandable. In the numbering of the illustrations, the first number indicates the illustration number while the second one indicates the page on which the illustration is to be found. For example, figure 2–12 means figure 2 on page 12.

With the introductory constructions in particular, the circuit diagram, functional drawing and model photo occupy an equally prominent position. Almost every circuit is accompanied by a model which clearly demonstrates its application. There is a great deal of fun to be had by those who want to do no more than just build the models. And who knows: in building the models these users may discover they have a bent for pneumatics so that they are no longer daunted by the circuit diagrams.

In this book, as a general rule the units of the SI system which has been legally valid since 1970 are used. 1 bar = 10 $_{cm^2}$ or approx. 1 kgf/cm^2, where 1 N is approximately 0.1 kgf.

The contents of the pneumatic kit are sufficient for the basic experiments, the most important circuits and simpler models. However, it contains only special parts so that the Start 100 kit is necessary for the construction of the models.

It is also worthwhile investing in the Motor + gears expansion kit together with the transformer unit "mot 4", while really keen pneumatics enthusiasts should possibly have the Electromechanics expansion kit.

For the experiments and models using the solenoid-operated valve the Electromechanics expansion kit is imperative.

For the operation of pneumatic devices compressed air is obviously required. The functional circuit models make the heaviest demands here in view of the quantity of air needed. These demands are met in the most elegant fashion by the mini-compressor available from the Fischer factory or the manually operated pressure accumulator pump.

In addition the fischertechnik model compressor is also available; this unit is economically priced as well as instructive, however its capacity is not adequate for all of the models and circuits desribed in this booklet. On the other hand it provides insights into the construction and method of operation of a compressor, and it allows one to carry out one's own experiments.

The models which can be operated with the fischertechnik model compressor are indicated by the following symbol in this booklet:

So real pneumatics enthusiasts will do well to invest in such a device. Further details on compressed-air sources are given on page 16.

With an adequate compressed-air supply all the models and circuits shown work perfectly, and it will be difficult not to appreciate the unique attraction of their special mode of operation. When working with fischertechnik Pneumatics you are sure to have a great deal of fun and learn a lot at the same time.

Karlheinz Hoseus

Basic principles

What is pneumatics?

If you look under the keyword "pneumatic" in the dictionary, you will see that the Greek word "pneuma" means wind, air, breath. Today anything that operates with compressed air is known as "pneumatic". Thus pneumatics is the sector of technology which is concerned with the behaviour of gases and in particular the application of compressed air and vacuum. Air pressure can be used either directly to drive equipment, machines or tools, or as an operating medium for control and regulation devices. A prominent position is therefore occupied by the *operating cylinder,* which can exert certain forces or produce movements with the aid of compressed air. Here we should also include the various types of compressed-air engine, which directly generate a rotary motion. Other important devices are the wide range of *valve systems* with which circuits for control and regulation purposes can be built. Since it is only natural that pneumatically operated machines and equipment should also be controlled or regulated pneumatically, both types of application are often closely interlinked.

Applications of pneumatics

Anything like a complete account of the applications of pneumatic devices would far exceed the scope of this book. Furthermore, many applications are so specialised that for the layman quite a detailed explanation would first be needed. Only a few application examples will be discussed here.

Operating cylinders actuated by compressed air are found in many clamping devices used to hold workpieces during machining. They are particularly widely used in automated production lines.

Lifting platforms for the assembly and repair of vehicles and machines often use lifting cylinders operated by compressed air.

Doors in trains, buses and buildings are often opened and closed pneumatically.

The brakes of commercial vehicles are operated pneumatically (air brakes).

Locomotives in mines and in industrial plants where there is a danger of gas explosions operate safely on compressed air.

Well-known pneumatic tools are pneumatic drills, sanders and compressed-air screwdrivers. The dentist's much-feared highspeed drill is also a compressed-air tool.

Compressed air can be used to atomise liquids (spray guns), transport various types of materials, raise liquids, and make measurements on components. Hovercraft can also be considered as pneumatic devices.

Whereas the above-mentioned devices generally make use of the force of *compressed air,* in the following examples use is made of the suction of *rarefied* (thinned) air. Devices of this kind are found in such places as in motor vehicles, where the vacuum in the inlet manifold of engines with carburetors is used to alter the ignition timing (i.e. for control purposes). In servo brakes the effect of the partial vacuum in the air intake is used to amplify the force of the driver's foot on the brake pedal. Some windscreen wipers are also vacuum-operated.

Vacuum devices are also used in pneumatic post systems, in grain elevators for unloading ships, and in many other conveyor systems.

These examples are enough. The various machines in the food, chemicals, textile and printing industry, to mention only a few branches of industry, constitute an inexhaustible wealth of applications which clearly demonstrates the enormous importance of pneumatics for modern production.

Characteristics of compressed-air systems

Compressed air is not a cheap form of energy. On the contrary, its production by means of a compressor needs quite a lot of power, generally in the form of electric current. Compressors are often driven by internal combustion engines, whose poor efficiency makes compressed air particularly expensive. Obviously, then, air escaping uselessly from leaks in the system quite simply means lost money so that freedom from leaks is one of the basic requirements of compressed-air technology.

Whereas the energy costs of compressed-air generation are relatively high, the plant and equipment are of simple and relatively cheap construction. Their simplicity begins with the fact that after doing its work the compressed air needs no return pipe but as a general rule can be simply released into the atmosphere. Even in a extreme application like underground mining, locomotives driven by compressed air do not pollute the atmosphere with harmful exhaust fumes like their diesel counterparts, but on the contrary release oxygen-rich air. The function of compressed-air equipment is easily understandable and purely mechanical. There are no hidden processes as in the case of electronics. The appliances are light but robust, and are also safe, for unlike electrical appliances they do not produce sparks. They are therefore particularly suited for use in mines (danger of firedamp) and industrial plants where there is a risk of explosion. There is no risk of electric shocks due, for instance, to defective insulation. Compressed-air appliances are also safe because they cannot be overloaded. A given air pressure produces a given force in a piece of equipment, and this force cannot be exceeded. No overstraining of the parts can occur. If the resistance to movement is too great or if an appliance jams, the drive simply stops; it generally starts running again when the trouble is cleared. Leaks are expensive, but do not generally impair the function of the system provided a sufficient supply of compressed air is available.

Furthermore, the leak can easily be detected from the noise of the escaping air. If necessary – and at corresponding expense – compressed air can be produced in pure form, i.e. free primarily from water and oil. Then it can safely be used in the food and pharmaceutical industries. No soiling then occurs in the event of a leak (in contrast to hydraulics, where the escaping fluid can spoil the product and contaminate the plant).

Besides the high operating costs of compressed-air plant, another drawback is that there is a limit to the maximum force that can be developed in the operating cylinders. The operating pressure is usually 6 bar; this allows a force of approx. 30 kN to be produced. Forces in excess of this require inconveniently large cylinder diameters and are associated with an excessive air consumption. It is not advisable to use higher operating pressures, since rupturing compressed air vessels burst apart explosively whereas a cracked hydraulic cylinder allows its fluid to escape relatively harmlessly. Thus hydraulic systems using a liquid operating medium are better suited for very high pressures. An example of this is given by the model shown on page 73. Because of the compressibility of air, it is very difficult to achieve exactly controlled movement sequences with changing forces (see multiposition cylinder, page 36). The operating speed is highly dependent on the working pressure, and is limited to 300 m/min = 5 m/s. In some cases the exhaust air normally emerging from the appliances and valves may be a nuisance, primarily as a result of noise. Whereas in our models the hissing of the compressed air is a rather pleasant sound, in industry it is often necessary to use silencers to reduce the noise of the exhaust air.

However, operating cylinders (clamping and lifting cylinders), compressed-air engines, pneumatic drills etc. are only one part of pneumatics. In automation a prominent position is occupied by a completely different application of pneumatic components, namely the transmission and processing of signals by pneumatic logic elements, known for short as "fluidics". This forms the basis for all kinds of automatic control devices in which compressed air acts as a signal carrier or as an auxiliary energy source.

These pneumatic logic elements can be used as switches, amplifiers, etc. in exactly the same way as the diodes, transistors, etc. employed in electronics. This is particularly advantageous for industrial applications because compressed air is in any case needed as an operating medium for other purposes (compressed-air tools, cleansing) and is therefore readily available. This instruction book makes a detailed study of this control technology.

In electronics, components with moving parts (e.g. relays) can be replaced with components having no moving parts (transistors, thyristors), and in a similar way the piston valves of pneumatics can be replaced with parts which operate completely or almost without moving parts (fluidics). These are the latest development in pneumatic control technology.

Pneumatic and hydraulic devices can be combined (servo brakes in motor vehicles, hydropneumatic suspension).

Pneumatic and electrical control systems can also be combined, as for instance by the electrical actuation of valves (solenoid-operated valves).

Examples of such combinations are given on page 70/71.

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Absolute pressure, overpressure, underpressure

So pneumatic devices operate with air. However, it must be said at the outset that nothing can be done in pneumatics just with air or any other gas. A quantity of air, however big it may be, is of no value for the purposes of pneumatics. Air is useful only as a result of the force it exerts in the pneumatic appliances. Thus the air pressure, i.e. the pressure of the volume of air available, seems to be the essential factor in pneumatics. But compressed air alone, however high its pressure, is not capable of performing useful work.

This is explained by figs. 1–7 to 4–7.

Fig. 1–7 shows an operating cylinder with a piston and piston rod. The piston is in its central position, and the two spaces in the right and left of the piston are connected to a source of compressed air supplying a pressure of (e.g.) 7 bar. (1 bar corresponds to roughly 1 kp/cm^2 in the units employed up to 1970.) Obviously the pressure exerted on the piston is the same on both sides, so that the piston does not move and no force is exerted on the piston rod. The pressure can be increased until the cylinder bursts, but the piston still will not move.

However, if as in fig. 2–7 the pressure on the right side is reduced to (e.g.) 3 bar, the pressure on the left side of the piston is now higher so that the piston moves towards the right, thus exerting a force on the piston rod which is proportional to the area of the piston.

If as in fig. 3–7 the right side of the cylinder is opened to the surrounding atmosphere, which has a pressure of approx. 1 bar, the force and speed of the piston movement are higher than in fig. 2–7.

Finally fig. 4–7 shows a case in which the left side of the piston is at atmospheric pressure, while on the right side there is a partial vacuum or "underpressure". In this case too the piston moves to the right. Since the pressure of the atmosphere is usually around 1 bar, whereas on the underpressure side the pressure could not be reduced lower than 0 bar even if all the air were removed, the force acting on the piston will be limited. *Vacuum systems* therefore need relatively large piston areas in order to achieve a given force. Fig. 5–8 strikingly demonstrates the difference between pressure and vacuum.

The decisive factor for pneumatic equipment is therefore the *pressure difference* resulting from the pressures on the two sides of the piston. The greater this pressure difference, the greater the force and speed of the piston movement.

Compressed air is therefore of use for pneumatics only if it can expand so as to reduce its pressure and at the same time perform work.

Vacuum systems are at a disadvantage because while theoretically the maximum pressure difference is 1 bar, in practice it can be appreciably less than this.

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The earth's atmosphere has a pressure which is known as *atmospheric pressure*. Depending on the weather situation, this is around 1 bar. If all the air is pumped out of a vessel, which is virtually impossible in practice, the pressure in this vessel is 0 bar. The compressor of a compressed-air plant compresses its intake of air to (e.g.) 7 bar. All these pressures are known as *absolute pressures* because they are expressed in relation to a space empty of air, or in other words a vacuum.

In the cylinder shown in fig. 3–7 the right side is open to the atmosphere and is therefore at atmospheric pressure, i.e. 1 bar. Thus the pressure of 7 bar on the left side of the piston acts against the pressure of 1 bar on the right side. The effective pressure on the piston is only the pressure difference of 7–1 = 6 bar. These 6 bar are known as the overpressure.

Thus

overpressure = absolute pressure – atmospheric pressure

$$p_o = p_{abs} - p_{atm}$$

As a rule compressed-air systems operate with an overpressure of 6 bar, so that the compressor must compress the air to an absolute pressure of at least 7 bar.

If as in fig. 4–7 on the right side of the piston the absolute pressure is smaller than the atmospheric pressure, we speak of *underpressure*. An absolute pressure of 0.4 bar corresponds to an underpressure of 1 – 0.4 = 0.6 bar. The underpressure can never be greater than 1 bar since the absolute pressure can never fall below 0 bar, which corresponds to a total vacuum.

Thus in this case

underpressure = atmospheric pressure – absolute pressure

$$p_u = p_{atm} - p_{abs}$$

Fewest errors occur if calculations are always based on absolute pressures, which is in any case necessary for scientific calculations. In practice, however, the concepts of overpressure and underpressure are widely used.

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Air as an energy storage medium

Everyone knows that force is needed to tension a spring. Figure 1–9 shows a spiral spring. It can be squeezed together until the coils touch each other. The spring force F rises in proportion to the travel of the spring s until the maximum spring force is reached at the full spring travel h. The spring force is said to rise in *linear* proportion to the spring travel.

We now take the big cylinder from the kit, pull the piston right out, and close the connecting nozzle at the opposite end of the cylinder with a P-plug (Fig. 2–9). Air is now trapped in the cylinder. If we try to push the piston rod into the cylinder, we feel a resistance which becomes greater the further we try to push in the piston rod. If we release the piston rod, it springs back. The enclosed air really does act like a spring. And like a tensioned spring (e.g. in a wound-up clockwork motor) the compressed air is also capable of performing *work*; it possesses *energy*! The work which we performed in pushing in the piston rod is stored in the air, and released when the air is able to expand again. This is the ultimate foundation of pneumatics: the air is compressed by a compressor, as a result of which energy is imparted to it. The air travels via tubes and valves into the cylinder, where it can perform work at the desired time.

In the "air spring" the force on the piston rod naturally comes from the enclosed, compressed air. However, this force does not increase in linear proportion to the travel of the piston rod, but rises at a higher rate as shown in fig. 3–9. With a very slow piston movement the pressure follows the red curve, whereas with a rapid movement like that of most practical applications, the pressure increases according to the even steeper black curve.

If the piston were to be pushed completely into the cylinder, the air would be compressed into an infinitesimally small space and its pressure would rise to an enormous level. But for technical reasons it is impossible to make the piston in such a way that it could compress the air to zero volume. Some air volume always remains in the space in front of the piston and in the connecting nozzle.

For this reason, and because of the unavoidable leaks between the piston and the cylinder wall, the pressure does not rise to an infinitely high level. In order not to damage the piston seal, we shouldn't try to push the piston rod right into the cylinder.

One application of the springing properties of air or other gases is in the suspension of vehicles. Figure 4–10 shows a functional model of a vehicle with air springing. The height of the vehicle can be varied by altering the volume of air enclosed in the cylinders (level regulation).

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In air springing the air is compressed and expands in the same cylinder. But in compressed-air systems two separate cylinders are provided for compression and expansion. Figure 6–12 shows the functional principle of a compressed-air system, while fig. 5–11 shows the corresponding model.

A valve with a blue plunger is connected as a shut-off valve between the cylinder-60, which is used as a compressor cylinder, and the cylinder-45, which acts as an operating cylinder.

If with the shut-off valve closed, i.e. not actuated, the piston is rapidly pushed into the cylinder until it is stopped by the spring clip-10, the air in the cylinder is compressed to about a third of its original volume. When the shut-off valve is opened, the air expands into the work cylinder and moves its piston.

However, the work performed in this set-up is not very impressive. There are a number of reasons for this. First one must not wait too long before opening the shut-off valve, because otherwise much of the air in the compressor cylinder will be lost due to leakage round the piston seal; then after the valve is opened the compressed air must also fill the tube to the operating cylinder, as a result of which its pressure is greatly reduced. For this reason the tubes have been kept as short as possible. The spring clip-10 must not be left out, since too high a rise in pressure with the shut-off valve closed could result in damage to the piston seal. If you try to repeat the experiment, you will find that the second time it works less well or not at all. This is because when the piston rod is pulled back no air can enter the compressor cylinder as a result of the closed shut-off valve. The valve must be actuated when pulling back the piston rod. As a result, the piston of the working cylinder is drawn back to its starting position as in a vacuum system, while when the valve is switched over the compressor cylinder is briefly opened to the atmosphere and can fill up.

The operations are again shown in detail in fig. 6–12. The top picture shows the two cylinders, in both of which there is a pressure p_0, in our case atmospheric pressure. For in the compressor cylinder (right) the enclosed air is not yet compressed, while the operating cylinder (left) is connected to the atmosphere via the valve. If with the valve closed the piston rod is pushed into the compressor cylinder as far as it will go and held there, the pressure in the compressor cylinder rises to a value p_1. If the valve is now opened, the air enters the work cylinder at a pressure p_2, which for the above-mentioned reasons is lower than p_1, and expands there so as to move the piston and perform work. The pressure in the compressor cylinder falls in roughly the same way as in the operating cylinder.

The unsatisfactory operation of our primitive compressed-air system is obviously due mainly to the inadequate air volume supplied by our "compressor", as a result of which the pressure falls markedly. Nevertheless, we can still do something with a simple arrangement like this. We simply leave out the shut-off valve. Now the piston of the operating cylinder immediately follows the compressor piston. If the piston of the former is unloaded, it has only to overcome friction in order to move. The volume of air forced out of the compressor cylinder is pushed into the work cylinder with no increase of pressure and so moves its piston. If the work piston now has to exert a force, the piston must be pushed into the compressor cylinder until the pressure has risen so high that it exerts the necessary force in the operating cylinder. The travel of the compressor piston will therefore have to be larger than that of the operating piston, since part of the travel of the compressor piston is needed to increase the pressure. If the work cylinder is called upon to exert a larger force, it may be possible to push the compressor piston in to the limit without developing an adequate pressure. However, in order not to risk damaging the piston seals it is preferable not to carry out this experiment with the short connecting tubes.

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Remote shutter release

This set-up can be used for a model of a remote control device that could be employed to actuate the electric motor of a cine camera. Fig. 1–13 shows a drawing of the arrangement using the motor and battery pack from the Motor + gears kit and the pushbutton switch from the Electromechanics kit (the pushbutton switch is also available as an add-on kit). Fig. 2–13 shows the model, while fig. 3–13 shows the circuit diagram. The actuator is adjusted by moving the connecting piece-15 so that the pushbutton switches correctly when the "master cylinder" is operated, but also switches back reliably when the diaphragm of the actuator is released. The long connecting tube is fitted on when the piston rod of the master cylinder has been pulled out to the limit. Because of the long tubes there is no need for precautions to protect the piston seal; the piston can safely be pushed in as far as it will go.

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Pneumatic hammer

If we connect together two double-acting (see page 18) cylinders as shown in fig. 1–14, the movement of the piston of one cylinder can be transmitted to that of the other. This is the principle of the pneumatic hammer. Because of the elastic properties of air, it can be considered as a type of spring hammer. Its construction is shown in fig. 2–14. The operating piston (here in fact the compressor piston) is driven by an electric motor via a crank. As a result, a pressure is generated alternately above and below the operating piston which raises or lowers the *hammer piston*. In fact the process is somewhat more complicated as a result of the elastic properties of air. The *hammer piston* flying upwards compresses the air above it, which therefore undergoes further compression in addition to that effected by the operating piston. On the expansion of the air which is doubly compressed in this way, the hammer piston is thrown downwards with a great force. Thus the inertia of the piston flying upwards is used to further compress the air. Control valves also enable single blows to be made with the hammer. Hammers of this type are used in forges.

Fig. 3–15 shows the easily built functional model. The operating cylinder is a cylinder-45, whereas the hammer cylinder is a cylinder-60. To ensure that the hammer works satisfactorily it is essential to fit the connecting tubes between the two cylinders when the work cylinder is at the bottom of its stroke and the hammer piston is roughly in a midway position.

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Sources of compressed air

So far we have managed without a real source of compressed air. But from now on we need compressed air in adequate quantities. Compressed-air reservoirs like bicycle or car inner tubes are only a makeshift solution because their pressure falls off rapidly when air is withdrawn from them. This results in a unsatisfactorily short operating time for the models and circuits, also such containers are unsuitable for connection to the specially designed shut-off valve, without which the filling of the reservoir and the withdrawal of air would be impossible. For these reasons we shall not take a closer look at this possibility.

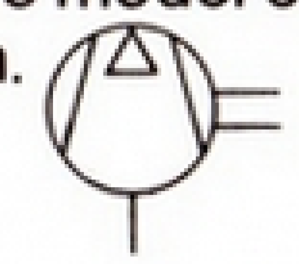
The best and neatest solution is therefore the fischertechnik *mini-compressor* (fig. 1–16), which is specially designed for this application and is capable of operating all circuits and models for an unlimited time. It supplies about 35 litres of air per minute at a pressure of approx. 0.3 bar. Consequently there is no risk of components being damaged by excessive pressure.

A further, very economically priced source of compressed air is the fischertechnik *pressure storage pump* (fig. 3–16). This manually operated pump supplies models and circuits without the need for electric power.

The pressure vessel with a built-in hand pump is pumped up to a maximum of 3 bar. If this pressure is exceeded, the safety valve opens. The compressed air now available is brought to the correct pressure by an adjustable flow control valve, and is sufficient for an operating time of approx. 5 minutes. For longer operating times the vessel can be pumped up again at any time. Detailed instructions are supplied with the fischertechnik pressure storage pump.

Finally, the fischertechnik model compressor is also available as a source of compressed air Figure. This unit is supplied in the form of a construction set; with the instructions provided the assembly presents no difficulties whatever. The construction and method of operation of a piston compressor and the details relating to its operation are also described at great length in the instruction pamphlet.

The fischertechnik model compressor is powered by a standard fischertechnik 6 volt electric motor. The motor is supplied with electric power by the transformer unit "mot 4". For this reason it cannot achieve the output capacity of the fischertechnik mini-compressor, which is connected up directly to the supply mains, even though it also delivers a pressure of 0.3 bar. If, however, a model or functional circuit uses too much air, then the model compressor will no longer be able to produce sufficient pressure and the model will not function. Therefore, the model compressor is not suitable for supplying compressed air to models and functional circuits which use large amounts of air.
Every model described in this booklet which can be operated without any problems with the model compressor is expressly indicated as such.



At any rate, however, it is advisable to actuate the manually operated valves by means of a short touch of the finger. For, as a result of the design, the compressed air source is connected for a short time with the outside air during the actuation of the valve, so that if the valve is actuated too slowly, too much air escapes unused into the outside and the pressure in the accumulator of the compressor decreases rapidly.

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Compressed-air turbine

Probably all of us have more or less enjoyed making the acquaintance of the compressed-air turbine in the form of the dentist's high-speed drill.

As we have found out, the pressure of the compressed air represents energy – in this case pressure energy. By means of a nozzle, i.e. a narrowed outflow opening, the pressure energy can be converted into kinetic energy. On flowing out through the nozzle the stationary air develops a velocity which generally depends on the pressure. If the flow of air strikes a stationary body, it is slowed down. As a result, some of the kinetic energy is transformed back into pressure energy. This exerts a force upon the body, which is consequently set in motion. Thus if a flow of air strikes the blades of a turbine wheel (fig. 1–17), the wheel rotates. As a rule the rotation speeds are very high.

Our model turbine (fig. 2–17) uses a gear wheel Z–40/32 as a turbine wheel. The teeth of the wheel act as blades. The nozzle supplied in the kit is directed against the teeth (see fig. 1–17) in such a way as to obtain the highest rotation speed. When the compressed air is turned on, the turbine runs up to speed with a characteristic sound, i.e. its speed gradually rises to a maximum. If the turbine is unloaded (idling), the maximum speed the turbine can reach is when the speed of a tooth (i.e. of a "blade") is the same as that of the air stream emerging from the jet. If the turbine is to drive a machine, and is therefore loaded, its speed is immediately reduced by an appropriate amount. If the load is too great, the turbine stops but is not damaged.

Because of the high speeds of compressed-air turbines (120,000–350,000 rpm) reduction gearing is needed in order to obtain usable speeds and an adequate torque. This is indicated in the model. However, for grinding and drilling tools high speeds may be desirable, so that in this case gearing is not essential. The turbine speed can be controlled by a flow control valve (P valve) connected in the feed line. But since this valve still has a certain throttling effect when fully open, the maximum speed is attained only when this valve is left out.

A second nozzle is supplied in the kit. It is a simple matter to convert the turbine to a two-nozzle version, and this worthwhile modification is left to the inventiveness of the reader.

Because of its high air consumption the turbine cannot be operated with the fischertechnik model compressor.

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Components and graphic symbols

Although we have built some satisfactorily functioning models without a detailed knowledge of the parts, we must now get to know the components in the fischertechnik Pneumatics kit somewhat better. In order to describe a compressed-air system or a pneumatic control system, roughly as in electronics we use a circuit diagram with standardised symbols which save drawing a detailed picture of the components. The graphic symbols for pneumatics are laid down in DIN standard 24,300 and ISO standard 1219. We have generally followed these standards in our circuit diagrams, and have deviated slightly from them only where this has seemed necessary to make the mode of operation more readily understood.

Operating cylinders

Our Pneumatics kit contains a number of different operating cylinders. The most important characteristics for the determination of the operating cylinders are the diameter d and the stroke h (fig. 1–18). The stroke is the distance through which the piston can travel in the cylinder.

If the diameter d of the cylinder or piston is known, it is possible to calculate the force F on the piston rod provided the pressure p is also known:

Our cylinders have a diameter of 13 mm. If our compressed-air source supplies an overpressure of 0.5 bar, equal to 0.05 N/mm^2, an operating cylinder can develop a force of

However, part of this force is used up by the friction of the piston seals and the piston rods passing through the cylinder cover.

Single-acting cylinders

Their symbol looks like this.

In single-acting cylinders compressed air is admitted to only one side of the piston, as indicated by the little line on the cylinder wall in the symbol. It can therefore operate in only one direction. The piston must be returned to its original position by external forces (weight of lifted object, etc.), or more commonly by a special returner spring. The symbol then looks like this.

Our kit contains one single-acting cylinder with a returner spring and a stroke of 16 mm (see fig. 2–18).

Single-acting cylinders are popular because of their simplicity of control and their low air consumption: their return movement is made non-pneumatically and therefore consumes no air. However, the spring limits their stroke to about 100 mm.

Double-acting cylinders

Their symbol is the same as for the single-acting cylinder except that the second part is indicated by an additional line on the cylinder wall.

Our kit contains one double-acting cylinder with a stroke of 16 mm, and one with a stroke of 32 mm (cylinder-45 and cylinder-60) (fig. 3–18): the stroke is not indicated in the symbol, i.e. all double-acting cylinders have the same symbol.

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The double-acting cylinder can operate in both directions. For this reason no springs or similar devices are needed for the return movement. Instead the return movement is also effected pneumatically by applying compressed air to the other side of the piston via the second port. For one forward and return movement the air consumption is therefore roughly twice as high as for a single-acting cylinder. The control of the cylinder is somewhat more complicated, and the forces exerted by the double-acting cylinder are not equal in both directions since on the side of the piston where the piston rod is fitted the effective piston area is somewhat smaller so that the force on the *return stroke* is less than on the *forward stroke*. Only cylinders as shown in fig. 1–17, with a piston rod passing through both cylinder ends, develop the same force in both directions.

Double-acting cylinders can be used as single-acting ones by supplying compressed air to only one side of the piston and using external forces to effect the return movement. It is also possible to seal off the second port of the cylinder so that the piston acts against the enclosed cushion of air, which naturally has the effect of a spring.

Diaphragm cylinders, actuators

The diaphragm cylinders contained in our kit are in principle single-acting cylinders. The diaphragm is pushed out by the force of the compressed air, and goes back into its casing when the pressure is released as a result of the elasticity of the rubber material. This symbol is therefore the same as for the single-acting cylinder (fig. 3–19). Diaphragm cylinders are intended for very short strokes, and have the feature of absolute air-tightness. Since these diaphragm cylinders are suited more for actuating valves than for performing work, we also call them "actuators". Our kit contains 4 simple actuators and one double actuator (fig. 4–19), which has the following symbol.

Valves

The valves employed in pneumatics are generally used as control elements. There are various groups of valves which are classified according to their functions, namely directional valves, non-return valves, pressure valves and flow control valves. Here we are concerned only with *directional valves* and *flow control valves.*

Directional valves

Directional valves are designated according to their number of ways and positions. A normal shut-off cock has 2 ways (inflow and outflow) and 2 positions (open, closed). It is therefore known for short as a 2/2 directional valve. In the symbols the compressed-air port is always designated with P, the operating lines are known as A, B, C, etc. and the exhaust (i.e. the connection with the atmosphere) as R. Control lines are designated with Z, Y, X, etc.

A valve is known as an *opener* if it remains closed when in its quiescent state, i.e. when not actuated, and lets compressed air through when actuated; it is known as a *closer* if it lets compressed air through when in its quiescent state and interrupts the flow when actuated.

The function of a valve can be seen from its symbol. A square box is drawn for each position. In the 2/2 directional valve this looks as in fig. 1–20 or 4–20. In the case of the opener (fig. 2–20) in its unactuated state the ports P (compressed air) and A (operating line) are blocked. On actuation (fig. 3–20) the two sides of the valve are connected together. Conversely, in the unactuated closer (fig. 5–20) P and A are connected together and compressed air can flow. On actuation (fig. 6–20) both ports are blocked.

3/2 directional valves are more convenient for the control of operating cylinders, since after each stroke the used air must be blown out into the atmosphere (exhaust). This is effected automatically by the 3/2 valve. Its inner construction is characterised by the symbols in fig. 7–20 (opener) and 10/20 (closer). It has three connections: P for the compressed air, A for the operating line and R for exhaust. Our pneumatic kit contains three opener-type 3/2 valves and one closer-type 3/2 valve. The openers can be identified by their blue plunger, and the closer by its red plunger.

Page 20

① **2/2 valve**
Opener
(normally closed)

② Not actuated

③ Actuated

④ **2/2 valve**
Closer
(normally open)

⑤ Not actuated

⑥ Actuated

⑦ **3/2 valve**
Opener
(normally closed)

⑧ Not catuated

⑨ Actuated

⑩ **3/2 valve**
Closer
(normally open)

○ Not actuated

○ Actuated

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Fig. 8–20 shows the opener-type valve in its unactuated state on the basis of the graphic symbol and a cross-section through the valve. The compressed-air line is shut off. The operating line is connected with the relief outlet. When the valve is actuated (fig. 9–20), the compressed air line is connected with the operating line and the exhaust port is blocked. Figures 11–20 and 12–20 show the corresponding processes in the closer-type valve. In this valve, in its unactuated state the compressed-air line is connected with the operating line and the exhaust port is blocked. On actuation the compressed-air supply is cut off and the operating line is connected to the exhaust port. If a 2/2 valve is used to control a cylinder, the piston does not stop after closing the valve because the compressed air in the cylinder continues to expand. Therefore either the piston must always travel to the end of its stroke or the cylinder must be opened to the atmosphere after the compressed air is shut off. The latter is exactly what the 3/2 valve does. If a single-acting cylinder with spring return were controlled with a 2/2 valve, the piston could not return to its original position after shutting off the compressed air, because it is first necessary to let out the compressed air which is still in the cylinder. This is made possible by using the 3/2 valve. It is therefore a universal type of valve which can also perform the function of the 2/2 type. For this reason our Pneumatics kit contains no 2/2 valves.

Our 3/2 valves are "pushbuttons". They automatically return to their original position after actuation. This is indicated by the spring shown in their symbol. They can be actuated by pressing directly on the plunger, but the roller lever shown can also be used.

This can be fixed in three positions on the valve casing. Because of the flexibility of the roller lever the valve need not be precisely adjusted.

In all our valves the compressed-air connection is on the side opposite the plunger. There is no special connection for the exhaust port.

A 4/2 valve is convenient for controlling double-acting cylinders. It has four ports, namely the compressed air connection P, the exhaust port R and the two operating lines A and B (fig. 13–21). In the unactuated state (fig. 13–21) the compressed-air line A and the work line B are connected together, and the work line A is connected to the exhaust port. On actuation, compressed air is fed into operating line A and operating line B is connected to the exhaust port. As shown by figs. 15–21 and 16–21, a 4/2 valve can be replaced by connecting together two 3/2 valves, one of them an opener and the other a closer, which are operated simultaneously. We can therefore manage without a 4/2 valve in our kit.

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Flow regulating valves

Flow regulating valves control the volume of air flowing through them. They constitute an adjustable narrowing of the tube (throttle valve). Our kit contains a flow regulating valve with adjustment screw which is given the name P-throttle. Its construction is shown in the cross-section drawing 17–22, and the symbol is shown in fig. 18–22.

Tubes

Our Pneumatics kit contains 3 m of plastic tubing with an internal diameter of 2 mm. It is pushed onto the *nozzles* of the various parts (valves, cylinders, etc.). The tubing must not be kinked when connecting up, because a kink acts like a partly or completely closed throttle valve. New pieces of tubing should not be pushed too firmly onto the nozzles since otherwise they may be difficult to remove. You should not pull on the tubes to remove them, but should strip them off with your fingernails directly on the nozzles. Additional tubing can be supplied if required.

Connection to the compressed-air source is effected via the P-distributor, which is connected to the outlet nozzle of the compressor or other compressed-air source with the short, wide piece of tubing. Of the 8 connecting nozzles of the P-distributor, those not required are closed with the P-plugs (fig. 19–22) to avoid air losses. The same applies to the T-pieces, which can be used together with the P-plugs to join together pieces of tubing. P-distributors and T-pieces can be fixed on the fischertechnik building blocks and base plates with their pins.

The P-distributor is not required for connection of the fischertechnik model compressor. Connection is effected in a straightforward manner via the T-pieces.

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Basic circuits

Control of single-acting cylinders

Now we shall solve our first pneumatic control problem: how to control a single-acting cylinder. For this we need an opener-type 3/2 valve. The circuit diagram is shown in fig. 1–23 and the construction in fig. 2–23, while functional drawings are provided in figs. 3–23 and 4–23.

When the valve is not actuated (fig. 3–23) the compressed-air supply P is shut off and the cylinder is connected to the exhaust port R via the operating line A. When the valve is actuated (fig. 4–23), the compressed air is switched to the cylinder and the piston (or the diaphragm of the actuator) is moved. When the valve-actuating roller lever is released, the valve shuts off the supply of compressed air and connects the operating cylinder with the exhaust port. Thus the spring can return the piston to its original position. In the case of the actuator the return movement is effected by the resilience of the rubber diaphragm.

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Pneumatic clutch

Fig. 5–24 shows a *pneumatically actuated clutch* as an application example. When the valve opens, the operating piston moves the drive shaft (axle-110) via the coupling-2 and separates the tyres-45 which serve as clutch plates. The movement of the operating piston can be slowed by the P throttle in the supply line so as to effect a gentle engagement of the clutch. (For more details on speed control see page 54.) Until a short time ago pneumatically operated clutch units of this type were used in semiautomatic vehicle transmissions, although they were designed for vacuum operation.

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Clamping device

In fig. 5–26 a single-acting cylinder is controlled by means of a closer-type 3/2 valve. Thus normally the cylinder is constantly under pressure and so exerts a force on the piston rod. This type of control is used primarily in clamping devices which are released only when the workpiece is changed.

Fig. 7–26 shows the model with a *clamping device* of this type. We imagine that the workpieces (building blocks-30 with borehole) are to be machined with a tool in the borehole. This tool is represented by a cord clamp which is fitted in a spring clip and can be lowered pneumatically. The tool is actuated by the cylinder-45 with spring. The workpiece is kept in the correct position by 2 diaphragm cylinders (actuators) and stops, so that once it has been "set up", the tool is aligned so as to enter the boreholes correctly in all subsequent workpieces. The short stroke of the diaphragm cylinders makes it highly suitable for the described purpose, since they occupy very little space.

As shown in the circuit diagram for the single-acting cylinder (fig. 1–23), the tool cylinder is actuated by a 3/2 valve. The clamping device releases only on actuation, and thus holds the workpiece firmly in place when the valve is not actuated. The two actuators are controlled by a closer-type 3/2 valve as shown in circuit diagram 6–25. Perhaps you would like to try drawing the circuit of the complete system with the aid of the part symbols. The solution is given on page 68. Note that generally the symbol takes no account of the position of the pistons in the cylinders.

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Logic circuits

The following two arrangements are intended to give you an idea of the possibilities of pneumatic logic circuits.

AND control

The cylinder is to contain compressed air only when the two valves I and II are actuated. If we write the sign "1" for "actuated" and "0" for "not actuated", so that "1" for the cylinder means "cylinder connected to compressed air" and "0" means "cylinder connected to exhaust port", we obtain the following relationship:

Valve I	Valve II	Cylinder
0	0	0
1	0	0
0	1	0
1	1	1

It can be seen that the cylinder is only connected to the compressed-air supply if valve I AND valve II are actuated. Otherwise, (i.e. if only one or neither valve is actuated), the cylinder is connected to the exhaust port. The above table corresponds to the *"function table"* of the AND function in logics.

Fig. 8–27 shows the circuit diagram, and fig. 9–27 the construction of a set-up which fulfils the above requirements. Such arrangements are used, for instance, as safety devices in presses. Here it is essential to ensure that the operator does not have his hand inside the press when it is operated. For this reason two buttons are fitted on the machine outside the danger zone in such a way that they can be operated only by both hands at the same time. This is an application of an AND arrangement: the machine switches itself on only if both buttons are pressed simultaneously. Our model (fig. 10–28) is equipped with such a safety device.

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Safety device on a press

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OR control

Here the operating cylinder is to be supplied with compressed air when at least 1 valve is actuated, i.e. valve I OR valve II OR both. This makes it possible to control the cylinder from a number of different places. Such arrangements are well known in electrical systems, where they can easily be installed (fig. 11–29). If a lamp is to be switched on from a number of places, this can readily be done with switches I and II. If an additional control point is to be installed, this can easily be done by fitting an additional switch III in the circuit.

Fig. 12–29 shows that this cannot be done so easily with 3/2 valves in pneumatic circuits, since the cylinder is connected to the atmosphere through each unactuated valve. If valve I is actuated, the compressed air flows out uselessly through the port R of the valve II, and vice versa. The problem can be solved by inserting a shuttle valve (fig. 13–29). Fig. 14–29 shows the simple construction of a shuttle valve and its symbol. As a result of the air pressure the ball automatically shuts off the line which is not needed.

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Fig. 15–30 shows how we can manage without a shuttle valve. Each 3/2 valve supplies compressed air to an actuator which operates the cylinder via the 3/2 valve III. The construction of this arrangement is shown in fig. 16–30.

Frequent actuation over short time intervals when using the fischertechnik model compressor results in the occurrence of a large decrease in pressure.

The following table shows the function of the OR circuit:

Valve I	Valve II	Cylinder
0	0	0
1	0	1
0	1	1
1	1	1

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Control systems for double-acting cylinders

The control of a double-acting cylinder is shown in fig. 2–31. Fig. 1–31 shows the corresponding circuit diagram. The construction of the circuit is shown in fig. 3–31.

Pressure is applied to one side of the piston through each of the two valves, so that the piston is moved in the desired direction. If neither valve is actuated, both sides of the piston are connected to the atmosphere so that the piston rod is freely movable.

Due to the relatively large loss of air at the piston-rod guide, the retraction of the piston rod into the cylinder is accompanied by a pronounced reduction in power when the fischertechnik model compressor is used.

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In the following arrangement (fig. 4–32) a 4/2 valve has been used. Depending on the setting of the valve, pressure is applied to one side or the other side of the piston, i.e. the piston is always stationary at one end of its travel, where it is held by the air pressure. As we are aware (see page 21), a 4/2 valve can be replaced by two 3/2 valves in tandem, one operating as an opener and the other as a closer. Fig. 5–32 shows the circuit diagram, and fig. 6–32 the construction. The simultaneous actuation of the two valves is achieved here by joining the two roller levers by an axle 30.

Detail: Roller levers with valves, fig. 6–32.

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The circuit diagram 7–33, the functional diagram 8–33 and the construction of the circuit as in fig. 9–33 show an alternative solution using a double actuator. Applications for these arrangements follow later.

When the fischertechnik model compressor is used, actuation must be delayed until sufficient pressure has been allowed to build up again.

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Programme control systems

Programme control systems are ones in which the movement of the cylinder follows a definite time-related pattern. The valves are actuated by cams, which must be shaped according to the desired programme sequence. These are mounted on a shaft rotated by an electric motor (fig. 1–34). For the single-acting cylinder the basic arrangement shown in fig. 1–23 is adopted, as you can see if you compare it with fig. 1–34. The cam discs are held in place in pairs by a flat hub. The timing can be altered by turning the discs of a pair in relation to each other. An appropriate model is shown in fig. 2–34. The fischertechnik motor drives the shaft with the cam discs via a multi-step reduction gear. The programme timing is naturally influenced by the motor speed and the ratio of the reduction gearing.

As shown in fig. 3–35, double-acting cylinders are controlled with 2 openers in accordance with fig. 1–31. The piston rod remains movable when the valves are closed. If this is not wanted, we choose the arrangement with an opener and a closer according to fig. 4–35, which corresponds to fig. 5–32. Each valve is actuated by its own cam disc. It is possible to manage with only one cam disc, if the valves are arranged as shown in fig. 5–35.

When the fischertechnik model compressor is used, care must be taken in the adjustment of the programme that sufficient pressure is allowed to build up during the switching intervals and that the actuation of the valves occurs rapidly enough.

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Multi-position cylinders

In some automatic machine tools the workpieces must be shifted a number of times through specific distances which often differ from each other. The workpiece moved by an operating cylinder must therefore take up a number of positions as accurately as possible. One would think this could be achieved simply by providing a cylinder of sufficient length and simply shutting off the air when the piston reached the desired position. But if we look more closely into the matter we see that this is not practicable. For if the compressed air is simply shut off, the air remaining in the cylinder tries to expand and pushes the piston on to the end of its travel if the force it must overcome is not too great. At all events the piston does not stop exactly where it should. If 3/2 directional valves are used, the air is released from the cylinder and the piston, which now has no overpressure on either side, continues to move for a distance as a result of its momentum. Here again exact positioning is impossible. In either case the piston must be moved to the end of its travel if it is exactly to take up a prescribed position. We therefore arrange a number of cylinders one after the other whose stroke corresponds to the required travel in each case. This arrangement is known as a "multi-position cylinder".

Fig. 1–36 shows the construction principle of such cylinders. Two double-acting cylinders are often arranged end to end (fig. 1–36), thus giving a *four-position cylinder.* The cylinders are available as complete units. By combining them with more cylinders it is possible to obtain up to 12 positions. Fig. 2–36 shows the symbol for a multi-position cylinder. Another arrangement is shown in fig. 4–37.

Each of the two cylinders is controlled independently of the other like a single- or double-acting cylinder.

Since our cylinders have a stroke of 16 and 32 mm, the possible movements for a four-position cylinder are as follows:

0 = not actuated   1 = actuated

In the case of single-acting cylinders the control system is particularly easy to understand. Our model shown in fig. 3–36 uses one single- and one double-acting cylinder and the programme control system according to figs. 1–34 and 1–35.

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Rotation or swivel cylinder

This type of cylinder is a compressed-air motor with a maximum rotation angle of 360°. Its symbol is shown in fig. 1–38. It is used for actuating shutoff valves for liquids, opening and closing doors, etc. Our model (fig. 2–38) shows the operation of a door with the use of a rotation cylinder. The arrangement shown in fig. 1–31 or 5–32 is used to control the double-acting cylinder; in the former case the door can be freely moved when the valves are not actuated, while in the second case the door closes when the button is released.

When the fischertechnik model compressor is used, an adequate interval must be inserted between actuations to allow sufficient pressure to build up again.

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Signal storage

If an operating cylinder is to be supplied with compressed air through the full length of its stroke, the valves must be held open until the piston has completed its travel. In many cases, however, what is wanted is for the valve to stay open until the valve has completed its travel after only a brief press of the button. What we therefore need is to store the valve-opening signal so that it remains effective after the button has been released. This task is performed by the *"pulse valve"* which effects storage of the signal. If the "on button" is pressed only briefly, the "on signal" is maintained (memorised) until the "off button" is pressed. As shown in fig. 1–39, we can make such a pulse valve from a double-acting cylinder and an opener-type 3/2 valve. Fig. 2–40 shows how the valve is constructed from a cylinder-45 and a valve with blue plunger and a roller lever. A building block-7.5 and an isosceles angle block serving as an actuating cam are mounted on the end of the piston rod. When the piston rod is retracted into the cylinder the cam presses on the valve plunger via the roller lever and thus opens the valve. The valve remains open until the piston rod is extended, as a result of which the valve closes again and stays closed so long as the piston rod remains extended. In this way the signal is stored. The signal ON and the opposite signal OFF are each given by one of two 3/2 valves which control the cylinder as shown in the circuit in fig. 1–31. The two lines running from the valves to the cylinder are control lines, and are therefore designated with Y and Z. They carry the "control air". The actual "operating air" is controlled via the firstmentioned 3/2 valve an its outlet A.

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Lifting platform

Fig. 3–40 shows this arrangement applied in the control of a lifting platform. The lifting piston is a single-acting cylinder, since the return movement can be effected by gravity. In our model, where the weight of the platform is small in relation to the friction, it is advisable to use a cylinder with a return spring. You need only momentarily to press one of the two roller levers and the lifting cylinder moves to the end of its travel. The P throttle valve is used to adjust the lifting speed.

In the circuit diagram (fig. 1–39), exceptionally the piston positions of the pulse valve are shown. The parts inside the box drawn made up of dots and dashes form the pulse valve, which has a symbol of its own; this is also shown in fig. 1–39.

Detail: Valve control, fig. 3–40.

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Another arrangement for a pulse valve is shown in fig. 4–41. Here two single-acting cylinders are used in place of the double-acting one. If actuators are used for cylinders, the valve occupies very little space. We shall come back to this type of construction in the next section.

In the control of double-acting cylinders there is an essential difference between the arrangements in fig. 1–31 and fig. 5–32: In the first case, in which, as we know, the piston rod remains freely movable when the valves are not actuated, the piston (if the valve is held open long enough) travels to its end position and remains there until the other valve is actuated. In this case signal storage is not absolutely necessary. The situation is different in the arrangement shown in fig. 5–32. Here the piston travels to one end position when the valve is actuated, and to the other end position when it is released. In order to hold the piston in each end position so that it remains there after releasing the valve, a good method is to use a 4/2 directional valve with signal storage, or in other words a pulse valve again, this time with 2 operating lines. A valve of this type is shown inside the box made up of dots and dashes in fig. 4–41. It consists of a double-acting cylinder and one opener- and one closer-type 3/2 valve operating in tandem. The symbol for such a valve is also shown in fig. 10–46. In addition to the usual connections P (compressed air) and R (exhaust port) the valve also has the ports Y and Z for the control lines and A and B for the operating lines. Fig. 5–42 shows the construction of this pulse valve, which is derived from that of fig. 2–40. The roller levers of the opener and closer are coupled by an axle 30, and are actuated simultaneously by the cam.

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An alternative arrangement with two actuators instead of the double-acting cylinder is shown in fig. 6–42. The mode of operation can easily be seen from the circuit diagram, since the positons of the piston are shown.

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The construction of the pulse valve from the parts of the Pneumatics kit and normal fischertechnik parts is shown in fig. 7–43.

The cam is made from a building block-15 and an isosecles angle block. It is pushed to and fro by the two actuators, and in each direction operates a valve with a blue or a red plunger. The cam must not slide too easily in order not to shift by itself; however, it must be reliably moved by the actuators so as to open an close the valves in a satisfactory manner. Some patience is required in adjusting this arrangement, but the valve can be housed in an extremely small space. The cam is prevented from falling out by an angle block and 2 building blocks-5. The pulse valve constructed in this way, together with the two 3/2 directional valves (openers) required for its actuation is incorporated in the small forklift truck shown in fig. 8–44.

Construction stages 1, 2 and 3.

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Fig. 9–45 shows a unit made up of the pulse valve and the two control valves. This control unit can be used for all models with double-acting cylinders, e.g. for the door. If only the opener of the pulse valve is used, it is also possible to control single-acting cylinders.

Construction stages 1 and 2.

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Reciprocation control

We are now able to control a cylinder in such a way that it makes reciprocating movements at a certain rate. This is done without any outside interference, and is an application of the pulse valve. The essential feature is that in its end positions the piston operates valves which supply the control pulses for the pulse valve. The circuit diagram of the system is shown in fig. 10–46. Fig. 11–47 shows the construction of the circuit using the pulse valve of the type shown in fig. 5–42. The type shown in fig. 7–43 can be used just as well.

Now let us take a look at the mode of operation as shown in fig. 10–46. When the piston of the operating cylinder 1 reaches its right-hand limit of travel, the valve II is opened by a stop on the piston rod of valve II. Compressed air reaches the control cylinder 2 via the control line Z. The piston of the control cylinder is moved to the left, as a result of which the valve III (opener) connects the left side of the piston of Z_1 with the exhaust port while the valve IV supplies the operating cylinder on the right side of the piston with compressed air via the operating line B. The operating piston therefore moves to the left until the stop on its piston rod opens valve I. Now compressed air enters the control cylinder via the control line Y, and the cylinder opens valve III and closes valve IV so that the left side of the operating cylinder contains air while the right side is emptied. The operating piston moves to the right, and the cycle begins again. The number of strokes per unit time (minute) depends on the air pressure, the capacities of the cylinders, the friction of the piston and piston rod seals and a number of other factors. As shown by fig. 11–47, the number of strokes per unit time (the stroke frequency) can be influenced by fitting a P throttle. Further details on this are given on page 54. This arrangement also has a built-in safety function. If for any reason the movement of the operating or control piston cannot be completed, the whole system comes to a stop. This ensures that the operating stroke is effected either over its full length or not at all. This can easily be tried out on the model.

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Pneumatic buzzer

The following circuit is more of a plaything.

Our readers are sure to know how an electromagnetic buzzer or an electric bell works. Fig. 12–48 is intended to refresh their memories. When the electromagnet attracts the armature, the contact spring cuts off the current at the interruptor contact; the electromagnet, which now has no current flowing through it, releases the armature so that the contact spring flies back and closes the circuit once more, and so on so that the armature is made to vibrate. We can now fix a hammer to the armature and make it strike a bell.

In our pneumatic buzzer we use two single-acting cylinders with springs. Fig. 13–48 shows the circuit. Cylinder 1 is an actuator, and cylinder 2 a cylinder-45. The function of the system can be described as follows:

Assuming that cylinder 1 has just closed the 3/2 directional valve I, the cylinder 2 is emptied via the operating line B and its piston opens the 3/2 directional valve II (closer). The cylinder 1 now receives compressed air, and its piston moves to the left and opens valve I. As a result cylinder 2 receives compressed air and its piston moves to the right and closes valve II; as a consequence cylinder 1 is emptied and its piston moves to the right and restores the original situation. The movement of the piston is so rapid that a buzzing sound is produced whose pitch can be varied by a P throttle. The movement of the piston can be deduced to very slow speeds. The model is shown in fig. 14–49.

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Time delay

It is possible to construct a special arrangement by which the movement of the operating cylinder does not begin immediately after actuating the valve but starts only after a time lag. This effect is achieved by means of a delay valve. As shown in fig. 1–50, such a valve consists of a combination of two 3/2 directional valves, a single–acting cylinder, a throttle valve and a reservoir. These parts are again enclosed by a line of dots and dashes in the diagram. Fig. 2–51 shows the function of the system. The actuator 1 receives an unthrottled supply of air directly via valve I. It therefore constitutes the operating cylinder which has to be controlled. Valve I in turn is controlled by the actuator 2, which is supplied with throttled air by valve II. If the adjusting screw of the P throttle is screwed in almost completely, it takes a certain, clearly measurable time before pressure can build up in the connecting tube between II and 2 and the volume of the cylinder 2. This volume which has to be filled is known as the "reservoir volume" and is shown in the circuit diagram by a special symbol separate from the components and tubes. Not until the pressure in the actuator 2 has reached the necessary level is valve I actuated and the cylinder 1 supplied with compressed air. Thus the movement of the actuator 1 takes place with a time lag: the larger the reservoir volume, the longer the delay. This volume can be increased by replacing the actuator 2 with the cylinder-45 with spring, which has a larger capacity. Fig. 4–52 shows the construction of the device. Besides the volume of the cylinder the delay time also depends on the position of the P throttle and the distance between cylinder 2 and valve I. In arrangements in accordance with fig. 1–50 only the forward stroke of the operating cylinder is delayed. The return movement begins immediately because the emptying of the cylinder 2 via the control line Z is unrestricted. Thus the cylinder returns immediately after valve II is released. If on the other hand as in fig. 3–51 the P throttle is fitted between the valve II and the cylinder 2, both the forward and the return movements of the cylinder are now delayed because the emptying of cylinder 2 is now also restricted.

Fig. 1–50 (graphic symbols): reservoir; throttle valve.

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In practice switching-on often has to take place

immediately while switching-off needs to be delayed. The circuit of a staircase lighting system is a good example of this. We can achieve this effect by using a closer for valve II and having cylinder 1 actuate an electric push-button. This button must interrupt the electric circuit when pressed. The way the circuit operates is shown in fig. 5–53.

In its normal state the cylinder 2 (control cylinder) is under pressure and feeds compressed air to the operating cylinder 1 via the valve I. Cylinder 1 actuates the button and shuts off the current so that the lighting is switched off. If valve II is now actuated, the control cylinder 2 is connected with the exhaust port and in turn empties the operating cylinder 1 via valve I. The piston of this cylinder is returned by its spring, releases the push button via the piston rod, and thus switches on the lighting. If the actuating button of valve II is now released, the pressure in the control cylinder slowly builds up as the reservoir volume is gradually filled up via the P throttle. Not until after a certain length of time does this pressure rise so high that the control cylinder actuates the valve I and the cylinder 1 is supplied with compressed air. This cylinder switches off the lighting once more by way of the push button.

The model of this system, which needs a few parts from the Electromechanics kit, is shown in fig. 6–53. These electromechanics parts are available in the form of add-on packs.

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Speed control

The speed of the piston movement depends on the volume of compressed air which flows into the cylinder per unit time. This can be continuously varied by means of a throttle valve. The valve should be located as close to the cylinder as possible, and may be used to control either the air inflow or the exhaust air.

As shown in fig. 1–54, in the single-acting cylinder the air flow can be controlled on only one side of the cylinder. In the arrangement in fig. 1–54 the piston makes a slow forward movement but returns at normal speed since the exhaust air flow is not restricted. On the other hand in the arrangement shown in fig. 2–54 both the inflow and the exhaust air are restricted so that the piston speed is reduced in both directions. Fig. 3–54 shows the associated models, in which we can see the effects of locating the P-throttle valve in different places. We have already seen an arrangement corresponding to fig. 2–54 in the model of the lifting platform (fig. 3–40).

In double-acting cylinders throttling is possible on both sides of the piston. The air inflow and outflow are on opposite sides of the cylinder in each case, i.e. when one side of the piston receives air the other side is emptied of air. In this connection restriction of the exhaust air flow is preferable because the piston is then always under pressure from both sides and therefore moves at a more steady rate. In relatively small cylinders both the inlet and the exhaust flows are restricted.

We have already fitted a P-throttle in our model of a door operated by a rotation cylinder. In the double-acting cylinder used in that case the inlet air flow is restricted in the forward movement and the exhaust air flow in the return movement. This enables the circuit to be kept very simple. With the aid of the P-throttle it is also possible to alter the frequency of the reciprocating cylinder and the pneumatic buzzer. In the case of the reciprocating cylinder the throttle valve can be fitted in either an operating line or a control line. You can test for yourself which arrangement gives the best effect.

Page 55/56

Air barrier

The well-known device of the *light barrier* has a counterpart in pneumatics, namely the *air barrier*. This consists of two nozzles which are exactly centered upon each other, namely the transmitter and the receiver nozzle. Their symbols are shown in fig. 1–55:

Transmitter nozzle (on the left); receiver nozzle (on the right).

The air flowing out of the transmitter nozzle is taken up by the receiver nozzle so long as no object is located between the nozzles. An object between the nozzles interrupts the air stream; thus the air barrier acts like a valve. However, as a result of eddy effects there is a loss of pressure even if the air flow is not interrupted, so the compressed air controlled by the air barrier cannot be used directly to perform work. Instead it controls a directional valve, which in turn supplies the operating cylinder with compressed air.

In our model (fig. 2–55) the air barrier is used to control a pendulum drive. It operates a closer-type 3/2 directional valve. The circuit diagram of the arrangement is shown in fig. 3–56.

On the upper extension of the pendulum rod the pendulum is fitted with a tag which passes between the nozzles at its maximum swing. So long as the tag is not located between the jets, the 3/2 directional valve is kept closed by the actuator 1. Thus no pressure is applied to the actuator 2. When the tag enters the space between the nozzles, the actuator 1 no longer receives air, and the valve opens and feeds the compressed air to actuator 2. The latter gives the pendulum rod a push so that the pendulum continues to swing. After the tag clears the air stream, the actuator 1 receives compressed air and shuts off the air supply to the actuator 2 via the valve. Some care is needed in the adjustment of the model. The duration of the swing can be altered by changing the length of the pendulum or the pendulum weight, but not by alterations in the pneumatic parts.

The combination of actuator 1 and the 3/2 directional valve acts like an amplifier for the control air, and thus corresponds to a relay or a transistor in an electrical circuit.

Page 57

Compressed-air engines

There are various types of compressed-air engines. Here we shall deal only with those which can be built with the parts in the Pneumatics kit.

We have already got to know the *compressed-air turbine*. Another type is the *compressed-air piston engine*. A version whose operation is easy to understand is the *link engine* with 4 cylinders. This is shown in fig. 1–57, although the valve gear has been omitted. The model engines are essentially derived from the steam engine and have either fixed or oscillating, single- or double-acting cylinders.

The *piston engines* make use of the expansion of compressed air which we got to know in our first experiment (see page 9).

After the air has flowed into the cylinder the inlet valve closes and the enclosed air expands, thus pushing the piston in front of it and performing work. The to-and-fro movement of the piston is converted by a crank drive into a more useful rotary movement.

Since the air cools markedly on expanding and always contains moisture, ice can form on the equipment and result in malfunctions. For this reason the air is allowed to expand only over a small part of the stroke and the inlet valve is not closed until the piston has completed 70 to 80% of its travel.

The speed of the engines is controlled by reducing the flow of air. Their torque depends on the pressure, and can be controlled by altering the pressure of the air supply. The symbols for compressed-air engines with one or two rotation directions are shown in fig. 3–57. The latter type are controlled like double-acting cylinders.

The circuit diagram of a compressed-air engine with one rotation direction is shown in fig. 2–57.

Fig. 3–57 (graphic symbols):

Compressed-air engine for *one* rotation direction.
Compressed-air engine for *two* rotation directions.

Now we come to the Description of our models.

Page 58

Vertical compressed-air engine with oscillating, single-acting cylinder

This is the simplest form of compressed-air engine we can build with our kit. As a result of the oscillating cylinder the mechanical construction is also extremely simple. The set-up is nothing more than the programme control of a single-acting cylinder which we have already seen in fig. 1–34. The only difference is that the cam disc is driven directly by the crankshaft. The mode of operation is shown in figs. 4–58 to 7–58. When the piston is at the top of its stroke, also known as *top dead centre* (TDC), the cam disc must just begin to open the 3/2 valve (fig. 4–58). Fig. 5–58 shows how the inflowing air forces the piston down, while at the same time the whole cylinder swivels sideways (oscillating cylinder). The compressed air now performs work. When the piston reaches the bottom of its stroke *(bottom dead centre* BDC), the valve must just close and begin to empty the cylinder (fig. 6–58). Fig. 7–58 shows how the spring returns the piston to top dead centre. The engine operates without expansion, i.e. the inlet valve is open over the full length of the stroke so that no expansion of enclosed air takes place. As you can easily work out for yourself and try on the model, the engine runs in only one direction. The speed can be controlled with the P-throttle.

Page 59

Compressed-air engine

If the engine is driven by a fischertechnik motor, it operates as a compressor and so can generate compressed air itself. The compressor must be driven in the opposite direction to the engine. When the piston is at BDC the valve just opens and the piston forces the air out of the cylinder. The exhaust port of the valve is closed. At TDC the valve closes and again connects the cylinder with the outside air, which is drawn in as the piston moves down.

When constructing the model, care should be taken that the cam discs fully actuate the valve via the roller lever, i.e. that they push the plunger in fully. The connecting tube to the cylinder must not impair its free movement. The symbol for a flexible tube is shown in fig. 8–59.

If you have more parts available you can construct a reversible motor which runs in both directions. All that is needed for this is a “reverse cam” turned 180°

away from the forward cam. This is made to operate the valve by shifting the valve parallel to the crankshaft.

As a rule a motor of this type does not start by itself and must be started up by turning the flywheel.

Fig. 8–59 (graphic symbol): flexible tube.

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Vertical compressed-air engine with oscillating double-acting cylinder

Figures 10–60 to 13–61 show the mode of operation on the basis of the circuit diagram of the engine, while fig. 14–61 shows the associated model. Here we have included no roller lever, but have arranged the cam discs to act directly on the plungers of the valves. Naturally there is no reason – apart from the extra space they occupy – why roller levers should not be used.

With regard to speed control, reversing and the use of the motor as a compressor, the same applies as has been said for an engine with a single-acting cylinder. The advantage of a double-acting engine is its smooth delivery of power. The air consumption is roughly twice as high as for a single-acting engine, but on the other hand the engine delivers roughly twice as much air when working as a compressor.

Observant readers will have noticed that the circuit shown in fig. 10–60 is the same as for the programme control of a double-acting cylinder shown in fig. 3–35, except that the cam discs are mounted directly on the crankshaft.

Page 62

Compressed-air engine with beam

The following compressed-air engine (fig. 15–62) is based on the well known type of steam engine constructed by *James Watt*. It has a fixed, double-acting cylinder whose piston movement is transferred to the crankshaft via a two-armed lever, the "beam". The pneumatic circuit is the same as that of the vertical, double-acting engine. Thus here we have a programme-controlled double-acting cylinder with the cam discs for the programme control mounted on the crankshaft. This model, which works extremely well, is intended for owners of somewhat more kit material, since more building blocks are needed than are contained in the Start-100 kit. The two valves are again actuated via roller levers.

Detail: valve control fig. 15–62.

Page 63

Horizontal compressed-air engine with fixed, double-acting cylinder.

This engine (fig. 16–63) is similar in construction to a steam engine or a large gas engine. Since the cylinder is fixed, the power is transferred to the crankshaft via a connecting rod. This engine also requires somewhat more material than is contained in the Start-100 kit. It is so powerful that it is capable of driving a fischertechnik motor as a generator and producing around 2 volts. If the fischertechnik motor is connected to a power source, the machine operates as a compressor provided the rotation direction is correct.

Detail: valve control

Page 64/65

More model engines

As suggestions for owners of more construction material, figs. 17–64 and 18–65 show a self-starting *two-cylinder compressed-air engine* in vee configuration and a *two-cylinder in-line engine.* The latter consists of 2 single-cylinder engines which are coupled together via the rotary discs. The valve control system, which is in accordance with the principle of fig. 8–33, is the same for both engines. The drive is via the gear wheel 40/32 and has a gearing-up effect. When constructing the engines, care should be taken that the crank pins of the two single engines are 90° apart.

All models must be built so that they are free-running to avoid unnecessary friction losses. The engines run fastest if no P-throttle is fitted, since this has a certain flow-reducing action even when fully open.

Rear view (flywheel removed).

Page 66/67

Pneumatic excavator (cover picture)

The circuit diagram is shown on the back cover of this book.

Construction stages 1, 2 and 3.

Page 68

Electropneumatic Control Systems

The operation of a gate, for example at the entrance to a plant, can be accomplished pneumatically. It is usually to be carried out from the porter's lodge, i.e. by remote control. This requirement could be satisfied by means of a control system like the one shown in Figure 2–54 with an appropriate directional valve in the porter's lodge. In that case, however, a rather long compressed-air line might have to be installed between the porter's lodge and the gate, which would be complicated, expensive, and due to possible leaks which might arise not at all advantageous from the maintenance point of view. Electrical wiring, on the other hand, can be conveniently installed, is not especially susceptible to technical difficulties, and is considerably less expensive an compressedair lines, particularly for large distances.

For these reasons combined control systems, i.e. electropneumatic control systems, are usually used in similar cases such as these. In these systems the signalling and signal processing are accomplished electrically, i.e. the control commands of the porter are initiated by means of an electrical key and are transmitted on through the electrical wiring; the actual performance of the work is accomplished pneumatically via an operating cylinder. The connection between the so-called information part and the energy part of the system is provided by an electrically actuated valve. It is normally fitted with an electromagnet dand is called a solenoid-operated or solenoid valve. The valve itself is a directional valve of the kind described on page 20; the electromagnet is powered by direct or alternating current, usually at 12 or 24 volts. The graphic symbol for a solenoid-operated valve (Figure 1–68) differs from the graphic symbols for other directional valves only on the actuation side (see also page 75).

The advantages of electropneumatic control systems lie in their speed and in the ready possibilities for connection in the signal flow, as well as in the possibility of spanning great distances without any technical difficulties. In areas and plants where there is risk of fire or explosion, however, pneumatic control systems will be preferable, in which there is no possibility of sparking.

Page 69

The fischertechnik solenoid-operated valve

Owners of the Electromechanics expansion kit can build the solenoid-operated valve shown in Figure 4–69. When assembling one must take care that the assembly board "15 x 45" is easily inserted between the building blocks 5 and the valve. In order to ensure that the armature does not remain stuck to the magnet (as a result of the remanent magnetism) a gummed label should be stuck onto the armature. In addition two to five gummed labels should be stuck onto building block 7.5. The exact number should be chosen, so that on the one hand the valve is fully actuated when the armature is attracted to the magnet, but on the other hand so that the valve returns to its rest position after the current has been shut off. The valve can be either an opener (blue) or a closer (red), according to the intended application. The actuation of the valve can be effected electrically either by means of a key or a switch, depending on the application.

Page 70

Electropneumatically operated gate

The above-mentioned operation of a gate is accomplished according to the model shown in Figure 5–70. Figure 6–70 shows the accompanying circuit diagram.

The arrangement of the throttle valve is as shown in Figure 2–54, so that it affects both the forward and return movement of the piston. The dead weight of the gate beam is almost counterbalanced by building blocks used as counterweights, so that only a very small force is required from the operating cylinder. With the arrangement shown in Figure 5–70 the cylinder closes the gate when the system is actuated. If the cable drum is turned around on the crankshaft, then the result is that the operating cylinder opens the gate. This fact can easily be demostrated by trying it out. The arrangement chosen will be the one which allows the operating cylinder to move the gate beam away from its rest position in the actual situation involved, i.e. in the case of a level-crossing gate it will lower the barrier, and in the case of an entrance gate it will raise it. In the actual rest position involved the operating cylinder will then be without pressure and the solenoid-operated valve without current. The choice as to whether a key or a switch is chosen for the operation of the electromagne depends on the duration of the actuation.

If the circuit shown in Figure 6–70 is used, the model can be operated with the fischertechnik model compressor, especially if short intervals are inserted between the individual actuations as necessary. The throttle valve avoids sudden, abrupt opening and closing of the gate and enables a realistic, slow movement to be achieved. When using the model compressor it is advisable to feed the solenoid-operated valve with current from the side output of the transformer unit "mot 4". In the case of older models of this unit the side output delivers alternating current, which can be recognized by a humming in the electromagnet, but is otherwise of no consequence.

Page 71

Electropneumatically operated sliding door

For the sliding door model shown in Figure 8–72 we have made use of the control system for double-acting cylinders illustrated in Figure 7–33. Because the required amount of travel of the door cannot be achieved with a single cylinder, we have arranged the two cylinders in series with respect to their operating movement, although we have connected them in parallel with respect to the air supply. As we know from Figure 5–32, the combination of opener and closer in tandem can be replaced by a 4/2 directional valve. The actuation is accomplished pneumatically in analogy with Figure 7–33, and is in accordance with the circuit diagram shown in Figure 2–68. Figure 3–68 is further simplified. It shows an electromagnetically operated 4/2 directional valve, and it replaces the arrangement enclosed by the line made up of dots and dashes in the complete circuit diagram (Figure 7–71). In order to ensure that the door does not slam too violently it is advisable to provide throttling for the closing motion. The opening motion occurs with less force anyway as a result of the air loss at the piston-rod lead-in and thus requires no damping.

If the door is to be kept shut permanently and is only to be opened as the occasion arises, then a closer should be installed in the solenoid-operated valve. The actuator is then continuously under pressure, and connects the two cylinders to the pressure line via the opener using the side facing away from the piston-rod seals.

Hardly any air losses arise here. Should one want to keep the door open permanently and close it, for example, only in the event of danger, then the cylinder chamber on the piston-rod side would have to be kept under pressure continuously, so that the air losses would have to be replaced from time to time by the compressed-air source. We leave it to the reader to dream up other, and possibly better, circuit variations.

The fischertechnik model compressor is not adequate for the operation of the sliding door.

Page 72/73

Hydraulic lifting platform

The advantages of **hydraulic** systems compared to **pneumatic** ones in cases where large forces are required have already been mentioned on page 6. These will be clearly illustrated with the help of the model shown in Figure 1–73.

First, we shall build the lifting platform equipped with a parallelogram frame shown in Figure 1–73 and install the two operating cylinders, which we shall connect up directly with tubing similarly as in the model shown in Figure 1–13. When the connecting tube is fitted, the piston of the cylinder with spring return must be pushed in all the way and the piston rod of the other cylinder pulled out all the way.

The functioning of the model will not be entirely satisfactory, since it is not possible to achieve a sufficient amount of Lifting.

When the piston of the master cylinder is pushed in all the way, the piston of the actuating cylinder has only travelled part of its stroke. The reason is obvious:

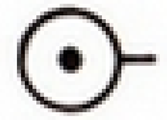
In order to lift the platform a certain force is required in the actuating cylinder, which of course is determined by the pressure existing in that cylinder. This relatively high pressure originates in the master cylinder, where the enclosed air must be compressed strongly enough to produce the pressure required. Only when this pressure has been attained can the platform begin to move. But in order to produce this required pressure the piston of the master cylinder first must move part of its total possible stroke, so that only the remainder of its stroke is available for the actual lifting motion.

The compressibility of air is a hindrance here and the natural solution is to use a fluid as the transmission medium. It is a well known fact that fluids are practically incompressible. In practice oil or a special hydraulic fluid is usually used, but water can also be used. We use water in the model because it allows for clean operation and does not damage the seals. When the system is filled up, it is essential that no air remains in it, as the compressibility of the air would neutralize the advantages of the fluid. For this reason a bleeder tube is installed at the highest point of the connecting tubing, as shown in Figure 2–73.

First, a piece of tubing is connected to the T-piece of the model and the other end is put into a glass of water. Then the system is filled up by pulling out the piston rods of both cylinders, so that water is sucked in. Then in this state the tubing is removed and the T-piece is sealed with a P-plug. Then the P-plug is loosened just enough to allow some fluid to escape at the T-piece and the platform to move to its lower end position. A large portion of the air will also escape along with the water flowing out. The P-plug is then put on securely again and the bleeding is usually sufficient. The piston of the actuating cylinder then travels all the way out, so that the platform attains its full lifting height when the master cylinder is actuated.

From time to time some of the water must be replaced in the system, since with the relatively high pressure some water will inevitably squeeze out at the cylinder gaskets.

Table of the graphic symbols used in this book
(Graphic symbols according to DIN ISO 1219 of August 1978)

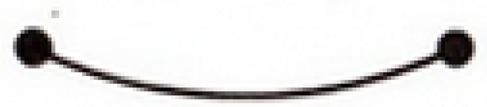

Compressed-air source

Operating line

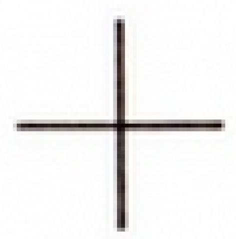

electrical wiring

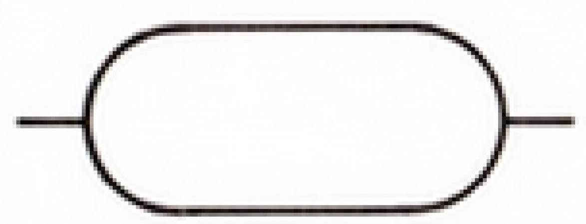
Control line

Demarcation of a subassembly


Flexible tube


Tube connection


Crossed tubes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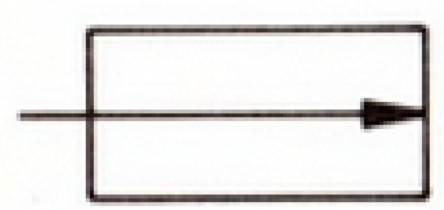
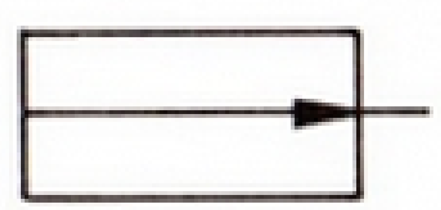
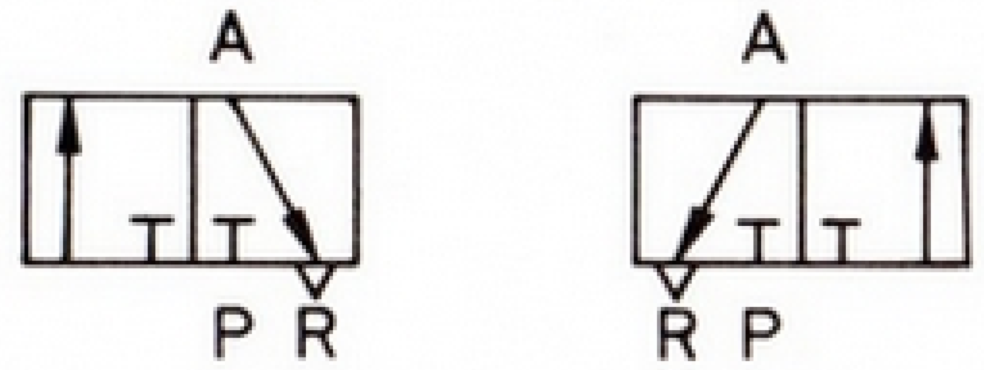
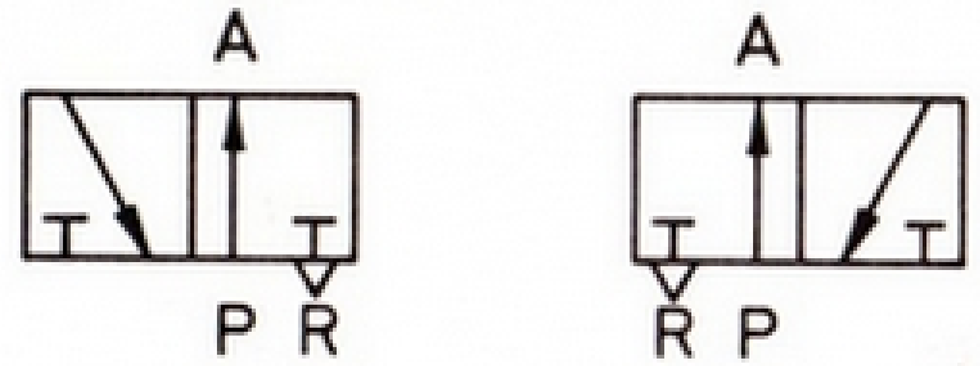

Transmitter nozzle

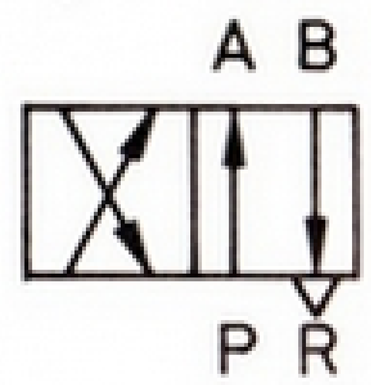

Receiver nozzle



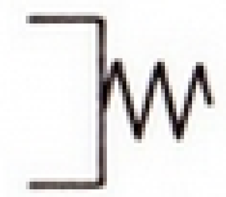
3/2 directional valve, normally closed

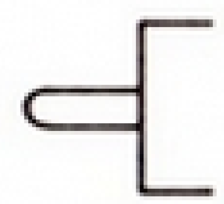


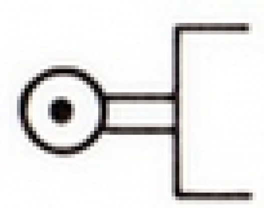
3/2 directional valve, normally open

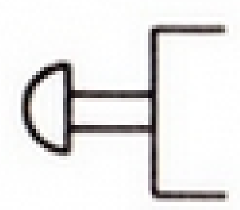


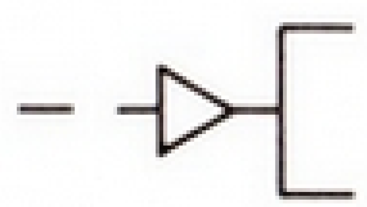
4/2 directional valve

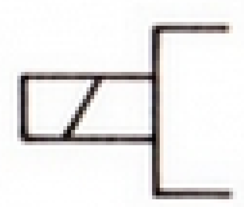

Return spring

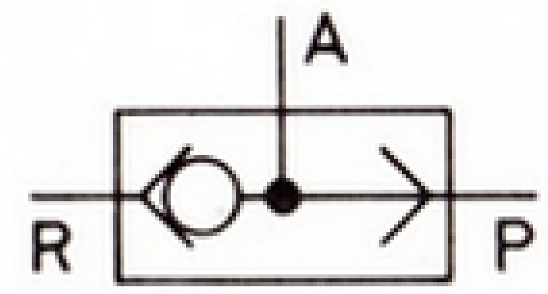

Valve actuation by push button


Valve actuation by tracer roller and by roller lever

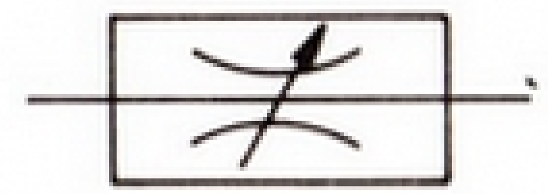

Valve actuation by button
Valve actuation by hand

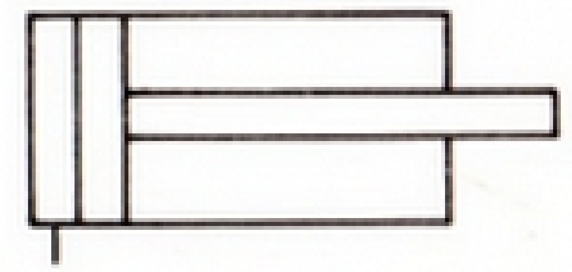

Valve actuation by compressed air

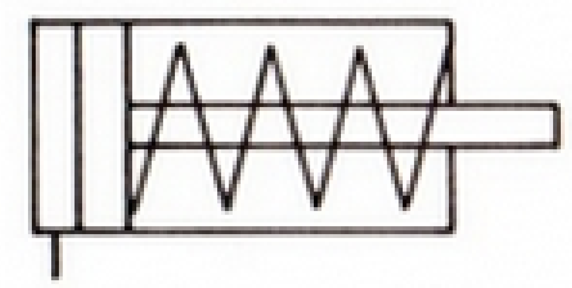

Valve actuation by electromagnet (solenoid-operated valve)

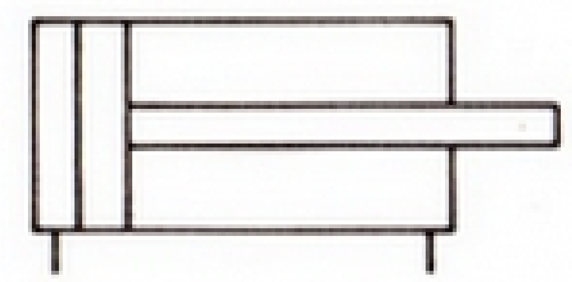


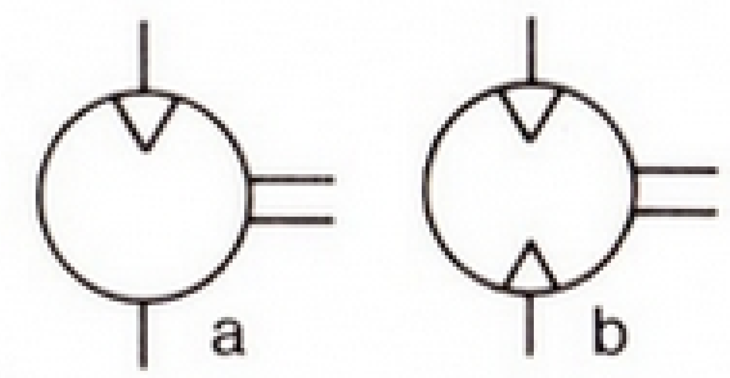
Shuttle valve


Throttle valve, variable


Single-acting cylinder


Single-acting cylinder with spring return (also diaphragm cylinder)

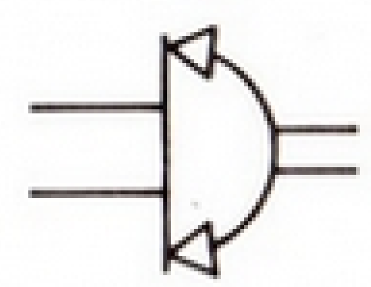

Double-acting cylinder

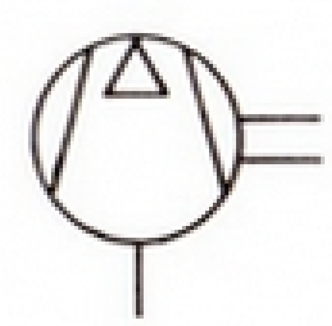


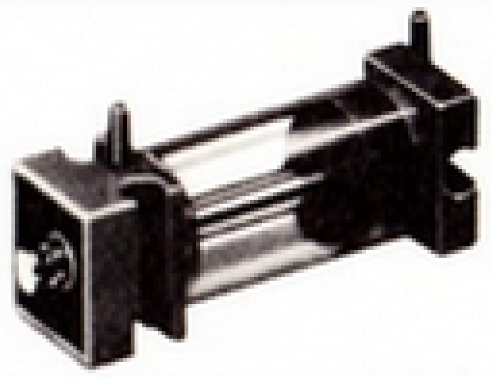
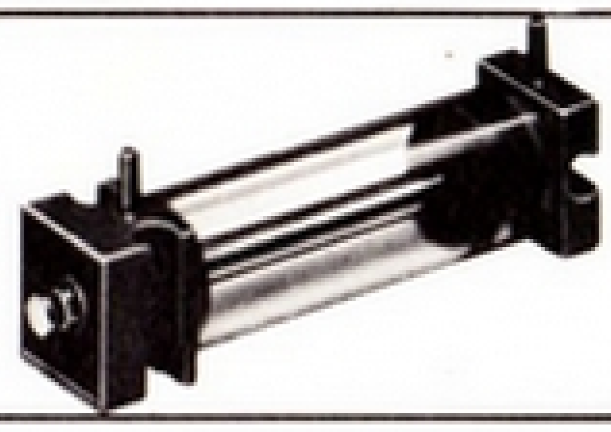
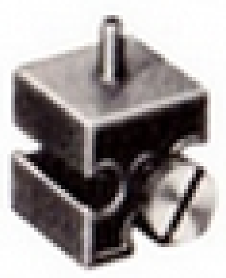
Compressed-air engine

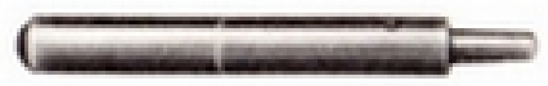
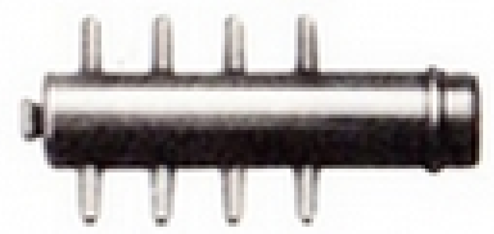
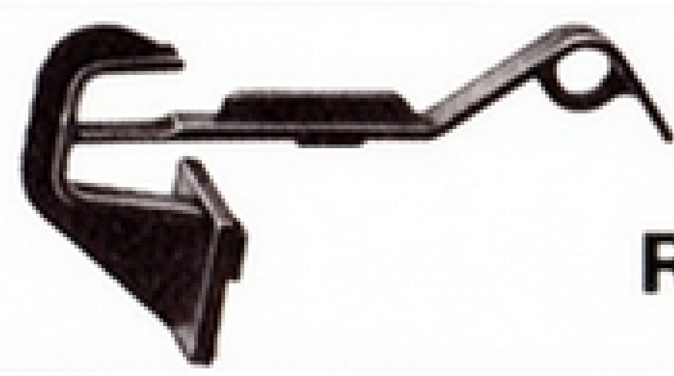
a. for 1 rotation direction

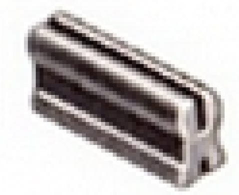
b. for 2 rotation directions


Rotary or swivel cylinder


compressor

		Stück
	Cylinder-45	1
	Cylinder-60	1
	Cylinder-45 with spring	1
	Actuator	4
	Double actuator	1
	P-throttle	1
	Valve, closed	3
	Valve, open	1

		Stück
	Nozzle	2
	T-piece	10
	P-distributor	1
	P-plug	10
	Tubing 2 x 0.5 x 3000 mm	1
	Tubing 10 x 0.5 x 50 mm	1
	Roller lever	4
	Building block-51	10

		Stück
	Building block-7.5	4
	Double rivet 8 mm	4
	Locking washer	6
	Connector-15	18
	Coupling-2	4
	Cylinder coupling	4
	Flat hub	1
	Flywheel	1
	Cam disc	4

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