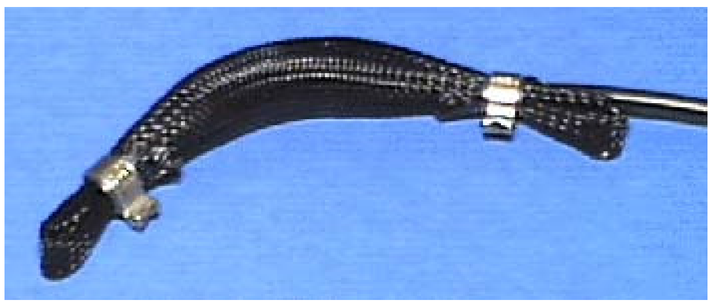
Biorobotics - Build Your Own Robotic Air Muscle Actuator

An air muscle is a simple pneumatic device developed in the 1950's by J.L. McKibben. Like biological muscles, air muscles contract when activated. Robotists find it interesting that air muscles provide a reasonable working copy of biological muscles. So much so that researchers can use a human skeleton with air muscles attached to the skeleton at primary biological muscle locations to study biomechanics and low level neural properties of biological muscles. (See Internet sources)



This feature is utilized by the research in many "Bio-Robotics" projects institute by numerous researchers. In published papers air muscles are also referred to as; McKibben Air Muscles, McKibben Pneumatic Artificial Muscle, Rubbertuator and as I refer to them simply as air muscle(s).

Applications

Air muscles have applications in robotics, biorobotics, biomechanics, artificial limb replacement and industry. The principle reasons experimenters and hobbyists will like air muscles are ease of use (as compared to standard pneumatic cylinders) and simple construction. Air muscles are soft, lightweight and compliant, have a high power to weight ratio (400:1), can be twisted axially and used on unaligned mounting and provide contractive force around bends, (see robot wars near the end of this article). Air muscles may also be used underwater.

How Air Muscles Work

TThere are two primary components to the air muscle are a soft stretchable inner rubber tube and a braided polyester mesh sleeve, see Figure 1. The rubber tube is called an internal bladder and is positioned inside the braided mesh sleeve.

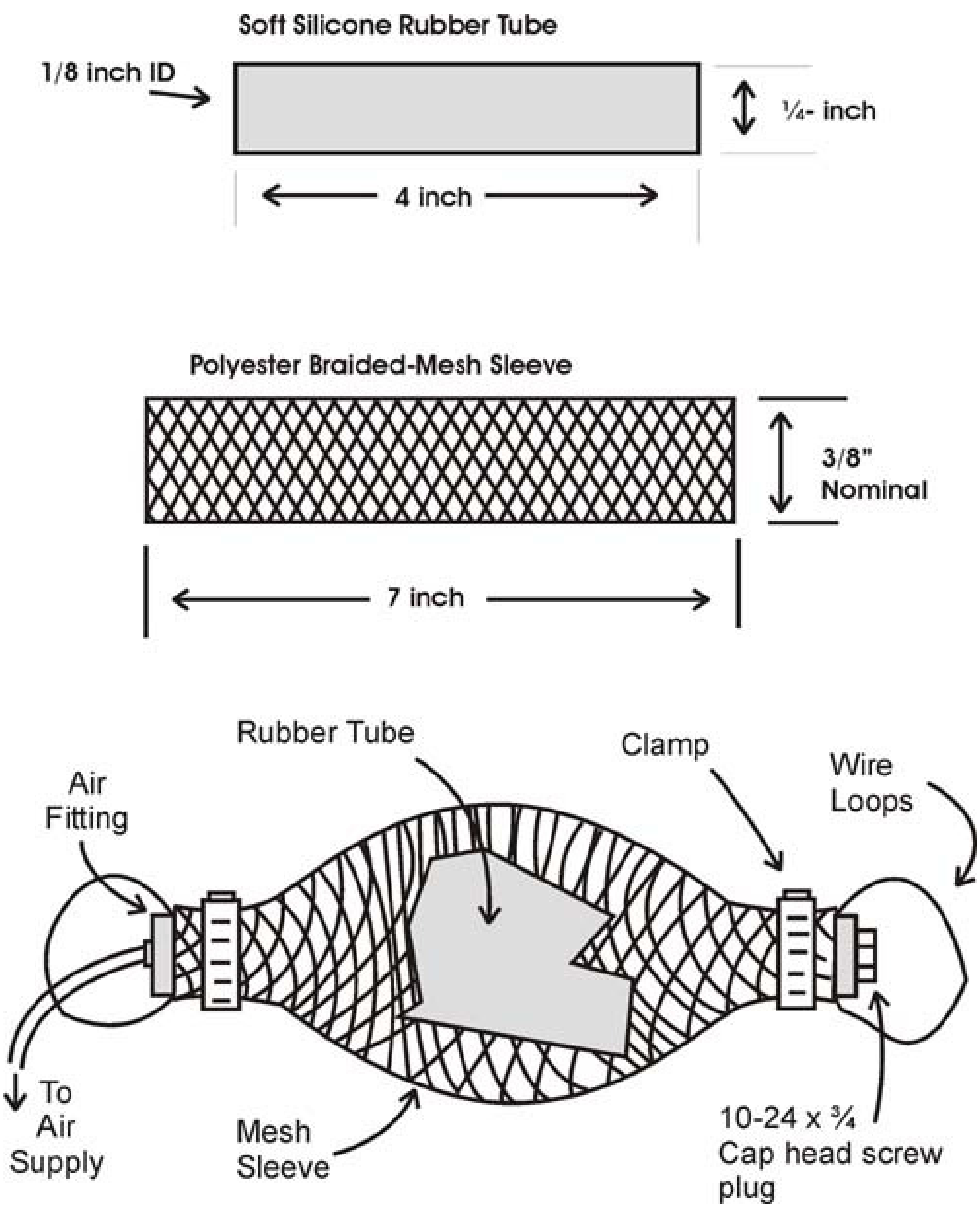


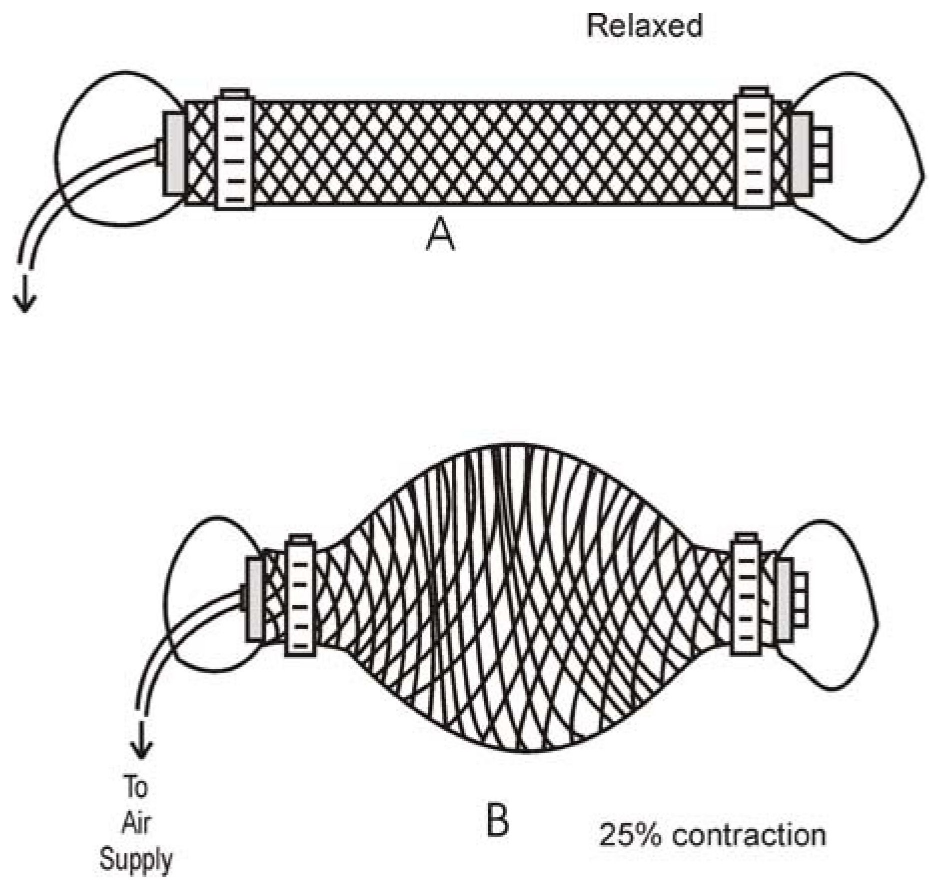
Figure 1

All that is left to complete the air muscle picture is an air fitting on one end and two mechanical fittings (loops) on each end of the air muscle that allow one to attach the air muscle to devices. The clamps in Figure 1 are made from 24-gauge wire tightly wrapped and twisted around the ends of the air muscle.

When the internal bladder is pressurized it expands and pushes against the inside of braided mesh sleeve, forcing the diameter of the braided mesh to expand. The physical characteristic of the mesh sleeve is that it contracts in proportion to the degree its diameter is forced to increase. This produces the contractive force of the air muscle.

To operate properly, it is important that the air muscle be in a stretched or loaded position when it's inactive or in a resting state. If not there will little if any contraction when activated. So the air muscle must be stretched in order for it to produce contraction when it is activated, see Figure 2. Typically the air muscle can contract to approximately 25 percent of its length.

The illustration of the contracted air muscle in figure 2 is greatly exaggerated. When the air muscle contracts, its diameter thickens equally along it's length and contracts (shortens) as described. Air muscles typically do not develop a large bulge in the center when it is contracted, however for purposes of illustration we will shown it this way.



When muscle is pressurized (B), it can contract up to about 75% of it's relaxed length

Figure 2

Air Pressure

Air muscles require a source of compressed gas (usually air). The air muscle we will build operates at approximately 50 psi. Air pressure can be generated by the easiest mean available to the experimenter including a small bicycle pump with an air pressure gauge.

An inexpensive automobile tire air pump that operates using 12 VDC. Other sources are a small air tank that can be filled up at a local gas station that has an air pump for inflating automobile tires. If you use an air tank make sure it is equipped with an adjustable air pressure regulator, this will prevent pressurizing the air muscle with too much air.

Making an Air Muscle

Air muscles are available commercially from Shadow Robotics in the U.K. in a variety of sizes. For experimental purposes its pretty easy to make your own air muscle in whatever size you require.

The inner tube is made from soft silicone tubing, approximately ¼" OD and 1/8" ID, see suppliers index. Go to a local pet shop that sells aquarium supplies. Purchase a small quantity of PVC clear tubing. (Same size as the silicone tubing, but less flexible and tougher) Pick up a few aquarium air valves and couplings too.

Many electronic distributors sell the polyester braided mesh sleeve. The braided sleeve is used as a flexible conduit for electrical wiring. Purchase a small quantity (6 feet) of 3/8" diameter.

Finish the materials purchase with a few 3/8" long 10-24 screws and a small quantity of 24 gauge galvanized wire available at a local hardware store.

Cut a 4-inch length of silicon tubing. Insert the 10-24 screw in one end of the tube. Insert an aquarium air coupling in the other end of the tube, see Figure 3.

Figure 3

Cut a 7 inch length of 3/8" braided mesh sleeve. To prevent the ends of the sleeve from fraying and coming apart we singe the ends with a match or candle flame, see Figure 4. The idea here is to just singe the ends of the polyester sleeve, its easy to go too far and melt too much of the sleeve. In that case cut another piece and start over.

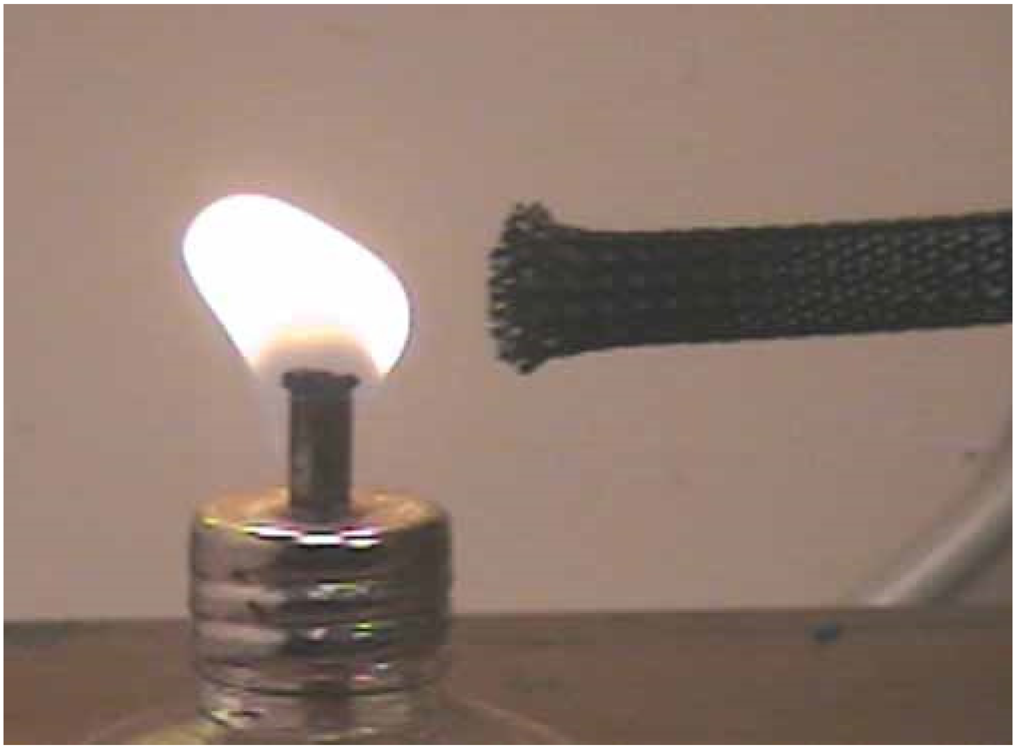


Figure 4

Insert the rubber tube inside the braided sleeve. Align one end of the sleeve with the bottom of the head on the 10-24 screw in the rubber tube. Wrap a piece of 24-gauge wire three or four times around the end, capturing the sleeve, tubing and threaded portion of the 10-24 screw. Then twist the ends of the wire together. Use a pair of pliers to make this as tight as possible. Cut of any excess wire. See Figure 5.

Figure 5

To finish the other side, push down the sleeve until it is aligned with the rubber tube on the air coupling. Wrap a piece of 24-gauge wire around this end, tighten wire with pliers then cut off any excess wire. See Figure 6. At this point you may want to pressurize the air muscle to insure the two fittings do not leak. Since the air muscle is not loaded only use a pressure of 20 psi. If any air leaks, try tightening the 24-gauge wire.

Figure 6

Cut two 14-inch lengths of the galvanized wire. These we will use to make the mechanical loops. Fold the wire in half to double. Form a 1-inch loop from the middle of the wire and twist the wire at the bottom of the loop, see figure 7. Next wire wrap the loop to the end of the air muscle as shown in figure 8. Do the same to the other side. Pull on the loops to insure that they are secure.

Figure 7

Figure 8

Testing the Air Muscle

The first test to perform is a simple static test. Wear eye protection when pressurizing the air muscle. Attach one end of the air muscle to a stationary object using the loop. At the other end hang about 5-6 lbs. of material to the air muscle using the other loop. This weight will load the air muscle (cause the air muscle to stretch). Pressurize the air muscle with approximately 50-psi. The air muscle should contract and easily lift the weight. While pressurized, listen for any air leakage. Repair any air leak, by tightening the 24-gauge wire.

First Mechanical Device

This first device illustrations the function and measures the contract obtained with the air muscle, see figure 9. The air muscle is mounted to a piece of 1" x 2" lumber approximately 16" long. One end of the air muscle loop is looped over a wood screw secured into the wood. A thick rubber band is looped through the air muscle loop on the other end. The rubber band is pulled until the air muscle is just fully extended. Do not extend or pull the rubber band any further as this will just added additional resistance to the air muscle and not contribute to its function. A woodscrew is secured into the wood at this point and the rubber band is looped over the screw. When you pressurize the air muscle you can measure its contraction. Release the air pressure from the muscle and it should extend into its relaxed position.

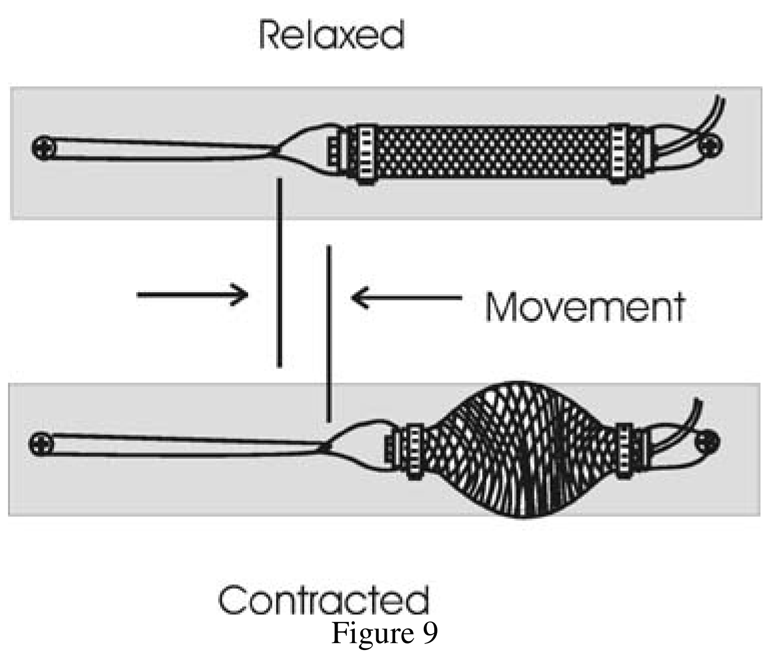


Figure 9

Second Mechanical Device

A lever is a simple mechanical device. A mechanical drawing is shown in figure 10 and photograph of a lever is shown in figure 11. Activating the air muscle causes the lever to rise. In the lever we are using a number of rubber bands to load the air muscle.

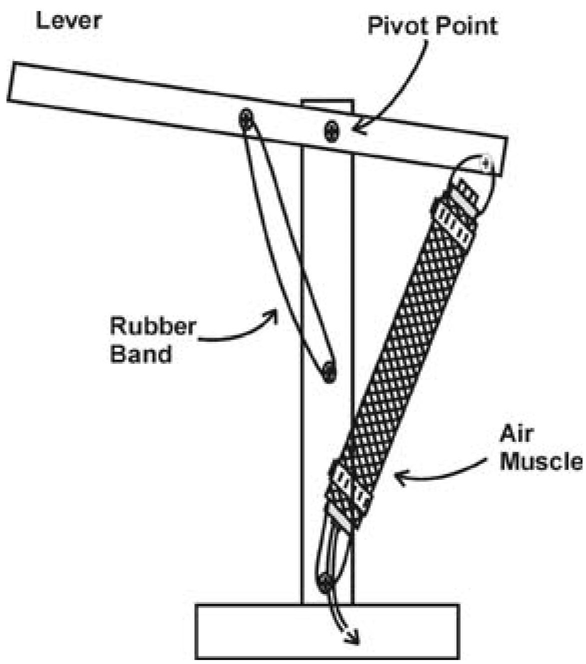
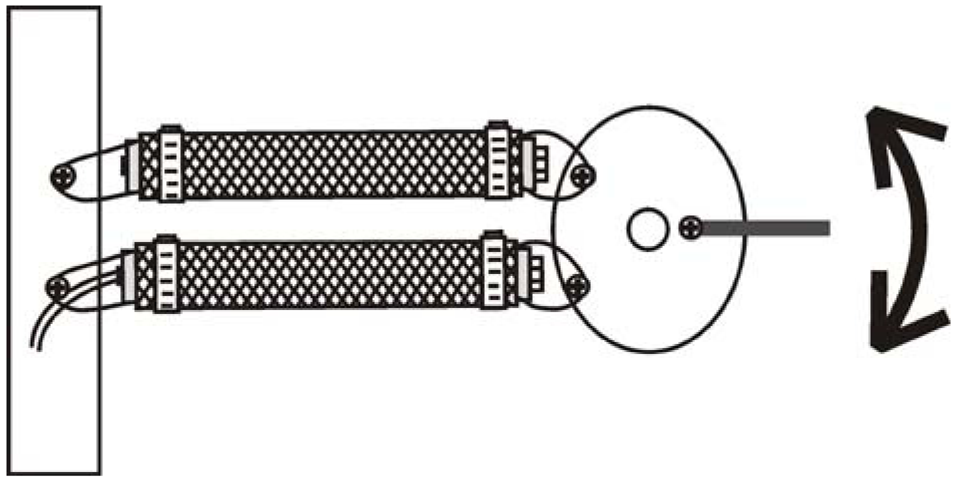


Figure 10

Figure 11

Figure 12 illustrates how two air muscles may be configured to provide a counter force or load for each other.



Controlling the Air Muscle

Typically 3-way air valves are used to control the air muscle see figure 13.

To activate the air muscle, valve labeled #2 is opened. This causes the air muscle to contract. Once activated the #2 valve may be closed without impacting on the state of the air muscle. The air muscle stays in a contracted state. To relax the air muscle, the air pressure must be vented by opening valve labeled #1.

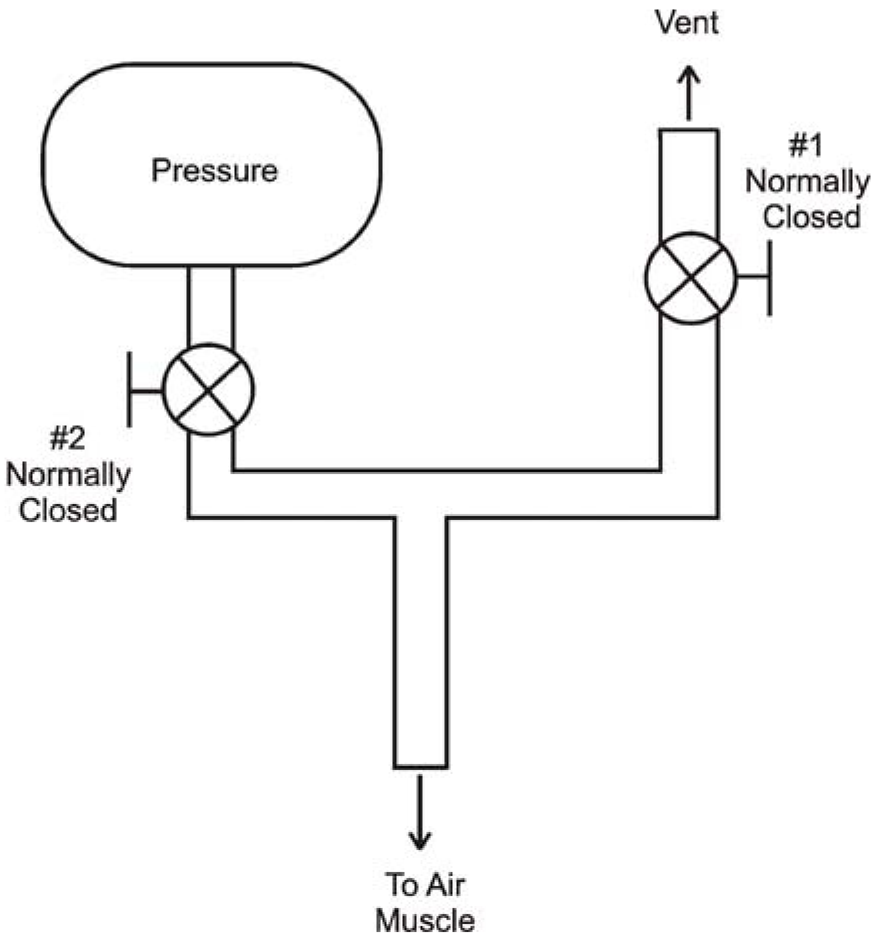


Figure 13

Electronic Control System

A three-way stopcock air valve may be purchased, see figure 14. The stopcock air valve allows you to control the air muscle manually. A three-way valve may be simulated or constructed using two one-way air valves. Small plastic aquarium valves purchased at a local pet shop have work quite well. However they are not rated for work at 50 psi and that's a good reason to wear eye protection, just in case they pop apart from the air pressure.

Figure 14

Using manual valves are fine for testing air muscles, to build a robot or industrial device we must provide a way for electronic control. Fortunately this is not difficult. There are a number of solenoid air valves available. I prefer the Isonic valves from Mead Fluid Dynamics. These are 3-way air valves that are activated using 5 Volts see Figure 14.

The 3-way Isonic values automatically vent the air muscle (through the back) when it is deactivated. To see how this particular valve works look back to figure 13, in the Isonic valve, the valve labeled #1 is normally open, this is the vent, through the back of the valve. The valve #2 is normally closed, this is labeled "In" on figure 14. The air stream to the air muscle is labeled "Out" in figure 14. When the electronic valve is activated valve # 2 opens allowing air pressure to the air muscle and valve #1 closes. When deactivated each valve changes state; valve #1 opens, venting the air muscles air pressure and valve #2 closes separating the air supply from the air muscle.

The front of the Isonic air valve has two quick connects-disconnects for air tubing. This particular air valve connects handles semi-ridge 4mm tubing, which is a good size for running air to the air muscle. To use the quick connect simply push the air tubing into the hole, it will lock in. To disconnect, hold the valve flange to the valve body with your fingers and pull the tubing out.

Mulitple Isonic air valves may also be mounted onto a common manifold that make making multiple air muscle control that much easier.

Figure 15 is a simple manual control schematic for a 5-volt control circuit for the Isonic valve.

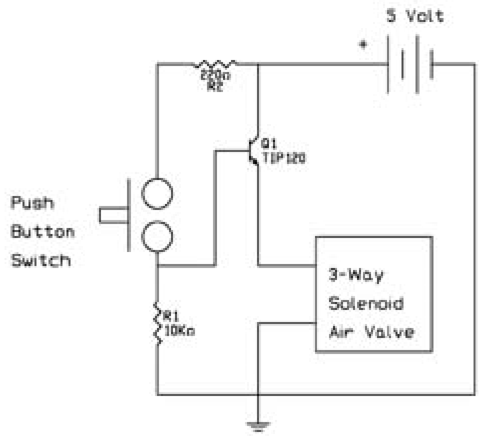


Figure 15

Going Further

Using pressurized air is an inconvenience, but one that may be overcome. For instance at Case Western Reserve University a team of faculty and students are building a cricket micro-robot that utilizes air muscles for walking and jumping. The micro-robot will walk and jump just like its biological counterpart. What makes this project so interesting is that the micro-robot is no larger than 5 cm (2 inches) in any dimension. To power the air muscles the team made a micro-pump that supplies 35 psi for the muscles.

Robot Wars

Many of the robots used in the Robot Wars series use pneumatic devices and flippers to over turn competitive robots. It is quite conceivable to substitute air muscles for pneumatic cylinders in these robots and thereby improve the strength to weight ration. In addition alignment for these flexible pneumatic devices are very forgiving. Thereby allowing the builder an easier construction since the robot may be built with far more open tolerances.