Tasks

Preliminary experiments

Construction task

First, build only the manual pump from the functional model. It consists of a pneumatic cylinder and a check valve. (The check valve allows the air through in only one direction, and does not allow it to return. We will learn more about this component in other models.)

Warning! Pneumatic cylinders can only be exposed to tension and pressure, not bending or shearing! Please do not bend the blue or red pistons of the cylinder. This could cause the cylinder to leak and make it unusable.

Topic task

Complete the following experiments:

1. Insert a hose onto the pointed outlet of the check valve. Activate the pump and feel with your hand how air flows out of the hose when the cylinder is depressed.
2. Hold the end of the hose closed with your finger. Feel how it becomes more difficult to move the pump. Why exactly is this?
3. Repeat experiment 2 by putting a kink in the hose instead of holding it closed. You have now made a simple valve! It either allows compressed air through (hose clear) or blocks it off (hose kinked).

Experimental task

Insert the free end of the hose into one of the two connections of a “double-acting” pneumatic cylinder (with blue piston rod, without built-in return spring) and then the other. The cylinder is called a “double-acting cylinder because compressed air is applied to it on both sides at its connections, thereby causing the piston rod to both retract and extend.

Hold the cylinder by both ends (base and end of the piston rod) freely in your hand. Complete the following experiments:

1. Pump, and allow the cylinder to extend. Feel the amount of force that can be created by doing so.
2. Switch the hose to the other connection, pump and allow the cylinder to retract.
3. Repeat these experiments, holding the open connection of the cylinder closed with your hand. What do you observe? What is the reason for this?

Tasks

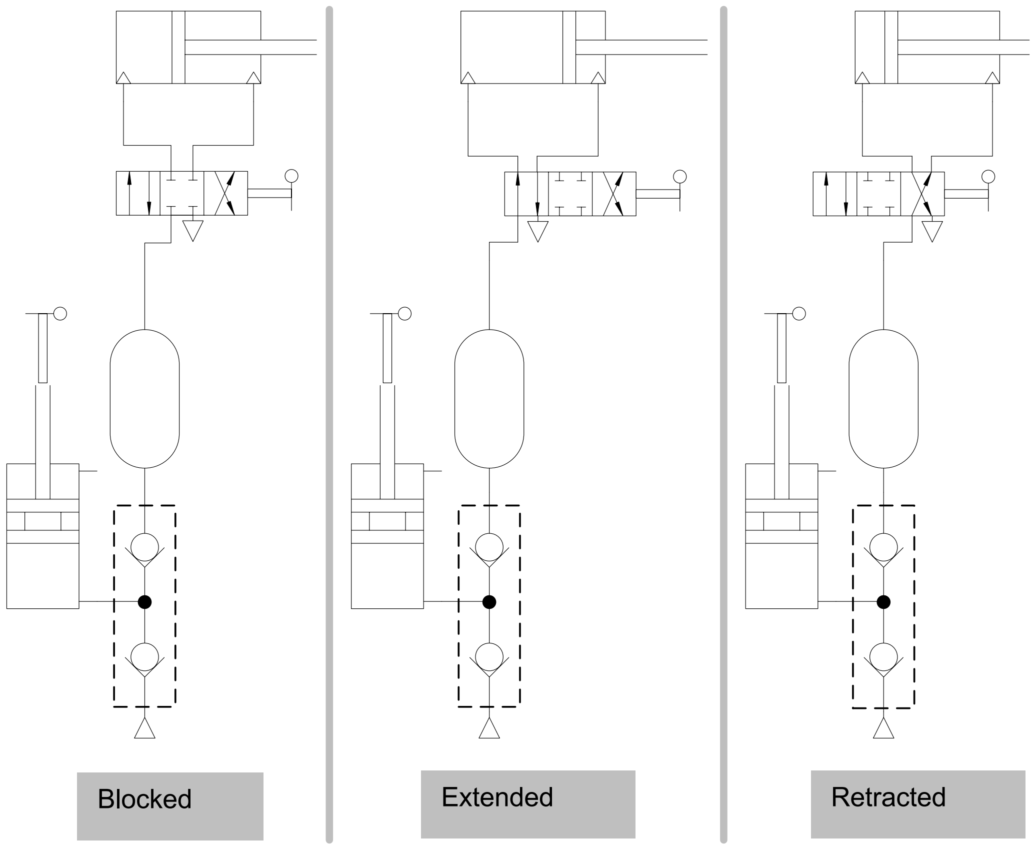
Controlling a cylinder with a valve

Construction task

Now, finish building the functional model. The elements are:

1. The **manual pump** you have already built.
2. A **tank** for compressed air. It stores the compressed air (similar to a capacitor or battery for electrical current).
3. A **pneumatic manual valve**. The compressed air is applied to its upper connection, and is fed into the left or right outlet, depending on the position of the blue rotary valve.
4. A **double-acting cylinder** (with blue piston rod) that is connected to the left and right connections of the manual valve with a hose on each side.

Connect the hoses to the model as described in the building instructions. As in electronics, in pneumatics there are circuit symbols for the individual pneumatic elements, and circuit diagrams for the entire setup:



These three circuit diagrams correspond to the model states, depending on the position of the manual valve. We will be explaining the circuit symbols using the drawing at the left called “Blocked”:

a) The left cylinder is the one for the manual pump. Manual activation is represented by the lever symbol at the top of the cylinder piston. The bottom connection of the cylinder goes to the fischertechnik check valve.
b) The check valve is shown in the dashed box. There are actually *two* effective check valves in this one fischertechnik component. The bottom one only allows air from the outside to come in (through the small hose in the base) (into the cylinder), but not out. The top one allows the air compressed by the cylinder only to flow out towards the system, not back. The intake air access is represented in the circuit diagram by the small triangle.
Check valves are often actually constructed as shown by the circuit symbols: A sphere is pressed (by spring force) into a seat, sealing it off. Air can only flow through the valve in the direction if the sphere is pushed away from the seat (against the spring force). It will then block passage in the other direction. Do not misunderstand the circuit symbol as an “arrow” indicating the direction in which the air can flow – actually, it can only flow in exactly the opposite direction.
The fact that this valve is activated manually is indicated by the lever symbol. (There are also valves with an automatic return function using a spring, by activating a “lever” by a moving machine component, or by activating compressed air using other valves to construct larger pneumatic circuits.)
c) The compressed air is fed into the pressure tank by the hose, where it can be stored and buffered.
d) From there, it is fed to the pneumatic manual valve. This valve actually has three positions: In the centre position, all connections are blocked. If you turn the blue lever to the left or right, the compressed air is fed (from the hose connection at the top centre) to one of the two (side) outlets. As we have learned, however, the “exhaust” has to be able to get back out again (similar to electrical current, which must be fed back through a second cable). It is important that the other connection is connected to the exhaust outlet (this is the lower, previously unconnected outlet for the fischertechnik manual valve). We will be discussing the circuit symbol for the valve in more detail later on.
e) The two outlets of the valve are connected to the two connections on the working cylinder. As long as we are pumping compressed air, we can turn the valve to extend or retract the cylinder as desired, or hold it in any position.

The circuit diagram for the valve shows its mechanism of action. The manual valve has four connections or “ways” (for the intake air, the two outlets and – crucially! – the exhaust outlet). It can be set to three switching positions (left, right, and the centre position that closes all connections). Therefore, this is a “4/3 way valve” – four connections, three switching positions.

Each switching position is simply shown in a box with lines or arrows showing which connections are connected in the respective switching position or (here in the centre position) closed off. The three boxes – one for each switching position – therefore represent which switching options the valve offers. The respective switching positions and the associated position of the working cylinder are shown as the active positions in the three circuit diagrams “Blocked”, “Retracted” and “Extended”. Therefore, we draw the connected valve connections on the circuit symbol boxes corresponding to the standard setting (such as the machine idle state).

The fact that the exhaust outlet of the valve is connected to the ambient air in this circuit is indicated by the small triangle in the circuit diagram.

Topic task

1. Experiment with the model. Pump, turn the pneumatic valve and observe what the cylinder does.
2. Set the valve so that the cylinder is retracted. Pump without activating the valve. Stop pumping and just activate the valve. How many “strokes” of the cylinder can you complete using the compressed air stored in the tank without pumping again?
3. Follow the path of the compressed air from the pump through the tank, the valve and the cylinder, as well as the path of the “exhaust” from the cylinder through the valve and out to the open air. Trace this for the circuit diagrams in all three valve switching positions.
4. If you have a simple piece of hose, you can leave it open, or block it off by holding it closed or putting a kink in it. A hose, therefore, is a valve: It has two connections (the two ends of the hose) and two switching positions (open and closed). Therefore, it is a 2/2 way valve. Draw the circuit diagram for this kind of valve.

Experimental task

1. What does the model do if you block off one hose by putting a kink in it?
   a) The hose between the pump and tank.
   b) The hose between the tank and valve.
   c) One of the two hoses from the valve to the cylinder, in combination with the switching positions of the valve (three positions of the valve and two hoses equal 3 x 2 = 6 experimental combinations).

   Conduct multiple experiments with these combinations, writing down your observations systematically.
2. What does the model do if you put a kink in the hose that closes it off most of the way, but not all the way? (We will be discussing this topic, “throttling” compressed air, in later tasks and models.)

Functional model – Learning about compressed air

Stefan Falk

Topic

Generating compressed air with a self-built pump and understanding its function in a pneumatic cylinder. Controlling a pneumatic cylinder using a valve.

Learning objective

- Compressed air makes a pneumatic cylinder extend and retract.
- Blocking the exhaust prevents this, so it must be able to flow out on the other side of the cylinder.
- Check valves allow compressed air through in only one direction, and can be used to build a compressed air pump and other components.
- Valves flow the inlet and outlet flows of compressed air, and can be used to control cylinders.

Time required

45 min.

Solution sheet

Preliminary experiments

Example solution for topic task

Topic task 2: Pumping becomes more difficult, because more and more air is being pumped into the hose. As this occurs, the air is being compressed, resulting in “compressed air”. The volume of the hose acts like a small compressed air storage tank (the flowing air under pressure increases the pressure in the hose in the same way as flowing electrical charge increases the voltage in a capacitor). The more pressure builds up, the greater the force pushing the pump cylinder back upward. The air pressure and pressure force acting on the piston from the inside move the piston until the inner force corresponds to the air pressure acting from the outside (or until the piston reaches a mechanical stop).

Evaluating the experimental task

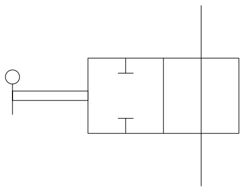
Experimental task 3: If you prevent the air in the side of the cylinder where the compressed air is not applied (pumped) from escaping out of the cylinder, you will no longer be able to move the cylinder to its end position. The air in the closed section will become more and more compressed, building up counter-pressure. The piston seal of the cylinder will be fixed in the position where the resulting forces act against one another between the pressure from the pump and the pressure from the closed half of the cylinder. **Key finding:** To move the cylinder, the “exhaust” on the side where the compressed air is not applied must be able to escape from the cylinder. **It is not enough to simply pump air into one cylinder – it must also be able to get back out on the other side!**

Solution sheet

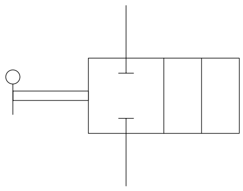
Controlling a cylinder with a valve

Example solution for topic task

Topic task 4: A piece of hose used as a 2/2 way valve has two switching positions. That means we need two boxes for the circuit symbol. Each box must represent two connections. One switching position must block off both connections, and one must connect them.



Open



Closed

We do not put an arrow in the box for the connected switching position, since without the context of the whole circuit diagram there is no definition of which direction the air would flow through the valve, and because the hose does not have any design restrictions on the flow (the air can simply move through in both directions).

Evaluating the experimental task

Experimental task 1: a) and b) will cause the system to stop, because the compressed air supply will be blocked. If the compressed air to the cylinder is blocked in c), it will not move. If the exhaust from the cylinder is blocked in c), it can only move until the counter-pressure that is built up is just as strong as the pressure of the intake air.

Experimental task 2: The “throttle” causes the system to work more slowly – the cylinders move slower than they would without a throttle. However, we can differentiate between two cases – they will be dealt with in more detail in subsequent tasks.

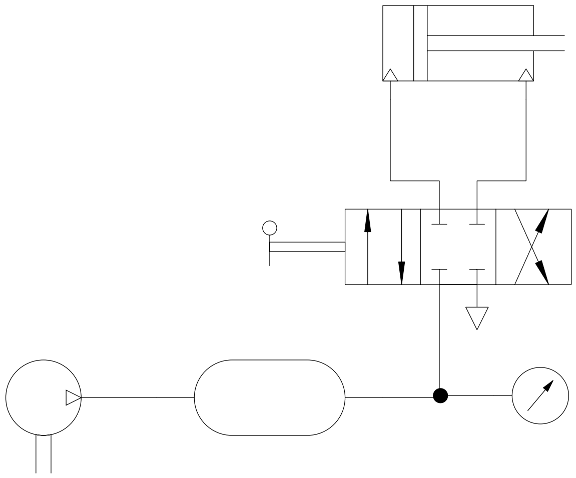
a) If the *intake air* is throttled greatly, the cylinder will move *backwards*. This is because the air pressure must first overcome the static friction of the cylinder piston. Once this occurs, the cylinder piston will move. At the same time, however, it increases the available volume. If the quantity of air remains the same, the pressure will be reduced – until the cylinder applies less force than the force of the sliding friction. This will cause it to stop again. This cycle will repeat until the cylinder reaches one of its stops (ends).
b) However, if we throttle the *exhaust*, the cylinder will be “tensioned” by pressure on both sides, and will move much more easily.

Tasks

Generating compressed air and measuring pressure

Construction task

Build the Expanded functional model. Leave out the throttle initially (the small black part with the blue knob). At first, just let the exhaust outlet of the valve lead directly into the ambient air. Connect the hoses according to the following circuit diagram:



The left element stands for the compressor. Its power supply is not separately shown. The circuit symbol for the manometer to the right of the air tank is also new.

Topic task

The compressor generates compressed air similar to our self-built manual pump. However, it has an electric drive, and is better than the manual pump in several ways:

- It delivers a constant flow of compressed air as long as it is connected to the power supply (with the fischertechnik compressor, the polarity of the connection to the 9V direct current does not matter).
- It can build up an air pressure of up to approx. 0.8 bar.
- It pumps more air volume than a manual pump would be able to in the same amount of time. The "throughput" of a compressor is generally indicated in litres of air per minute (L/min).

The **manometer** is used to measure air pressure, or more precisely: to measure the pressure differential between its connection and the ambient air. The ambient air exercises a pressure of approx. 1 bar on the surface of the Earth; the compressor, in contrast, generates a pressure that is 0.8 bar higher.

Pressure is the relationship between force and area. In standardised SI units, this would be the force in *Newton* (N) in relation to area in m². The SI pressure unit is the *Pascal*:

$$1\ \text{Pa} = \frac{1\ \text{N}}{1\ \text{m}^2} = 1\,\frac{\text{N}}{\text{m}^2}$$

Bar is another unit used for pressure, and has a simple relationship to a *Pascal*:

$$1\ \text{bar} = 10^5\ \text{Pa} = 100{,}000\ \text{Pa} = 100{,}000\,\frac{\text{N}}{\text{m}^2} = 100{,}000\,\frac{\text{N}}{100\ \text{cm}\cdot 100\ \text{cm}} = 10\,\frac{\text{N}}{\text{cm}^2}$$

Since 10 N is approximately the force (it is 9.81 N to be exact) that 1 kg of mass weighs on the surface of the earth, a *Bar* corresponds to around the weight force of 1 kg per cm².

Complete the following tasks:

1. Set the pneumatic valve to the centre position (all connections are closed). Switch the compressor on. How much pressure does the manometer show?
2. Switch the compressor off. What does the measured pressure do then? Why is that?
3. Switch the compressor back on. Extend and retract the cylinder by activating the manual valve. Compare the force the cylinder creates subjectively (a precise measurement is not required) with the force that could be generated by the manual pump.
4. Extend the cylinder and retract it once again. Compare subjectively how fast the cylinder can extend and retract using the compressor instead of the manual pump. What happens to the measured air pressure during the experiment?
5. Retract the cylinder and allow the compressor to continue pumping until the pressure displayed on the manometer no longer increases. Then switch the compressor off and extend and retract the cylinder multiple times. How many strokes can you carry out in this way (compare the results with the same task using the manual pump)?

Experimental task

1. We can also systematically check the leak-tightness of the overall system. Complete for each valve position
   a) Centre position (blocked),
   b) Position for extended cylinder (are leaks around the washer in the cylinder relevant?) and
   c) Position for retracted cylinder (are leaks around the washer and at the piston outlet relevant?)

   the following procedure: Switch the compressor on and allow it to pump until the pressure no longer increases. Note this pressure for the starting time = 0 seconds. After switching off the compressor, read off the pressure on the manometer at constant intervals (such as every ten seconds), and record it in a table.

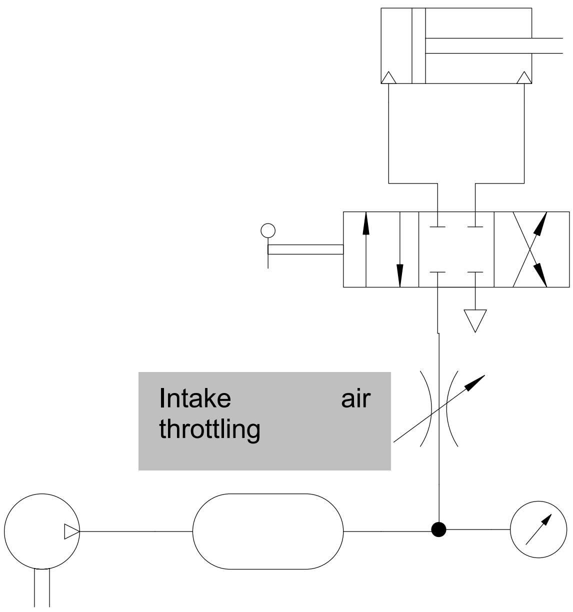
2. Show all three measurements in a separate pressure/time diagram (time on the x axis, pressure on the y axis). Where do the greatest losses of pressure occur, and where do the smallest occur?

Tasks
Moving a cylinder slowly

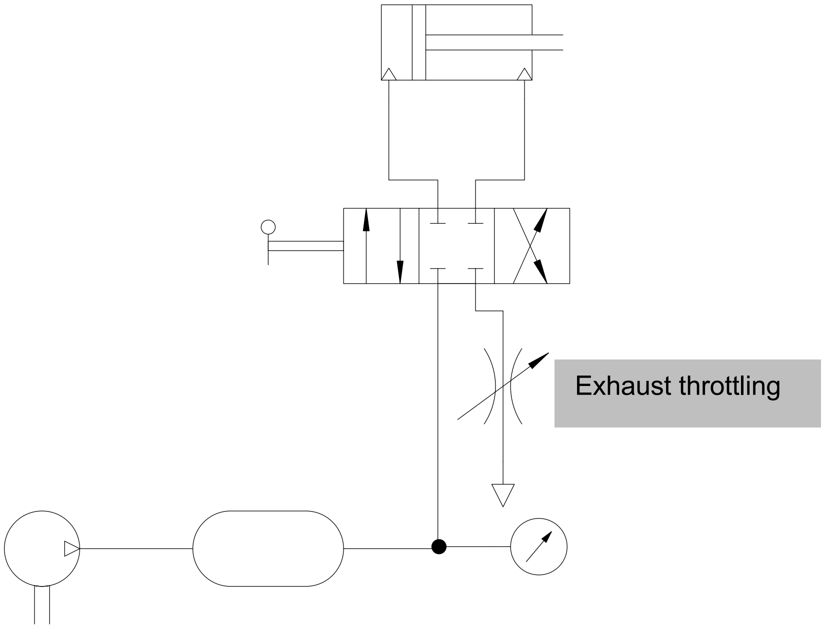
Construction task

Industrial pneumatic systems are generally operated with a pressure between 6 and 8 bar. This allows pneumatic cylinders to be extended with a large amount of power if needed – and very quickly. Often, a powerful movement is needed, but it needs to be slow and controlled. A movement that is too fast could endanger machine components, workpieces being handled, or even people. This is achieved by *throttling* the compressed air – we allow less air to flow through a hose or line in a certain amount of time, by simply restricting the diameter of the line. Now, there are two positions at which we can throttle the compressed air in a cylinder:

a) It might seem like a good idea to throttle the *intake air*: We allow the compressed air to flow into the cylinder more slowly (the circuit symbol for the variably adjustable throttle once again looks very much like how throttles are actually designed, although no squeezed hoses may be used for the purpose in industrial pneumatics):



b) However, we can also throttle the *exhaust*: We allow the intake air to flow into the cylinder unthrottled, but use a throttle to prevent the exhaust on the other side from flowing quickly out of the cylinder.



Let's try it! Add the throttle to the expanded functional model. It is simple to use: Insert a hose through it; then you can turn the blue handle to screw in a screw. This will press on the hose and allow you to finely adjust the "remaining" diameter of the compressed hose. We will be testing out both the intake air and exhaust air throttling in this way.

Topic task

1. **Intake air throttling:** Install the throttle in the hose between the tank and the valve, in the intake air inlet of the valve (the throttle can also be simply pushed onto the hose without any other attachment). Throttle hard to see the effect clearly. Let the cylinder retract or extend, and look closely! What do you observe? What changes if you place something heavy on the panel in front of the retracted cylinder, then allow the extending cylinder to push it out of the way with strong throttling?
2. **Exhaust throttling:** Remove the throttle from the intake air hose. Instead, connect a hose to the previously unused fourth connection of the manual valve (the exhaust outlet) and guide it through the throttle. Throttle hard again to maximise the effect. What does the cylinder do now? Then repeat the experiment with the hard to push load.
3. What is your **finding** from these two experiments?

Experimental task

1. How slowly can you make the cylinder move without stopping?
2. What do you observe when the exhaust is throttled to an extreme degree?

Solution sheet

Generating compressed air and measuring pressure

Example solution for topic task

Topic task 1: The compressor can build up approx. 0.8 - 1.0 bar pressure. If the pressure is significantly less, there is probably a leak. Check:

- Are all hoses inserted correctly?
- Is the T-connector firmly mounted on the manometer connection?
- is the T-connector firmly closed with a P plug?
- Are there any valves or cylinders that are leaking?
- Is another compressor working?

The troubleshooting process is easier if you exclude parts of the structure from the pressure by simply clamping off the hose in question.

Topic task 4: The cylinder must be able to extend and retract much more frequently per time unit than with the manual pump.

You should observe that the pressure measured by the manometer always falls briefly when a cylinder movement is completed, because if the pressure is high enough the air flows into the cylinder faster than the compressor can deliver it. Once the cylinder has reached its end position, normal pressure is built up once again.

Evaluating the experimental task

Experimental tasks 1 and 2: Production-related variations in the leak-tightness of the pneumatic components could cause the results here to differ. Typically, the pressure will hold the longest with the valve closed (centre position), will not hold as long as the cylinder extends, and will hold for the shortest time when the cylinder retracts due to the additional leakage at the piston outlet. Different cylinders can have different levels of leak-tightness.

Solution sheet

Moving a cylinder slowly

Example solution for topic task

Topic task 1: The intake air throttle causes the cylinder to move jerkily and in small steps. This is because the air pressure must first overcome the static friction of the cylinder piston. Once this occurs, the cylinder piston will move. At the same time, however, it increases the available volume. If the quantity of air remains the same, the pressure will be reduced – until the cylinder applies less force than the force of the sliding friction. This will cause it to stop again. This cycle will repeat until the cylinder reaches one of its stops (ends). This effect is even worse when greater forces are applied. **Therefore, intake air throttling is usually not useful.**

Topic task 2: When the exhaust is throttled, the vented half of the cylinder remains under pressure. This causes the cylinder disc to become “tensioned’ between two volumes under pressure. This creates a much finer, less jerky movement. It is also less subject to interference by external forces, because the cylinder pistons are held in place with a relatively large amount of force. **Exhaust throttling results in a more even cylinder movement.**

Topic task 3: The finding is: **The exhaust throttle is the right throttle!**

Evaluating the experimental task

Experimental task 1: Exhaust throttling allows the cylinder to move so slowly that it takes tens of seconds to complete an entire stroke. You could even stretch it out to a minute or more with careful adjustments.

Experimental task 2: If the throttle is so strong as to allow almost no air through, the effect is visible, since it takes a while for enough exhaust to escape and cause the counter-pressure to be reduced to such an extent that the cylinder can overcome its static friction. The cylinder remains stopped for a moment when the valve is switched, before it begins to move.

Solution sheet

Generating compressed air and measuring pressure

Example solution for topic task

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Solution sheet

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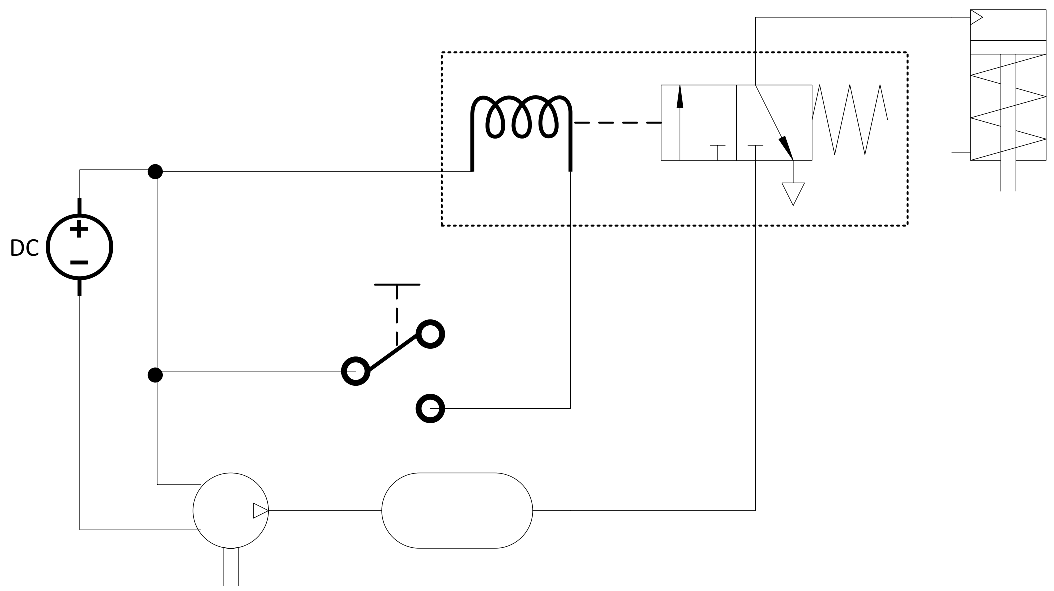
Tasks

Electro-pneumatic barriers with single-acting cylinder

Construction task

Build the barrier according to the building instructions. Use the “single-acting” cylinder (with red piston and installed return spring) as the cylinder. Observe the following points while building:

- The barrier must function easily and run smoothly. Do not install the two axle bearings that bear the rotational axis of the barrier too tightly; instead, leave enough play for the barrier to be moved easily. The axis must sit “flush” – the three bearing modules it passes through must sit in a clean line.
- When installing the cylinder, ensure that you do not load or bend it in a lateral direction if possible. Note the direction in which the groove on the lower joint module points. Insert the cylinder onto the top axle and joint module at the same time, or insert it first into the joint module and then thread the axle through the cylinder and the top axle bearing.
- You must use the top two connections of the fischertechnik button for it to make contact when it is pressed.
- The top connection of the solenoid valve is the one for the compressed air feed; the side connection is the outlet that is connected either to the compressed air or exhaust depending on the switching position of the valve.
- The polarity of the electrical connections of the solenoid valve is not important; it will work the same in both current directions, just like the fischertechnik compressor.



The power supply (at the left of the circuit diagram) is shown here as well, since it is required to connect the button and solenoid valve.

The solenoid valve (shown in the dotted frame in the circuit diagram) is a 3/2 way valve: 3 ways (intake air, outlet and exhaust) with two switching positions. However, it is activated by an electromagnet. Once the magnet receives current, the valve “switches on” and switches to allow passage between the intake and outlet. If it is not receiving current, it blocks the intake air and instead connects the outlet with the exhaust (this automatic reset is symbolised by the spring in the circuit diagram). With our solenoid valve, the exhaust does not have a separate connection; of course, there is an exhaust outlet, since it would not work without one.

The single-acting cylinder requires only one compressed air inlet to work. It can be extended with compressed air, but will automatically return to the initial position when bled through the installed return springs (only with the force of the springs, however). You can use it anywhere large forces are needed only in the extension direction, and it requires only one compressed air inlet to control.

This is advantageous when using the solenoid valve, since it is just a single 3/2 way valve. To control a double-acting cylinder with these solenoid valves, you would need two – one per cylinder outlet.

Topic task

1. Test the model thoroughly. What works well? What don’t you like?
2. Describe why the cylinder in this model must be attached on a swivel on both ends.

Experimental task

1. Install a throttle in the hose between the solenoid valve and the cylinder. What can you adjust with it?
2. Install the throttle instead in the hose between the tank and solenoid valve. What can you adjust with it now?
3. Close off the second outlet of the cylinder (on the side with the spring) with a P plug. What changes?
4. Instead of the two top connections, use the two bottom connections of the button. What changes?

Barrier with single-acting cylinder - Single acting cylinder, solenoid valve

Stefan Falk

The model of the barrier in this task sheet is also used in later task sheets as well. It is a good idea to leave it built if possible.

Topic

We will be using pneumatics in a real model – a self-built barrier. As we do so, we will learn about “single-acting” cylinders and electromagnetic valves. In further tasks, we will be modifying the barrier. It is a good idea to leave it built if possible.

Learning objective

- Understanding the action and applications of a single-acting cylinder
- Connecting electrical and pneumatic components using buttons and solenoid valves

Time required

45 min, depending on how fast the builder wants to build and how much time they spend experimenting.

Solution sheet

Single acting cylinder, solenoid valve

Example solution for topic task

Topic task 1: The barriers open and close reliably if everything is installed correctly and can move easily. When the button is not pressed, it is closed; pressing the button opens it. When you release the button, the barrier closes once again.

However, the barrier's movements are unnaturally fast and jerky, which is not desirable.

Topic task 2: The centre point of the joint on the bottom end of the cylinder describes a circular movement around the rotational axis of the barrier when the barrier moves. The cylinder piston, therefore, is not moved only in the lateral direction of the cylinder, but rather also transverse to it. The joints at both ends are required so that it does not become bent and so that the model works (the joint module on the bottom, the cylinder connection to an axle on the top).

Evaluating the experimental task

Experimental task 1: This allows us to throttle both the intake air and exhaust air of the cylinder. The barrier moves more slowly. The throttle effect can be different in the two directions of movement, because it is reset only with the force of the spring.

Experimental task 2: Now the throttle is only effective when the cylinder is connected to the (throttled) intake air. The exhaust, in contrast, can flow freely out of the cylinder and through the valve to the outside. Only the downward movement of the barrier is slower; it still closes at the same speed as the variant without a throttle.

Experimental task 3: The plug has no or almost no effect. Finding: The piston outlet of the single action cylinder is clearly not totally sealed.

This makes the cylinder move more easily, ensuring that the force of the return spring is sufficient to return the cylinder. However, no exhaust damping is possible on this cylinder connection. The front hose connection of the single acting cylinder is not useful, but only required for production.

Experimental task 4: This allows us to reverse the signal of the button – or “invert” it. The solenoid valve now receives current when the button is *not* pressed. In this case, therefore, the barrier is normally open, and closes (via the return spring) only if and for as long as the button is pressed.

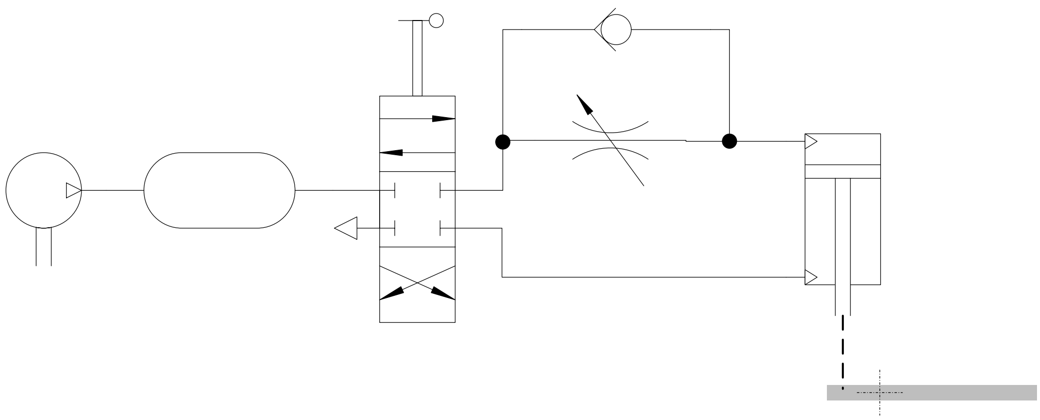
Tasks

Throttling a double-acting cylinder in only one direction

Construction task

Use the basic model of the barrier you built in the previous task, or build it according to the building instructions. This time, however, use a double-acting cylinder (with blue piston, without return spring) and the manual valve instead of the solenoid valve. We have to activate both sides of the cylinder, and a single solenoid valve would only work for one.

In this task, we want to cause the barrier to close slowly (so that no one standing under it is hit), but open quickly. As we previously learned, throttling the exhaust is the right approach. Connect the hoses as follows:



We are using one throttle in the hose between the valve and the top end of the barrier cylinder. When the barrier closes, the cylinder retracts, and the exhaust on its upper connection in the barrier model must be throttled.

The problem is that the intake air needs to be able to flow unthrottled into the cylinder so that the barrier can lift quickly. We can solve this using a check valve, like the one we learned about with the manual pump. It allows compressed air through in one direction (unthrottled) and blocks the path to the other direction completely – just like a diode allows electrical current in only one direction.

We connect the check valve in parallel to the throttle. Once again, please note that the small triangle on the circuit diagram should not be misunderstood as an arrow indicating the flow direction. The opposite is actually true: In the circuit diagram, the air can flow from the valve to the cylinder through the check valve, but the flow in the opposite direction – when the exhaust flows out of the cylinder as it is retracted – is blocked. The exhaust must move through the throttle slowly, therefore, while the intake air reaches the cylinder quickly.

Topic task

1. Experiment with the model. Set different throttle strengths, and observe how only the downward movement of the barrier is slowed, not the opening movement of the barrier.
2. What happens if you install the check valve in the other direction (but still parallel to the throttle)?

Experimental task

1. What would you need to add if you wanted to use a second throttle and second check valve to throttle opening of the barrier, but independent of the throttling strength for the closing movement?
2. If we do not have any check valves, but do have two throttles, we can also connect the second throttle to the exhaust outlet of the manual valve as we learned previously (alternatively, we can simulate this by putting a kink in the hose). Add information to the circuit diagram and describe how the two throttles are working now.

Barrier with double-acting cylinder - throttling a double-acting cylinder in only one direction

Stefan Falk

The "Barrier" model built for the previous task is also used for this task.

Topic

We will be showing how you can throttle the movement of a double-acting cylinder in just one direction, or throttle it at different strengths in both directions.

Learning objective

- By connecting a throttle and check valve in parallel, the throttle can be relevant in only one direction; it can simply be bypassed in the other direction by the check valve.
- This allows the compressed air to be throttled in just one direction of flow, while it practically flows freely in the other.
- In this way, we can throttle the exhaust on one side of the cylinder, while allowing intake air into the cylinder without throttling. This creates directionally-dependent throttling.

Time required

45 min, if the barrier from the previous task is still built.

Solution sheet

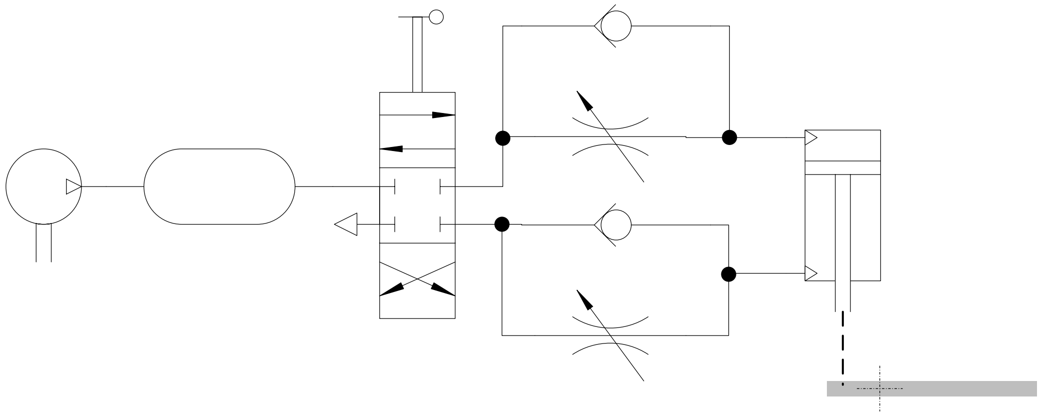
Barrier with double-acting cylinder - throttling a double-acting cylinder in only one direction

Example solution for topic task

Topic task 2: This would throttle the intake air when the barrier is opened, but would not throttle the exhaust. The effect would be that the barrier would open slowly but in a jerky manner (because the intake air was throttled, but not the exhaust). However, it would close quickly. As we have previously learned, exhaust throttling is the best option.

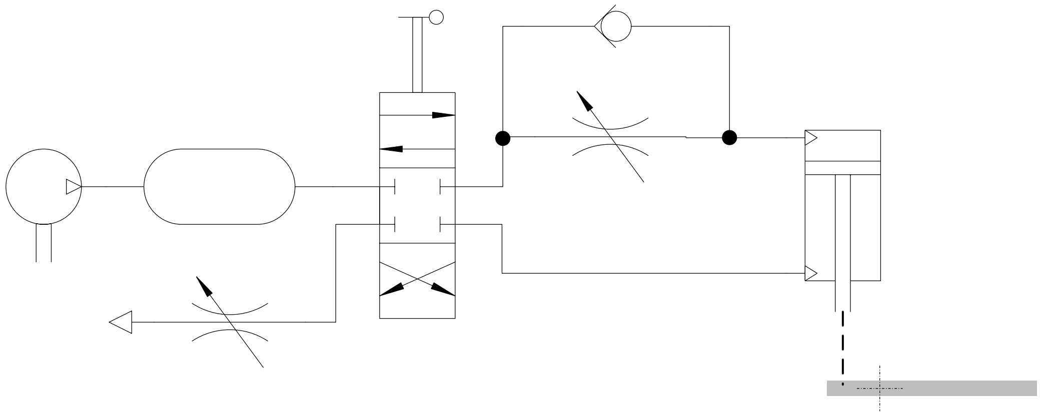
Evaluating the experimental task

Experimental task 1: You would also need to install a parallel connection of throttle and check valve on the other cylinder connection as follows:

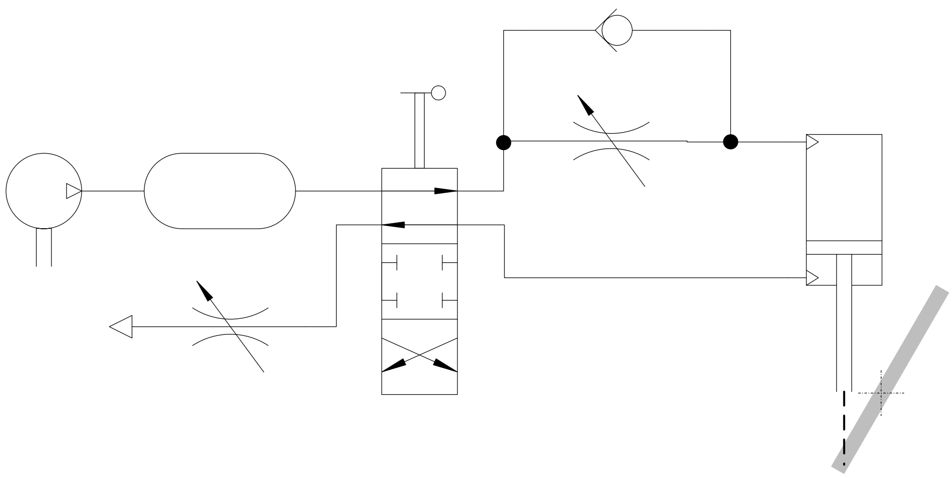


Both of the check valves must be installed so that they throttle the exhaust, but not the intake air.

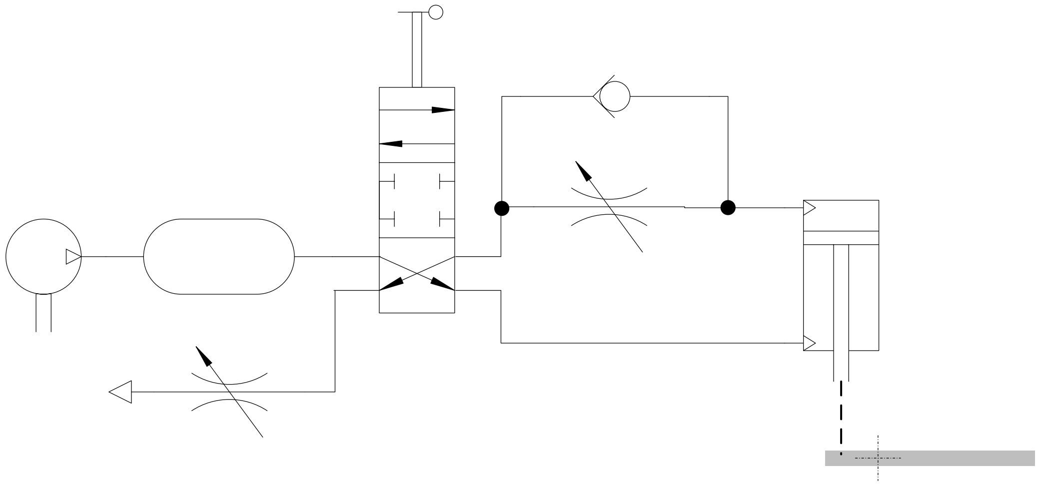
Experimental task 2: The second throttle would be installed as follows:



When the barrier is opened, and the cylinder extended downward, the intake air on the cylinder would not be throttled due to the check valve, but the exhaust would very likely be throttled at the bottom connection – see the following valve position:



When the barrier is closed, both throttles act in a series:



However, the stronger throttle is the only one that is primarily active. With this circuit, you can throttle closing of the barrier more than opening, but not vice versa. If you want to do the opposite, the throttle/check valve combination would have to be connected to the other cylinder connection.

Barrier with double-acting cylinder - throttling a double-acting cylinder in only one direction

Stefan Falk

The "Barrier" model built for the previous task is also used for this task.

Topic

We will be showing how you can throttle the movement of a double-acting cylinder in just one direction, or throttle it at different strengths in both directions.

Learning objective

- By connecting a throttle and check valve in parallel, the throttle can be relevant in only one direction; it can simply be bypassed in the other direction by the check valve.
- This allows the compressed air to be throttled in just one direction of flow, while it practically flows freely in the other.
- In this way, we can throttle the exhaust on one side of the cylinder, while allowing intake air into the cylinder without throttling. This creates directionally-dependent throttling.

Time required

45 min, if the barrier from the previous task is still built.

Vacuum gripper - Generating and working with vacuum pressure

Stefan Falk

If you do not have much time, the pneumatic manual valve can simply be used in this model instead of the button and solenoid valve.

Topic

We will be generating air pressure that will be *less* than the ambient air and using it in a suction gripper.

Learning objective

- A mechanically activated cylinder like the one in the self-built manual pump can generate not only overpressure, but also vacuum pressure on the other connection.
- This can be used with a suitably flexible suction cup to hold, lift and move light parts with a smooth surface.

This technology is used in industrial applications, for instance to package small parts. Parts are picked up by a suction gripper, for instance from a magazine or conveyor belt, and placed in a package. This can be carried out at a fast cycle time, so that many parts are handled per time unit.

Time required

45 min. for construction and topic tasks. Another 45 minutes, depending on the desired construction or more for the optional construction experiments.

Solution sheet

Generating and working with vacuum pressure

Example solution for topic task

Topic task 1: Several seconds should be possible if the part that is lifted is not too heavy and does not have a rough surface.

Topic task 2: It should be possible to grip at least the enclosed wooden discs, and possibly also a fischertechnik component with a smooth surface.

Evaluating the experimental task

There are a very large number of ways to initiate movement of the suction cup. Student creativity may result in a range of functional solutions.

Tasks

Electro-pneumatic compressed air motor

Construction task

Build the compressed air motor model using the building instructions. Note:

- Just as with the barrier model, the cylinder in this model must have a flexible connection on both ends. The small axle fulfils this function on the top. On the bottom, the jointed module is important. Do not mount the cylinder fixed onto the panel without a joint.
- To function correctly, the swivelling parts must be stiffly constructed. Do not forget the strut on the cantilever, and route the vertical connecting rods out of two connected fischertechnik struts.
- The axis of the moving parts must be connected so that it is easy to move. For this purpose, the three axle bearings (the red modules 15 with drill hole) must be arranged “flush” - in a line and not offset to one another. To ensure this, it helps to have the grooves on the bottom building block in the axle direction, because the axle bearing module is then guaranteed to sit precisely transverse to the axle.
- The position of the switching disc and button are important elements to adjust. The button must be reliably activated during turning by the switching disc, and the disc must be attached correctly in the direction of rotation to cause the cylinder to be filled with compressed air or vented at the right moment.

Topic task

1. Experiment with different rotational angles in which the switching disc can sit. Find the position in which the motor runs the best.
2. Count how many revolutions the motor completes per minute as it idles.
3. Why is the flywheel required?
4. Brake the motor by the snap-on coupling on the end of the drive axle using your fingers, so that the motor just barely still functions. How many revolutions per minute does it complete now?

Electro-pneumatic compressed air motor

Stefan Falk

Topic

We will be constructing a compressed air motor that works similar to a steam engine.

Learning objective

- In the compressed air model functional model, combining multiple disciplines delivers success: Pneumatics, electrical systems, and mechanics/kinematics.
- It will only be possible to find the right solution by combining all of these fields correctly.

Time required

45 min.

Solution sheet

Electro-pneumatic compressed air motor

Example solution for topic task

Topic task 3: Without the flywheel, the motor is not able to move past the “dead points” of the cam movement. These are the points where the crank is at the very top or very bottom. In these positions, the cylinder and mechanism cannot output any torque, because the force required to do so would have to be transverse to the connecting rod. The flywheel ensures that the motor can overcome these dead points until force and torque can be transmitted once again. The flywheel therefore acts as a “mechanical energy storage” that absorbs kinetic energy (rotational energy) when the motor starts up and feeds it back in at the “dead point”. The weight on the outermost edge of the flywheel is primarily important: The greater the weight, the greater the “storage capacity” of the energy storage.

Tasks

Pneumatic platform lift

Construction task

Build the scissors lift table model according to the building instructions. Ensure that the entire mechanism is stable, yet moves easily. All axles should be cleanly “flush” with one another, and nothing should be tilted.

First use just a single pneumatic cylinder. We will add a second cylinder in different ways in the experiments.

Topic task

1. What is the heaviest weight the platform lift can still lift with just one cylinder? For the sake of simplicity, use different objects that you have on hand and place them on the platform lift.
2. How great is the “stroke”, or the difference in height between the highest and lowest position? Use a ruler or tape measure to measure this.
3. To increase the force, install two cylinders beside one another so that they are exercising force in parallel.
   a) By what factor did the force with which the platform lift is driven increase?
   b) What is the heaviest weight that can be lifted now?
   c) How does this change in the design impact the length of the stroke?
4. To increase the path of travel and thereby the stroke, install two cylinders in sequence.
   a) How does this affect the available force?
   b) How long is the stroke now?
   c) Why is the stroke not twice as long as with one cylinder?
5. Why can exhaust throttling be important with this kind of platform lift?

Experimental task

Use your hand to shift the horizontal slide element in defined steps (for instance by 5 mm each time) and measure the stroke which can be achieved (with the zero point in the bottom position of the platform lift). Use this information to create a diagram with the path of travel on the x axis and the stroke on the y axis.

Scissors lift - Pneumatic platform lift

Stefan Falk

This model is relatively difficult to construct. Plan enough time, depending on how much experience you have with fischertechnik models. In addition, you will need suitable objects to act as weights, as well as a ruler or tape measure to complete all of the tasks.

Topic

We will be building a platform lift – a so-called “scissors lift” – and operating it pneumatically. Two additional developments require little conversion work, and can deliver either more lifting force or a greater stroke length.

Learning objectives

- The mechanism of the scissors lift and the care required to construct it precisely,
- The increase in force that can be generated by pairing two pneumatic cylinders in parallel,
- The increase in path that can be generated by connecting two pneumatic cylinders in a series,
- An understanding of the mechanical correlations with unequal gear transmission.

Time required

90 min.

Solution sheet

Pneumatic platform lift

Example solution for topic task

Topic task 3. a): The forces of the two cylinders are added together; the total force is exactly double that for one cylinder. The pressure is defined as force per area:

$$p = \frac{F}{A}$$

F is the force and A is the effective area of the cylinder disc. The force, therefore, is the product of pressure and area:

$$F = p \cdot A$$

If we double the area by connecting the second cylinder in parallel while keeping the same pressure, then the force will double as well:

$$p \cdot 2A = 2 \cdot F$$

a) The stroke remains unchanged, since the distance travelled by the cylinder is the same as with one cylinder.

Topic task 4. a): The force is now unchanged, since the effective area of the cylinder has not changed. The arrangement has the same effect as using a longer cylinder.

b) The path of travel is twice as long. The stroke is greater, but less than double.

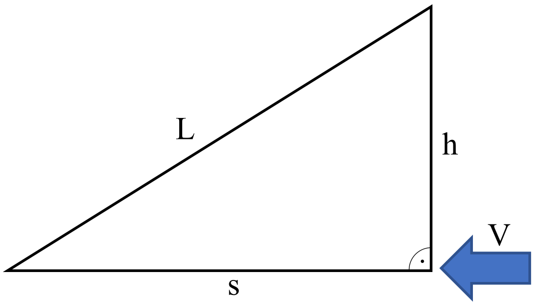
c) In the lower position of the platform lift, a short travel distance causes a large change in the stroke. In the upper position, however, the same travel distance causes only a small change in stroke (but a greater stroke force).

Topic task 5: The platform lift as we have built it stops moving abruptly when the cylinder reaches its stop. If materials or people were on the platform lift, they could slip or fall down (therefore, railings would be a good idea on the lifting surface). The throttling results in a lower speed while maintaining the same force the platform lift can apply.

Another development would be *end position damping*. This is damping that goes into effect shortly before the cylinder reaches the stop. This allows high speeds to be combined with a softer end to the movement. See the references to further information [2].

Evaluating the experimental task

The correlation between path of travel and stroke can be calculated as follows:



L is the length of the bar, the lower end of which is away from the cylinder. s is the length of the projection of L on the plane. h is the stroke (here measured from the plane). L, s and h form a right-angled triangle.

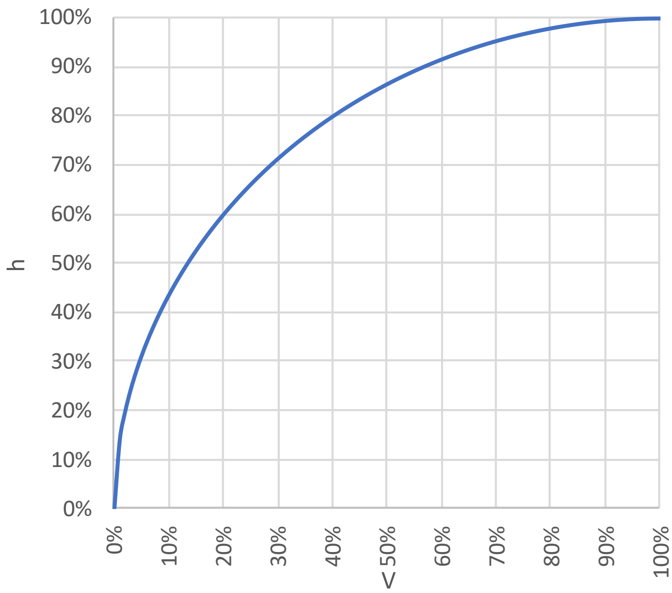
V is the path of travel of the cylinder, starting from the zero point position (which is not actually reachable due to mechanical restrictions) where the bar is flat against the plane. Therefore, the equation is:

$$s = L - V$$

$$L^2 = s^2 + h^2$$

$$h = \sqrt{L^2 - s^2} = \sqrt{L^2 - (L - V)^2} = \sqrt{L^2 - (L^2 - 2LV + V^2)} = \sqrt{2LV - V^2}$$

This results in the following curve:



Tasks

Vacuum pressure stacking game

Construction task

Build the project model according to the building instructions. Ensure that the entire mechanism is stable, yet moves easily. Observe, in particular, the following design details:

1. The pneumatic cylinder used for turning is connected on both (!) ends with flexible connections. If it had a rigid connection on one end, it would become tilted. The piston rods would be subject to strong bending forces, and could bend or break. The seals of the cylinder could become damaged. The machine would not work. Note: *Pneumatic cylinders should only be exposed to tension and compression, and never to "shearing" - a force lateral to their path of travel.*
2. It is a good idea to route the hoses to the lifting cylinder through the *centre* of the slewing ring. They will become somewhat twisted, but if they are routed "from the outside," much more hose and space would have to be reserved so that the hoses could follow the movement. However: Without specialised elements you cannot push the part to be turned as far as you want in one direction. Of course, the rotational movement in this machine only extends to a moderate angle, so there is no problem.
3. The lifting cylinder may not be "tensioned" too closely between the two side carrier elements in order for it to work smoothly. This can be adjusted easily by finely shifting the carriers in the groove of the hub.

Topic task

1. First, let the system simply swing between the two end positions of the pneumatic cylinder.
   a) How would you handle the task of precisely moving a machine part to two end positions using an electric motor drive?
   b) If you used a pneumatic cylinder for the drive, in contrast, what could you eliminate? What is the advantage of the pneumatic controller?
2. Now, look at the centre position as well, when the gripper is above the centre shelf.
   a) What is the problem here with using a pneumatic cylinder?
   b) What design feature (which we learned about in previous tasks) could you use to precisely reach the centre position?

Experimental task

1. Try to reach the centre position as precisely as possible.
   a) What can you adjust to make this easier?
   b) What do you have to give up to make this improvement?
2. Play the "Tower of Hanoi" with the machine. There are two discs on the centre shelf, one on top of the other. A smaller disc is always on top of the next larger disc (with the smallest at the top and the largest at the bottom). The task is to move the entire stack of discs to the third shelf just by moving one disc after the other, and do so in such a way that a larger disc is never on top of a smaller one

at any time during the operation. The centre shelf can be used for intermediate placement. There are not three different sizes of discs in the components available, but there are three “workpieces” of different colours. They have a flat surface – unlike coins, for instance – and are therefore suitable for our vacuum gripper. Define a “correct” order, for instance, so that a darker workpiece is never placed on top of a lighter one, or simply label the workpieces “1”, “2” and “3”.

a) In what order do the workpieces have to be transported, from where and to where, to solve the task?
b) Could you do this with a stack of 4, or 5, or ... workpieces, sorted by size?

Project model - Vacuum pressure stacking game

Stefan Falk

This model is relatively difficult to construct. Plan enough time, depending on how much experience you have with fischertechnik models.

Topic

This model illustrates pneumatic systems using a somewhat more complex model – a pneumatic positioning unit that can also be used as a game.

Learning objective

- Construction techniques from mechanical engineering
- Translating linear movement into rotational movement
- Suitable feed of compressed air to a rotating machine part

Time required

This model has a more complex construction, and will require multiple units, for instance of 45 min.

technika

Solution sheet

Vacuum pressure stacking game

Example solution for construction task

An example design to solve the task is shown here. This solution should use as few components as possible, and only fischertechnik components. Please add photos. Then a Designer file will be created for the suggested solution and attached (concluded by the coordinator if necessary), and a component list will be generated (attached).

Example solution for topic task

Topic task 1:

a) End position switch-off devices need to be built into electric drives (for instance by adding one button on each end position).
b) The end position switch-off devices are not required for pneumatic cylinders; they are essentially “built in”: The cylinder has natural stops on both ends, after all. There is no need for the additional wiring or for adding end position buttons. The advantage is a simpler design and the use of less materials (if the compressor is already installed).

Topic task 2:

a) A pneumatic cylinder can only approximately approach a centre position without further measures.
b) One option would be *multi-position cylinders*, which we learned about in the “Scissors lift table” model. You could install two pneumatic cylinders in sequence, so as to reach a centre position precisely and reproducibly when only one of them is extended.

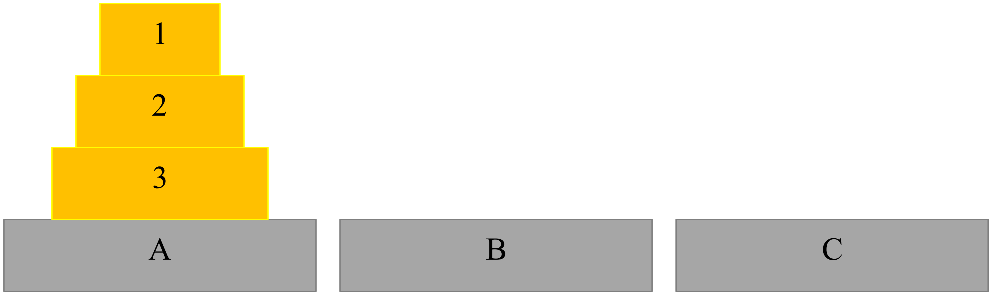
Evaluating the experimental task

Experimental task 1:

a) You can throttle the exhaust of the cylinder more for the rotational movement. This would cause it to move more slowly, and you can reach the desired position more precisely.
b) The disadvantage is that the movement would go more slowly. This can cause a lower throughput (such as “processed parts per time”) in production machines.

Experimental task 2:

a) Let’s name the shelves A, B and C, and the workpieces 1, 2, and 3 sorted by brightness (you can also label the workpieces with a number for the sake of simplicity). The initial positions are as follows:



Then the discs must be placed as follows: 1 → C, 2 → B, 1 → B, 3 → C, 1 → A, 2 → C, 1 → C.

b) Actually, you could do this for *as many* discs as you want with just three shelves! The solution algorithm can then be described as follows:
   1. Move the entire stack of discs down to the bottom one to the intermediate shelf.
   2. Move the exposed "largest" disc to the target.
   3. Move the entire stack of discs from the intermediate shelf to the target (on top of the disc that is there).

   As long as the "entire stack of discs" includes more than one disc, use exactly the same method ("recursive") on it and use the shelf you cleared in the last step as the intermediate shelf.

   For any number *n* of discs on the stack, you need a total of

$$2^n - 1$$

   steps to completely solve the task. For three discs, therefore, we need

$$2^3 - 1 = 8 - 1 = 7$$

   seven steps.