LEGO® Inchworm

By Kevin Clague

Images by Kevin Clague

Have you ever tried to blow up a balloon? You take a big breath of air, you squeeze your lungs hard, and you force air into the balloon, making it expand. This is pneumatics – using air pressure to make things change shape. Pneumatics is the science of controlling pressurized gas or air.

LEGO® uses pneumatics to represent hydraulics in construction machinery like cranes and backhoes. Hydraulics uses fluid pressures and fluids can spill and be messy, while pneumatics uses air pressure, which is mess free. LEGO® pneumatics were first introduced in 1984 and has gone through several versions, the latest of which was introduced in the Mercedes Arocs set, made available in 2016.

So, what pneumatic components does LEGO® make? First let's start with pumps[1] (shown in **Figure 1**). When left alone, a pump is in the shape of the leftmost pump. When you squeeze the pump, pressurized air comes out the port near the bottom of the pump. This is similar to you blowing air into the balloon. When you relax your hand and release the pump, the spring expands the pump, and you are letting the pump breathe in air for the next round of squeezing.

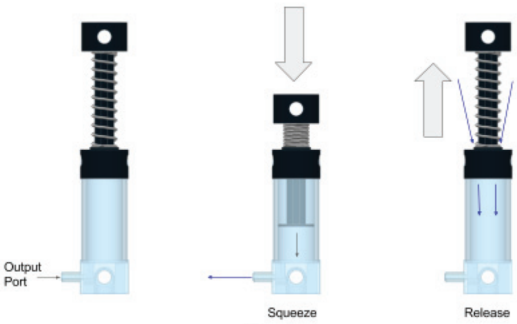

Figure 1- Pumps

In **Figure 2** we see pneumatic linear actuators. LEGO® fans usually call these cylinders or pistons, but in fact the linear actuators are made of a cylinder (the outside) and a piston (the inside), but for practical reasons I will use 'piston' to mean linear actuator for the rest of this article. There is a shaft attached to the piston that comes out the end of the cylinder. The piston is inside the cylinder, and breaks the inside of the cylinder into two separate parts (think of them kind of like two balloons). In Figure 2 the piston starts in the contracted state (on the left). The port at the bottom of the cylinders is the expand port, because when you push air into that port it pushes on the piston and makes the piston move away from the expand port, causing the actuator to expand (i.e. get longer, as seen in the middle picture). The port at the top of the cylinders is the contract port, because when you push air into that port it pushes on the piston and makes the piston move away from the contract port causing the actuator to contract (i.e. get shorter, as seen in the right picture).

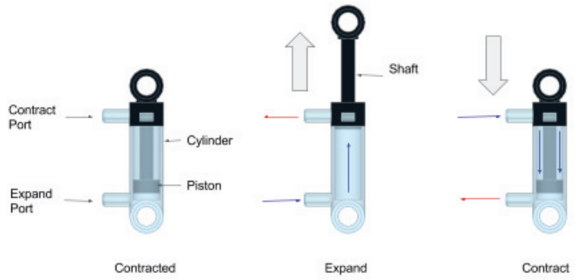

Figure 2 - Actuators

In **Figure 2 and 3** I use blue arrows to show air flowing into the pistons, and red arrows to show air flowing out of the pistons.

Another important pneumatic component is a switch (also called a valve) shown in **Figure 3**. At the top, the switch has a handle. When the handle is turned to the left, air coming into the center port goes out the right port of the switch as indicated by the blue arrows. Also, any air coming into the left port comes out of the case around the handle as shown by the red arrows. This gives the air coming out of a piston a way to escape. When the handle of the switch is straight up, the air going into the center port goes nowhere. Also any air going into the left and right ports goes nowhere. The switch is off. When the switch handle is flipped to the right, air going into the center port goes out the left port as indicated by the blue arrows. Any air going into the right port comes out of the case around the handle as shown by the red arrows.

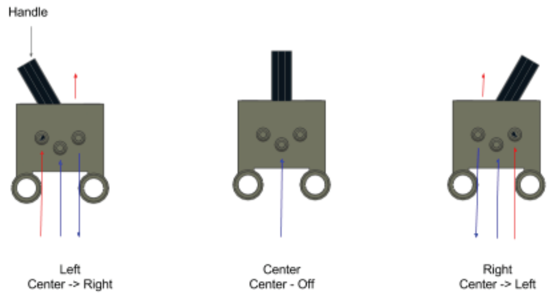

Figure 3 - Switches

Figure 4 shows the classic LEGO® pneumatic circuit showing the most basic pneumatic components. It contains a pump for making air pressure, a switch for controlling the airflow, a piston for making parts of a LEGO® model move, and hoses to hook all the pneumatic parts together. In this circuit, you pump the pump, you flip the switch back and forth, and the piston expands and contracts.

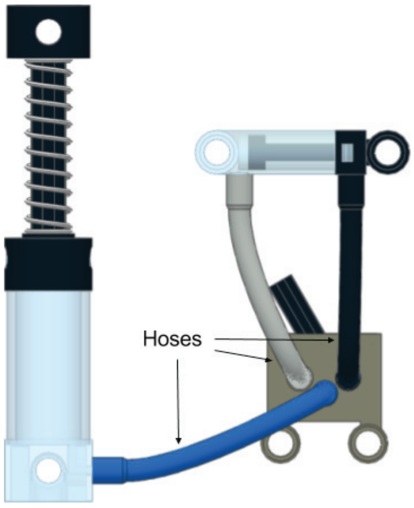

Figure 4 - Classic pneumatic circuit

If you go back in Technic history there have been a number of styles of LEGO® pneumatic parts. Today LEGO® makes two sized pumps – the large one we've seen already, and a small one (without a spring) which is meant to be pumped by motors to make air compressors. Currently there are four piston sizes. There is the small one we've already seen, and a large one about the size of the larger type of pump. When LEGO® launched the Mercedes Arocs set (42043), it also introduced longer versions of the small diameter and large diameter pistons.

This classic LEGO® circuit is not the end of the story. If you take things one step further and make pistons flip the switches, instead of humans flipping them, you open up a whole new world of pneumatic possibilities. This youtube video by 1nxtmonster[2] shows a two piston, two switch pneumatic engine. The front piston flips a switch that makes the back piston change shape to match the front piston. The back piston flips a switch that makes the front piston change to the opposite shape. Add air pressure and the engine goes through this repeating pattern of expand, expand, contract, contract.

Now we're going to take the time to learn a little science. Pascal's Law, named after Blaise Pascal, describes how much force a piston can produce. Here is the relevant formula:

Force = Pressure x Area

So when a piston tries to expand, the force available is the area of the piston face closest to the expand port times the pressure of the air pushing on that piston face. When a piston tries to contract, the force available is the area of the piston face closest to the contract port times the pressure of the air pushing on that piston face.

At a given pressure, the larger the area the larger the force, and the smaller the area, the smaller the force.

Notice that the expand face of LEGO® pistons have a larger area than the contract face because of the shaft that goes into the center of the contract face. This means LEGO® pistons have more force to expand than to contract. So, if you start with a contracted piston, and you apply the same pressure to both ports of the piston at the same time, the piston will slowly expand.

This is important because the small piston, shown in the figures so far, does not have enough force to flip a switch like the large pistons shown in the engine video. Next, we're going to see an engine-like model, but without the crankshaft. The model will need two small pistons working together to flip a switch. I like making models using the small pistons because they expand and contract much faster than the larger pistons used to make the engine. This makes the model more interesting to watch.

We need a mechanical linkage that connects two small pistons to a switch so that when the pistons are expanded the switch is flipped left, and when the pistons are contracted the switch is flipped to the right. This linkage is shown in **Figure 5**. Given there are two pistons per linkage, we need to hook the two expand ports together using hoses and a pneumatic-T. A 'T' has 3 ports – we push air into one port and it comes out through the other two. Now both pistons will try to expand at the same time. The contract ports are also hooked together in the same way.

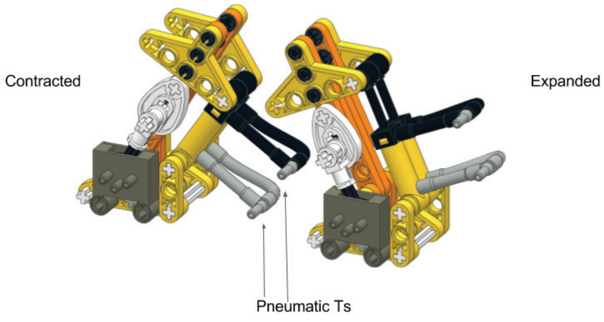

Figure 5 - Piston/switch linkage

Figure 6 shows an engine-like circuit using our small piston/switch linkage. The left linkage's switch outputs make the right piston change to match the left piston's shape. The right linkage's switch outputs make the left piston change to the opposite of the right piston's shape.

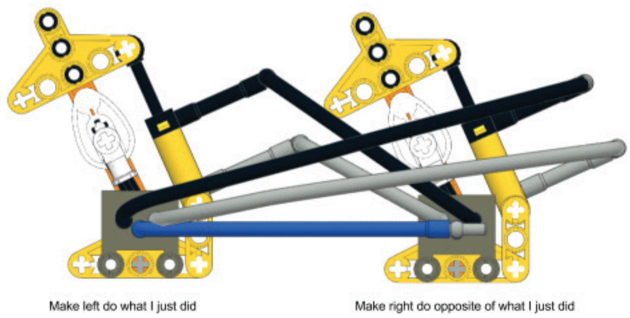

Figure 6 - Timing circuit

Figure 7 shows the four states of the Figure 6 circuit.

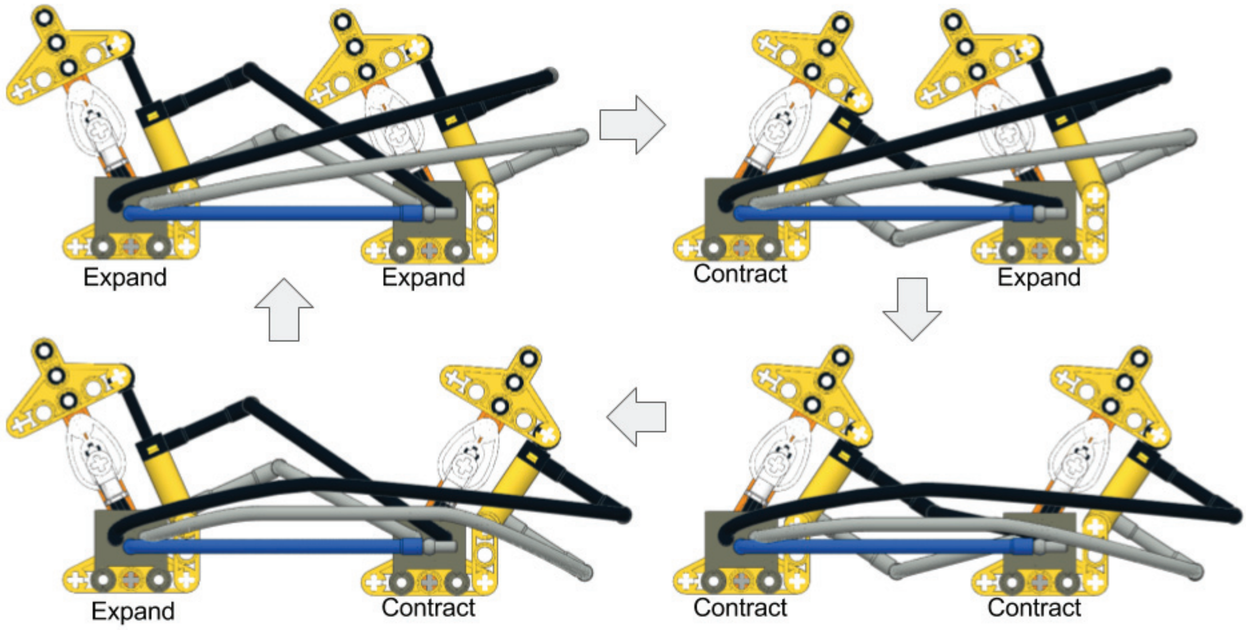

Figure 7 - Four states of engine

If we mechanically hook these two linkages together, we can make what I call an inchworm, as seen in **Figure 8**. The base of the front linkage becomes the top of the back linkage. Also, I added 1x2 rubber links as feet. The inchworm crawls forwards as the linkages go through the four stages shown in Figure 7.

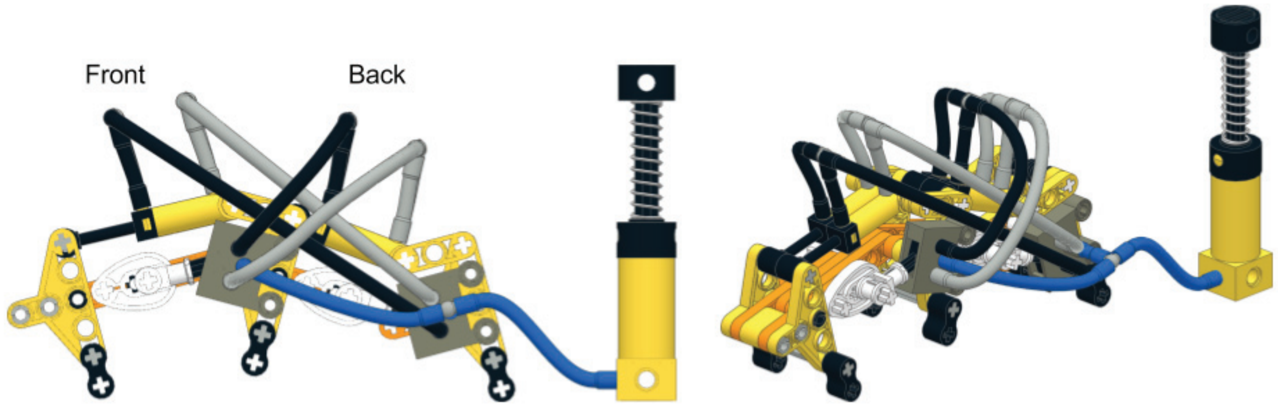

Figure 8 - inchworm

This is my 12th version of an inchworm-like LEGO® pneumatic creature, and it has taken me nearly ten years to figure out how to make one so simple and small. I learned some things about physics along the way. So far, I cannot figure out how to make it any smaller. I could probably take a few parts away, but that would not make the walking mechanism or the pneumatic circuit any simpler.

If you own some LEGO® pneumatic pieces but don't have the small pistons, try making your own linkage mechanism and try to make your own pneumatic engine or inchworm using the pneumatic parts that you have.

There are many different kinds of walkers and crawlers that you can make based on variations of the simple pneumatic engine, including two legged walkers. Using engine designs with three piston groups, you can make four, six and eight legged walkers using techniques outlined in my Pneumatic Sequencing Tutorial in HispaBrick Magazines 13 and 14. Using more complicated circuits you can make engines run backwards or forwards just by flipping switches. There are lots of cool things you can make using LEGO® pneumatics! LEGO® Technic is such a wonderfully inventive product line!

[1] In the newest version of the pneumatics pump the spring has been encapsulated. The illustrations in this article use the previous version for practical purposes.

[2] https://www.youtube.com/watch?v=lXLnphCnKFU
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