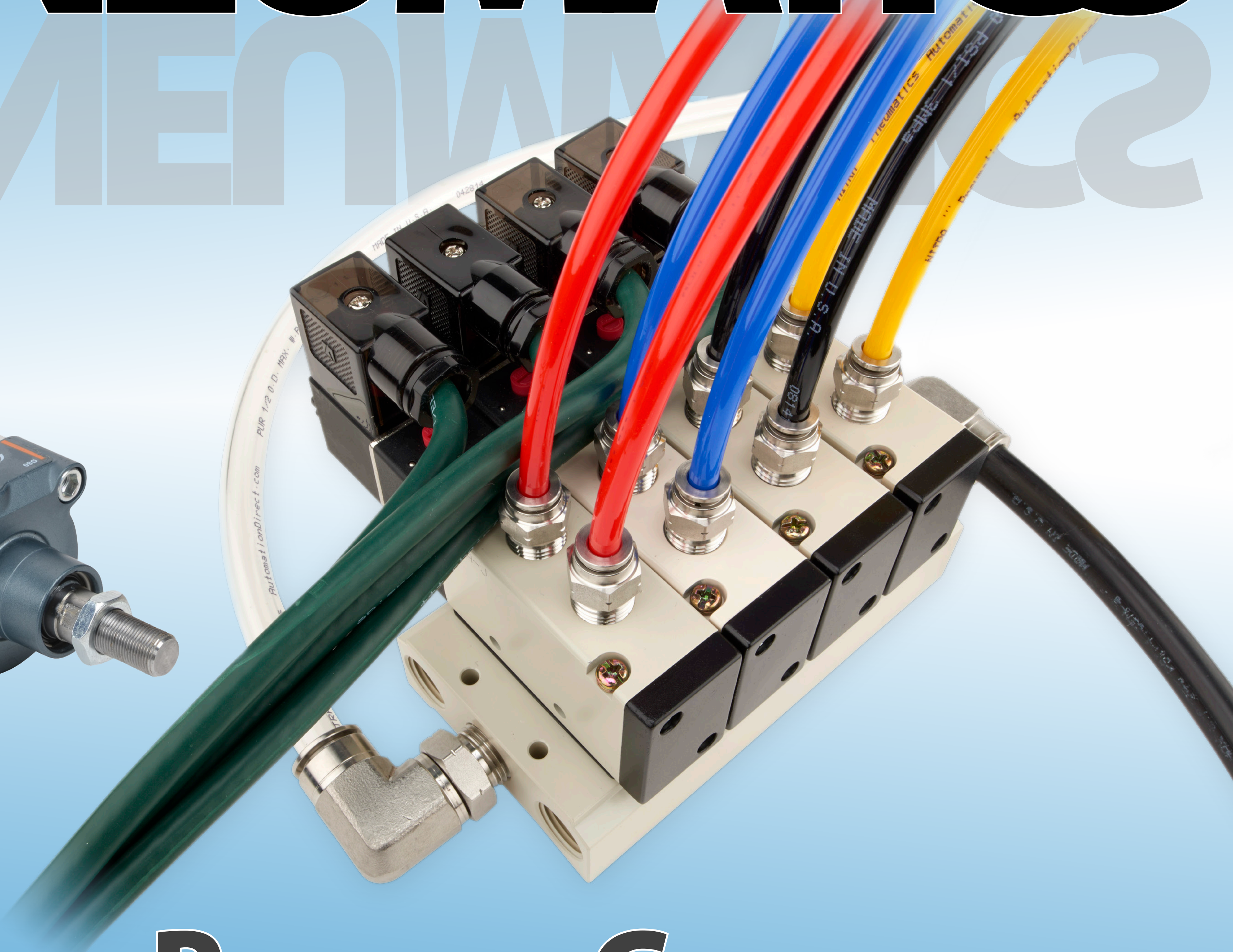
PNEUMATICS



Practical Guide

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PNEUMATICS

PRACTICAL GUIDE

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Why Use Pneumatics

In manufacturing facilities, compressed air is so widely used that it is often regarded as the fourth utility after electricity, natural gas and water. But compared to electricity, compressed air is more expensive, so why is it so widely used to drive factory automation systems?

The main reasons are lower upfront and maintenance costs, which combine to make pneumatics the most popular and cost-effective choice for executing mechanical motion. It's hard to beat the simplicity and reliability of pneumatics.

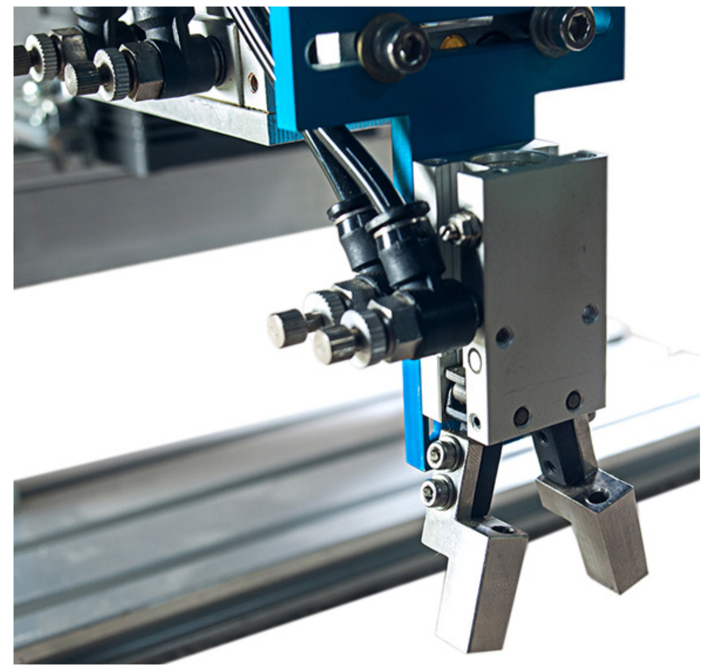


Figure 1A: Pneumatics in action (aluminum pneumatic robot hand)

Linear Power Transmission Options

Linear power transmission is typically done with fluid (pneumatic with air or hydraulic with oil) or electric power. In electric power systems, electromechanical devices such as belts, pulleys, chains, sprockets and clutches convert rotational motion from motors to linear force. The main exception is linear motors, a relatively expensive specialty technology used to move very light loads.

Although many vendors often promote the competing technology of their choice, the choice of power transmission depends on the application. It's not uncommon for larger machines to have all three of the power transmission technologies in use simultaneously. But many other machines only use pneumatics due to some advantages over other power methods.

Linear Power Transmission Comparison

Table 1A below lists some of the general advantages associated with pneumatic, hydraulic and electrical means of producing linear mechanical motion.

Characteristics	Pneumatic	Hydraulic	Electric
Complexity	Simple	Medium	Medium/High
Peak power	High	Very high	High
Size	Low size/force	Very low size/force	Medium size/force
Control	Simple valves	Simple valves	Electronic controller
Position accuracy	Good	Good	Better
Speed	Fast	Slow	Fast
Purchase cost	Low	High	High
Operating cost	Medium	High	Low
Maintenance cost	Low	High	Low
Utilities	Compressor/power/pipes	Pump/power/pipes	Power only
Efficiency	Low	Low	High
Reliability	Excellent	Good	Good
Maintenance	Low	Medium	Medium

Table 1A: Linear Power Transmission Comparison

Pneumatic systems are simpler than hydraulic and electric systems, conferring advantages in upfront costs and maintenance. Fluid power systems produce linear motion with simple pneumatic and hydraulic cylinders and actuators. Converting electrical to linear power often requires one or more mechanical devices to convert the motor rotation.

Pneumatic and hydraulic power transmission methods typically produce more power in a smaller space, so small pneumatic cylinders can be used to provide the high required clamping or positioning force needed to hold a product in certain machining and other applications.

Control of this power is usually easier with pneumatics and hydraulics than with electric systems. A simple valve, regulator and flow controls are usually all that's needed to control cylinder direction, speed and force. An electric actuator often needs an electronic controller, multiple I/O points, communication cables, and possibly encoder feedback, along with more complex automation system programming.

A pneumatic actuator typically has two very repeatable end-of-travel positions which are set by using a hard stop, cushion or shock. Electric actuators are also very repeatable, and can be easily designed with multiple stop positions. With new advances in electronics, pneumatic control of multiple stop positions is also now possible although not as precise as electric can be. Whether it is end-of-stroke or multiple stop positions, both pneumatic and electrical actuators can attain the desired position at high speeds.

"Pneumatic hardware is also much simpler to design, and less expensive to purchase and install."

Operation of a compressor may have additional costs compared to electric, but the availability of clean dry air in most facilities is common. In addition, pneumatic components often have the lowest maintenance costs, such as when replacing seals, or a whole cylinder for that matter, which is often much cheaper than servicing, let alone replacing, an electric actuator.

Noise is becoming less of a concern with fluid power devices. Designs have improved over the years, greatly reducing clatter to about the same level as a stepper-driven electric actuator. New improvements in designs and efficiency of compressors, and the standard use and distribution of clean dry air in a manufacturing facility, also make pneumatics a good choice for industrial automated machinery.

A Good Application for Pneumatics

Pneumatic power transmission methods are often the best way to move parts and tooling in industrial machines. These pneumatic systems perform a myriad of tasks in automated equipment such as clamping, gripping, positioning, lifting, pressing, shifting, sorting and stacking. Some adaptive uses—each of which could include closed loop control for more precise positioning—include tensioning, pressing, labeling, embossing, crimping and cutting.

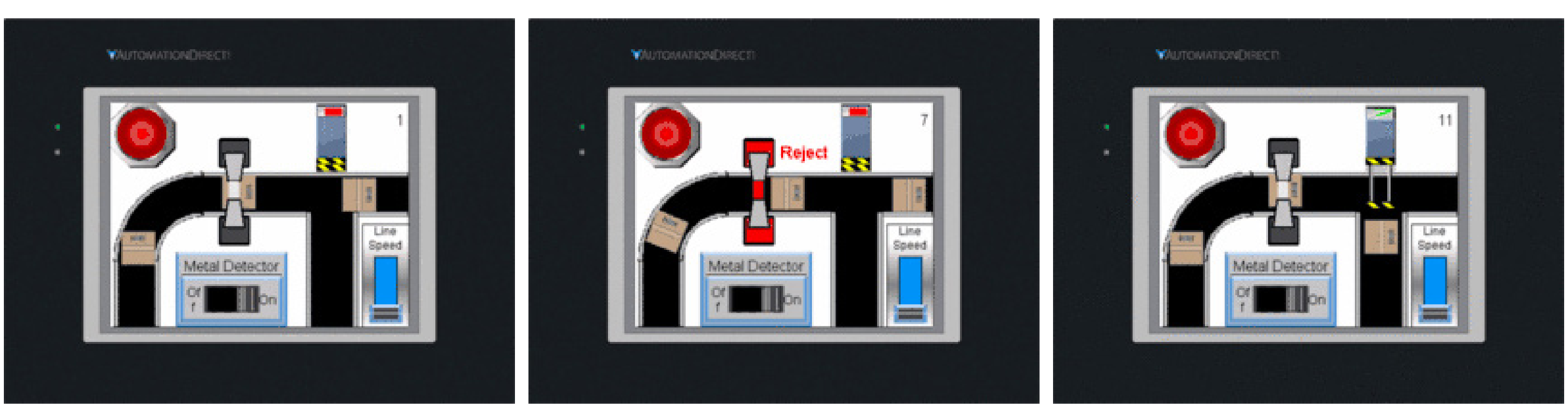


Figure 1B: Simple pneumatics application: Air cylinder powered ram to divert rejects to another conveyor

The tried and true pick-and-place method with horizontal and vertical travel and a gripper is probably one of the most common uses of pneumatics. Clamping or part positioning functions are also widely implemented with pneumatics. If tooling needs to move, a part needs to be held, or a force or tension needs to be applied, pneumatic systems can likely provide a solution.

Basic Pneumatic Hardware

All pneumatic systems will have certain basic components. The first is a compressor, and then a system to distribute the clean, dry air it produces.

Common pneumatic components on automated machines include:

- air preparation system (shut-off/lock-out, combination filter/regulator, soft start valve)
- control valves and manifolds (manual, air pilot, solenoid operated)
- air cylinders and actuators
- tubing and hoses
- push-to-connect fittings
- cylinder position sensors
- discrete pressure switches
- specialty components and accessories

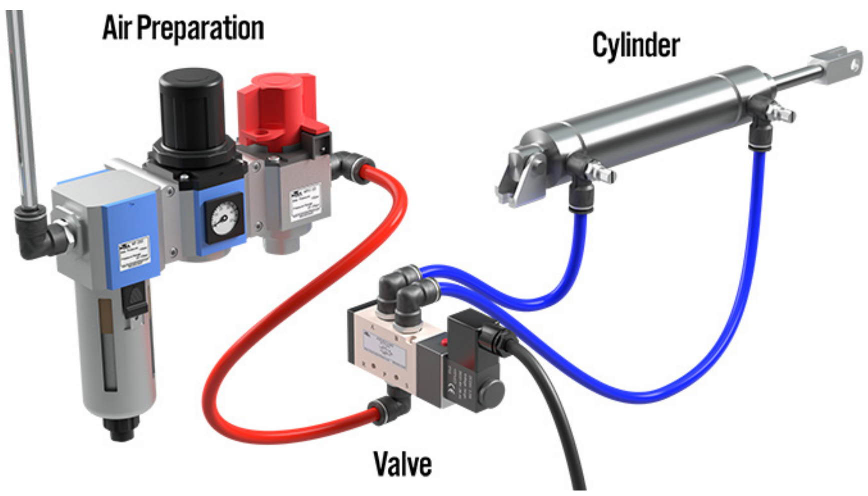


Figure 1C : Basic pneumatic system

Since most facilities have a plant air supply, the machine pneumatic system starts with the air preparation unit to which the plant air is connected. The air prep system should include a manual and lockable shutoff valve, filter, water trap and pressure regulator. An electrically-operated soft start might also be considered to remove air during an emergency stop, guard open or similar safety event. The air prep system may also include a lubricator, but it's usually not necessary unless pneumatic rotary tools are in use.

The air prep system typically feeds the valves or valve manifold that can include manual, air-piloted and solenoid-operated control valves to turn the air supply off and on. These valves feed control air to a variety of pneumatic cylinders and actuators where power transmission happens.

Pneumatic cylinder position sensors and pressure switches are a common component in pneumatic systems. There are also a wide variety of special pneumatic components such as flow controls, quick exhaust valves, hand valves, check valves, inline pressure regulators, gauges and indicators.

Getting Started

With pneumatic systems, a little guessing is okay, but be sure to understand the application. How much force do you need? How fast do you need to move?

With pneumatic power transmission, it is important to define the mass of what is going to be moved along with its velocity and acceleration profile. The required power to be transmitted to the part or tooling must also be specified. With that information and mounting decisions made, the cylinders, tubing and valves can be specified.

Pneumatics is the best choice in many applications, unless you need the highly accurate and programmable motion positioning offered by electric systems, or the very high levels of force provided by hydraulics. But in most cases, pneumatics can provide a simple, reliable, cost-effective solution. So, in your next motion application ask yourself, "Why not pneumatics?"

Pneumatic Circuit Symbols Explained

Before we get any further with specifics on pneumatic system components let's take a look at the symbols used to represent these components. Throughout the eBook we will include these circuit symbols and offer you some practical advice in how to incorporate these components into an industrial application.

Valve Symbols

Directional air control valves are the building blocks of pneumatic control. Symbols representing these valves provide detailed information about the valve they represent. Symbols show the methods of actuation, the number of positions, the flow paths and the number of ports. Here is a brief breakdown of how to read a symbol.

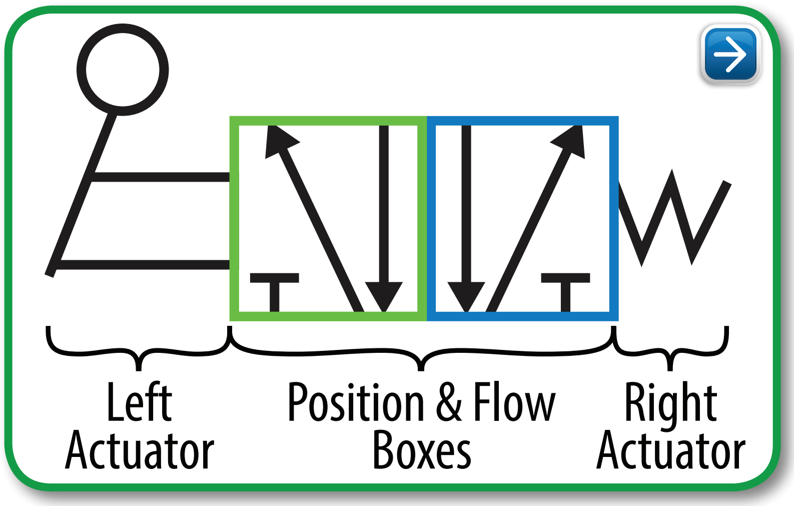


Figure 2A: 2 position, lever actuated, spring return valve

Most valve symbols have three parts (see Figure 2A below). The Actuators are the mechanisms which cause the valve to shift from one position to another. The Position and Flow Boxes indicate how the valve functions. Every valve has at least two positions and each position has one or more flow paths, thus every valve symbol has at least two Flow Boxes to describe those paths.

Position and Flow Boxes

The number of 'position and flow boxes' that make up a valve symbol indicate the number of valve positions. Flow direction is indicated by the arrows in each box. These arrows represent the flow paths the valve provides when it is in each position.

The Flow Box next to the 'active' actuator always shows the current flow path(s) of the valve. In the example above, when the lever is NOT being activated, the spring return actuator (right side) is controlling the valve, and the box adjacent to the spring shows the flow path. When the lever IS actuated, the box next to the lever shows the flow path of the valve. A valve can only be in one position at a given time.

In Figure 2B (a three position valve), the valve has both solenoids and 'spring return' actuators on both sides, the spring return actuators will return the valve to the center position but *only IF neither of the solenoids is active*:

With this three position valve, the center flow box shows the flow path when neither actuator is active and the springs are holding the valve in the center position. In this fairly common example, the center box indicates that there will be no air flow (and the associated cylinder won't move) unless one of the two actuators is active. This type of valve can thus be used to "bump" or "inch" a cylinder incrementally along its extension or retraction stroke for various purposes.

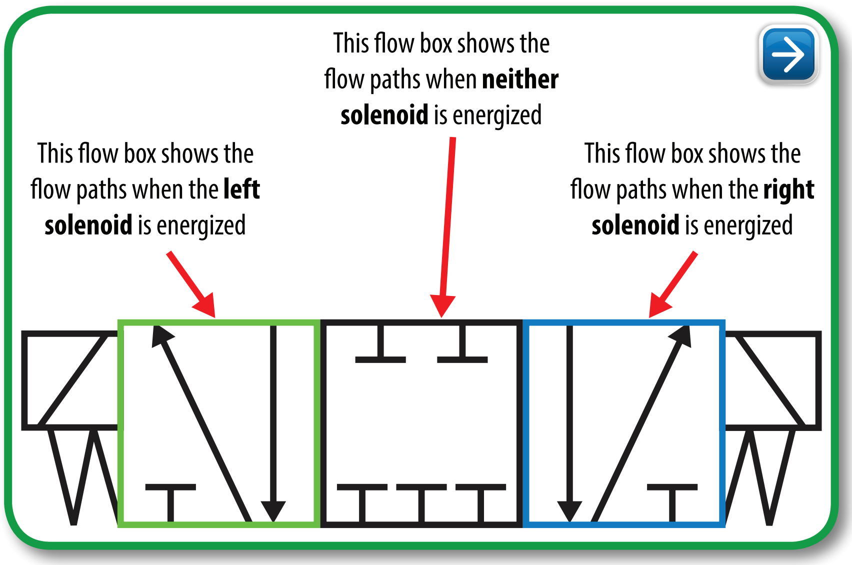
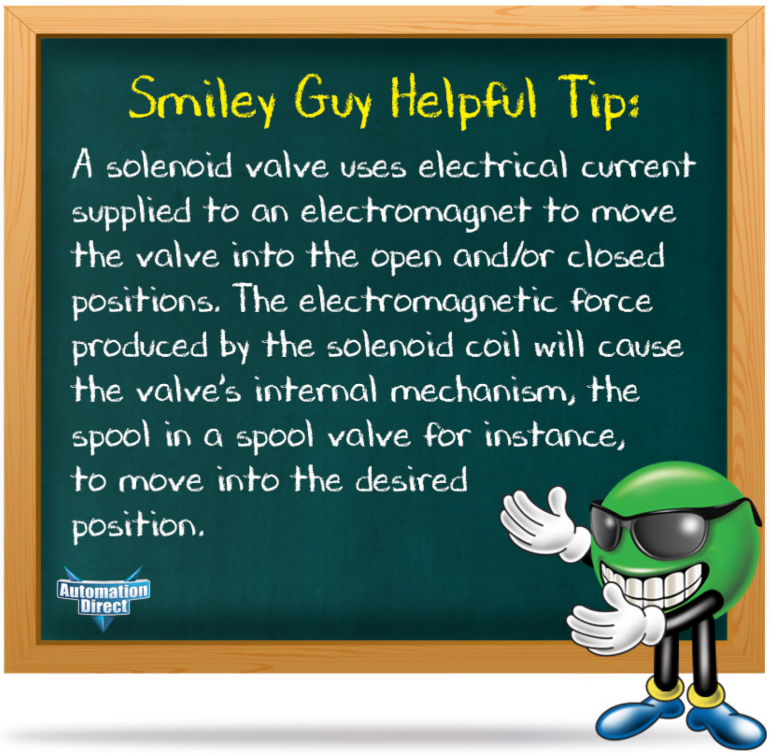


Figure 2B: 3 position, double solenoid actuated, spring return valve



Ports

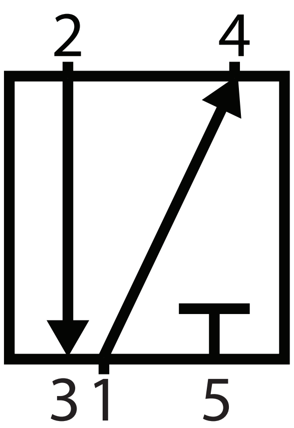


Figure 2C: 5-port valve

The number of ports is shown by the number of end points in a given box. Count only the ports in one flow box per symbol (For example there are three boxes in the Figure 2B valve symbol showing each of the three different positions possible for the valve). In Figure 2C, there are a total of 5 ports. Sometimes a port (usually an exhaust port) goes directly to atmosphere and there is no mechanical means for attachment of silencers, flow control valves, or any other accessories. To indicate this (in some flow diagrams), ports with attachment capability will have a short line extending beyond the box (as shown on ports 1,2, & 4), while the ports you cannot attach to will not have the external line segment (ports 3 & 5 in this example).

Port Labeling

Port labels are typically shown on a single flow box per symbol. Different manufacturers label valve ports with different letters, but the labels at right are fairly standard. "P" represents the pressure inlet port, "A" and "B" are outlets (generally plumbed to the 'extend' and 'retract' ports on a cylinder), and "R" and "S" indicate the exhaust ports.

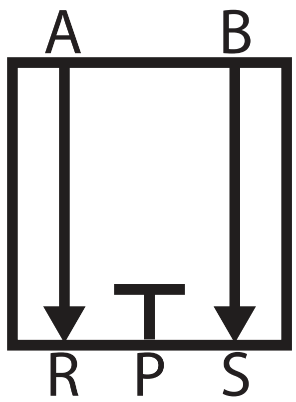


Figure 2D: Port labeling

Ports vs "Ways"

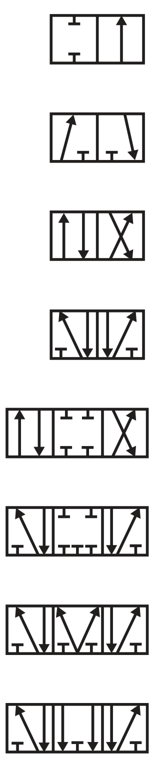
Valves are often referred to by their number of ports, and also by the number of "ways" that air can enter or exit the valve. In most situations the number of ports and ways are the same for a given valve, but take a look at Figure 2C above.

It has five ports, but it is considered a 4-way valve because two of the ports share the same exhaust function. This is a holdover from hydraulics – where the two exhaust paths are joined (internally to the valve), so that only one return port is required, and only one return line is required to get the hydraulic oil back to the storage tank for re-use. In other words, in a pneumatic system the two exhaust ports (R and S in Figure 2D) are only counted as a single "way" since they both connect the valve to the same place (atmosphere). In the case of our pneumatic valve with similar functionality, the separate exhaust ports are created for mechanical simplicity (and as a cost saving measure), but they are not considered distinct "ways".

The symbols on the next page detail many of the ports, ways, and positions of common pneumatic valves. The specification for "ways" can be somewhat tricky; analyzing the circuit symbols is a better method for verifying that a given valve offers the required functionality.

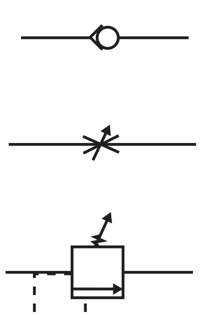
Common Valve and Actuator Symbols

Directional Control Valve Symbols



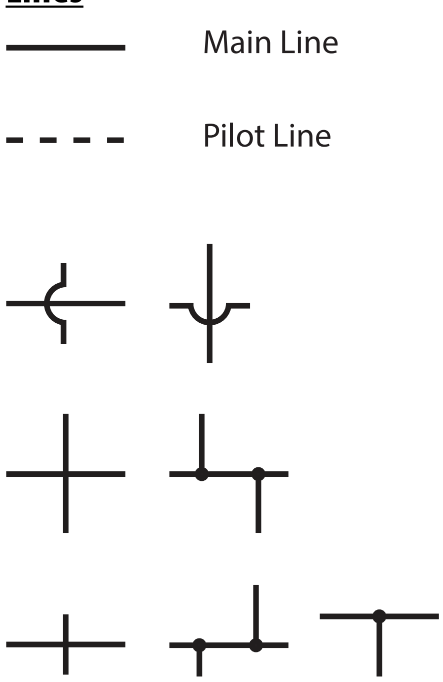
- 2-position, 2-way, 2 ported
- 2-position, 3-way, 3 ported
- 2-position, 4-way, 4 ported
- 2-position, 4-way, 5 ported
- 3-position, 4-way, 4 ported Closed Center
- 3-position, 4-way, 5 ported Closed Center
- 3-position, 4-way, 5 ported Pressure Center
- 3-position, 4-way, 5 ported Open Center

Simple Pneumatic Valves



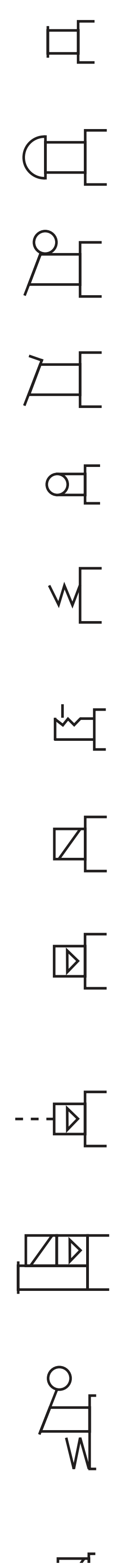
- Check Valve
- Flow Contol
- Relief Valve

Lines



- Main Line
- Pilot Line
- Lines Crossing
- Lines Joined
- Lines Joined

Actuator Symbols

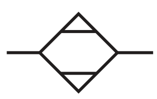


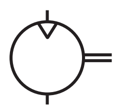
- Manual
- Push Button
- Lever
- Foot Operated
- Mechanical
- Spring
- Detent
- Solenoid
- Internal Pilot
- External Pilot
- Piloted Solenoid with Manual Override
- Lever Operated, Spring Return

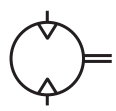
Other Pneumatic Symbols

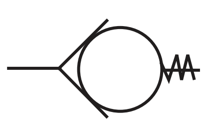
Other pneumatic components also have schematics or symbols, but these generally do not require as much explanation as those for the valves. Here are symbols for other commonly used pneumatic devices: Check out our Interactive Circuit Symbols **here**.

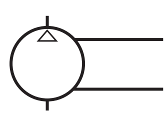

Accumulator

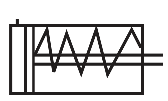

Air Dryer

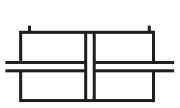

Air Motor (One Direction Flow)

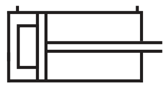

Air Motor (Two Direction Flow)

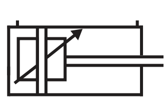

Check Valve (Spring Loaded)

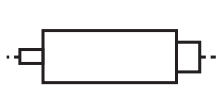

Compressor

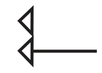

Cylinder (Spring Return)


Cylinder Double Acting
(Double Rod)

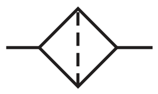

Cylinder Double Acting
(Single fixed cushion)

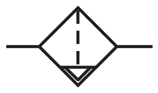

Cylinder Double Acting
(Two adjustable cushions)

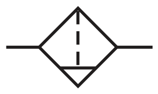

Differential Pressure

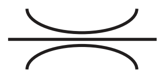

Direction of Flow

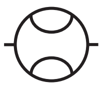
Exhaust Line or Control Line

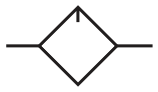

Filter


Filter (Automatic Drain)


Filter (Manual Drain)


Fixed Restriction


Air Motor (Two Direction Flow)


Lubricator

What's Next?

Now that we have an overview of the basic components included in a pneumatic system, where do we go from here? Well, let's start by taking a closer look at each component beginning with what is needed to prepare the air supplied to the system. The air prep devices are important because they regulate, clean and lubricate (if needed) the air that will be used to power the components in a typical pneumatics application.

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Understanding Pneumatic Air Preparation

A steady supply of clean and dry air is required to protect all the pneumatic components in machines, equipment and processes and to ensure their proper operation. While controlling mechanical motion with pneumatics—such as clamping, positioning, pushing and lifting—is often the focus, clean and dry air with enough flow to provide the required pressure must be designed into the system.

It Starts with Plant Air

From the plant or shop compressor to the machine, compressed air often flows through multiple devices, pipes and fittings that can add particulates, oil and moisture. Even if the main plant compressor includes an air dryer, filter, water separator and regulator, the air should still be prepared at the machine before it is used. Air preparation at the machine can be important if there is a long distance from the main compressor to the point of use where additional water or especially if there is a long distance between them where additional water or particulates could build up. This helps ensure your machine gets the best possible protection and longest possible service life. An air preparation system should include regulators, filters and lubricators, in addition to manual and electrical air dumps for safety.

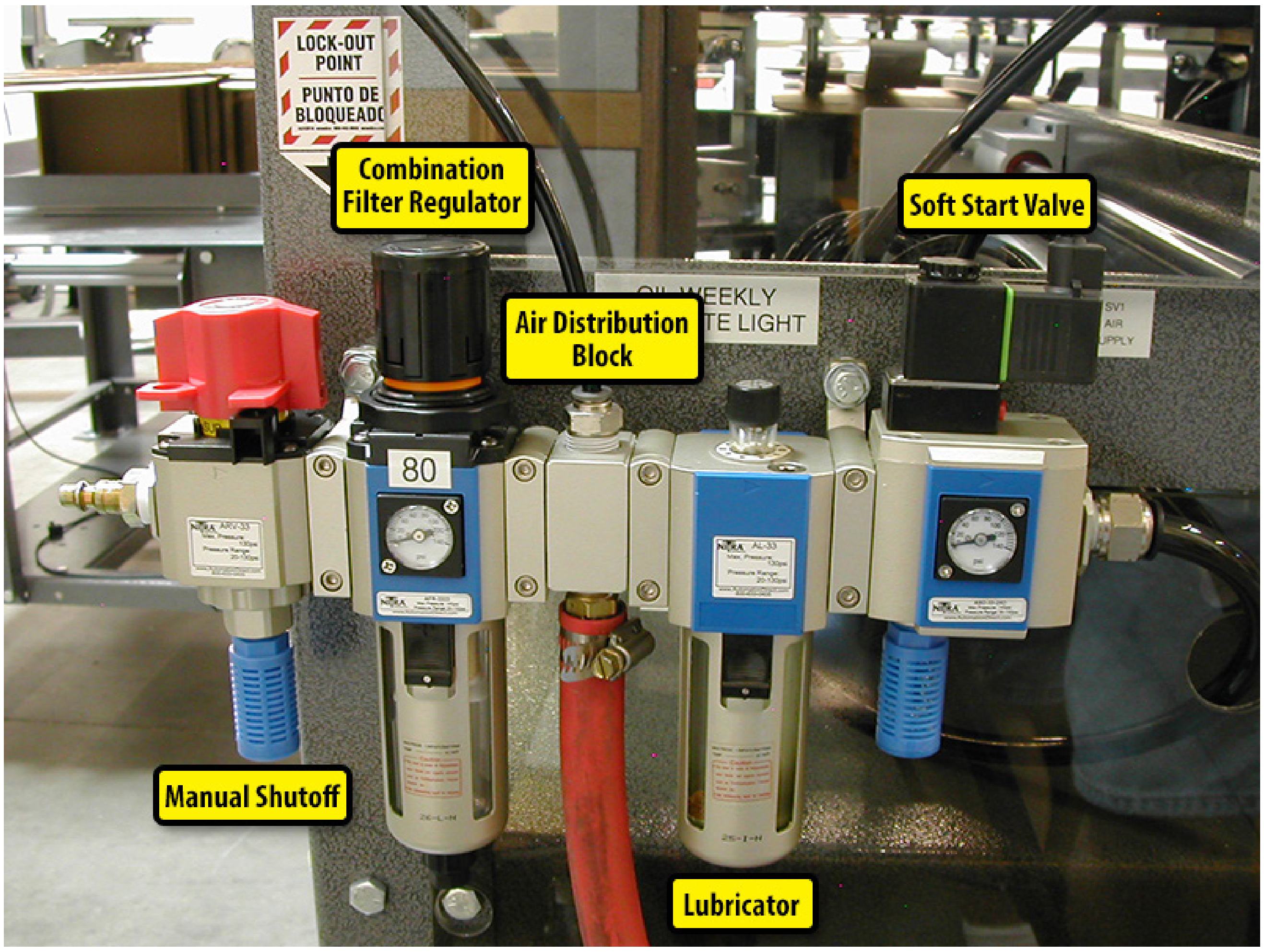


Figure 3A: Air preparation assembly on a machine using pneumatics

Ensure Adequate Air Flow

A properly functioning pneumatic system requires a proper supply of plant air. Without adequate plant air, the pressure will sag during use, especially when the machine requires high air flow during operation. Even surrounding equipment and manual air blow nozzles may demand flow and cause pressure sagging. Increasing the size of the supply pipes is a first step to eliminate pressure sag, but the problem can be low pressure all the way back at the compressor or plant air prep system.

It is not uncommon for flow restrictions, leaks and pipe run distance in the plant air distribution system to drop air pressure by 5 to 10 psi. Because of this, it is a good practice to require air pressure at the input to the machine air prep system to be 10-20% higher than the machine operating pressure (be sure the plant air does not exceed the maximum operating pressure for air prep components). It's also recommended to up-size the supply pipe to the next larger size required by machine flow. If the supply pipe appears to be too small or if there are supply pressure variations, this design guideline probably wasn't followed.

Getting Prepared

It is not a bad thing to have an oversized air preparation system, as this can leave room for additions or unanticipated demands. The air prep system should start with a manual shutoff relief valve with lock-out to remove air for maintenance. For additional safety, OSHA also requires air to be dumped during an emergency stop or other safety event. For this purpose, an electrical soft start valve that dumps air when power is removed is recommended. The soft start valve also keeps the pneumatic equipment from banging when air is applied.

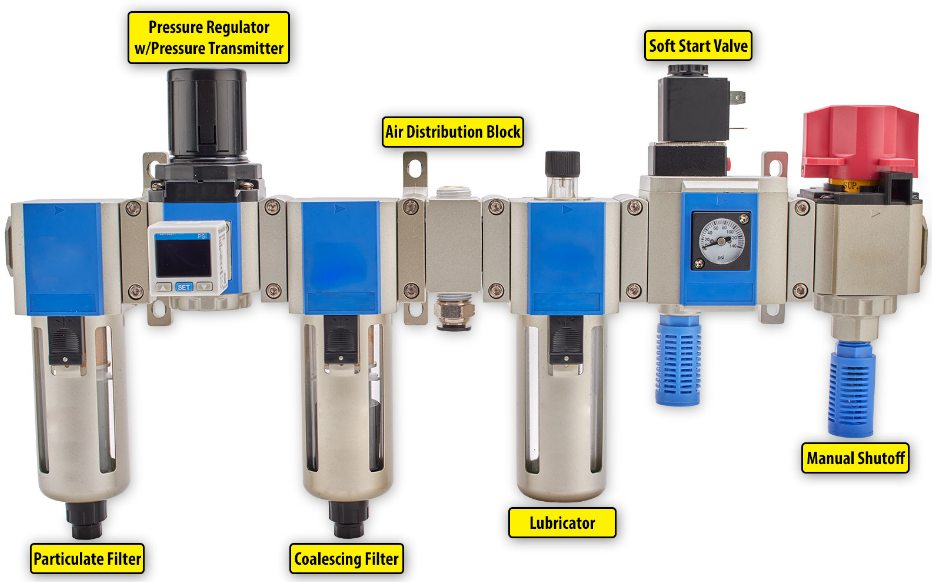


Figure 3B: Air Prep System

Figure 3C: All-in-one air prep unit

The **filter, regulator and lubricator (FRL)** is installed just downstream of the manual shutoff relief valve. The air filter provides particulate removal and moisture separation filters in a wide range of port sizes, typically from 1/8" to 1". Standard filters remove particulate to around 40 µm, while fine filters are available to remove particulates down to 5 µm or less.

These filters are necessary to reduce contaminates and moisture in the compressed air at the machine. All pneumatic components benefit from this, but keep in mind that a filter that is too fine for the application can become blocked quickly. While a 40 µm filter works well to protect valves and cylinders, process instrumentation or high speed pneumatic tools will benefit from a finer particle filtration. Special, finer filters may also be needed for food, pharmaceutical and paint shop applications, and specify coalescing filters if oil vapors or aerosols need to be removed from the air stream. Be aware that coalescing filters don't take the place of particulate filters - you may need both.

The air filter bowls often include manual, semi-automatic or automatic drains to remove trapped liquid that has been separated from the air. The manual drain is just a valve. The semi-auto drain is similar to a check valve; it is closed when pressure is applied and opens when pressure is removed. The auto drain automatically opens when the liquid in the bowl reaches a certain level. These removable bowls also allow easy replacement of the filters. A variety of accessories are available to mount these combined filter/separators individually, or to a downstream regulator.

Dryers

Some air prep systems may need dryers. Air used for painting and other special purpose applications may require dry air. There are two commercially available types of dryers: refrigerated compressed air dryers and desiccant compressed air dryers.

Refrigerated air dyers work by cooling the compressed air to a preset temperature where the water condenses and is removed by a compressed air trap. The air is then warmed (or allowed to warm) back to room temp. The resulting air will be dry as long as it stays above the preset temperature. This preset temp would be the "dew point" of the dried air, typically around 35-40 degrees.

Desiccant compressed air dryers use a desiccant medium to pull water from the air. Periodically the dryer uses a hot air cycle to drive the water from the saturated desiccant, and the process repeats. These dryers can reach much lower dew points, potentially down to -90 degrees or lower.

Refrigerated air dryers are good enough for most applications - but if you are using compressed air outdoors in a cold environment - you may need to consider a desiccant dryer.

Pressure Adjustment

The regulator is selected to match the port size of the upstream filter. It adjusts the pressure of the filtered air between a typical range of 20-130 psi, with lower pressure ranges often available for applications needing more precision. Most piloted valves require 30 psi to operate. Pulling the knob up and rotating it changes the air pressure, and this knob locks in the pressure when pressed down.

Equipment design often dictates the required operating pressure. A minimum operating pressure must be maintained, with values below this level sensed by a pressure switch to alert an operator. Although higher pressure than required may make the machine run faster, it can cause excess wear and tear due to the banging caused by fast cylinder motion. While over 100 psi may be supplied to a machine, operating at 60 to 80 psi is usually a good design goal.

Features of note in a regulator are a pressure relieving design and a built-in, integral pressure gauge. The pressure relieving design will relieve pressure if the set point is lowered or if a downstream condition raises the pressure. The only way to reduce the pressure in a non-relieving design is to cycle the downstream equipment. An integral pressure gauge is always a good idea to provide quick indication of system air pressure, and to assist when setting the regulated pressure. The pressure gauge indicates the regulated downstream pressure, not the incoming/upstream pressure.

Combination filter regulator air prep units are also available. These units have all the capabilities of the separate filters and regulators described above combined into a single unit. This design can save significant pneumatic panel space if a single regulated air pressure works for the application, and it also saves money.

Some applications may require a precision regulator. Standard model regulators may not be accurate enough or may allow downstream pressure to vary if the upstream pressure changes. The best precision regulators can hold a 0.05 psig variation even with a 100 PSI upstream pressure change. It is usually best practice to mount the precision regulator near the subsystem that requires precise regulation.

Figure 3D: Combination Filter Regulator

Figure 3E: Precision Regulator

Lubricate with Care

If needed, a lubricator is installed downstream of the regulator. Often, if lubrication is provided, all machine pneumatic components are lubricated. In this case be sure to match the port size of the upstream regulator to maintain proper air flow. A smaller unit can be used if only a few components need lubrication.

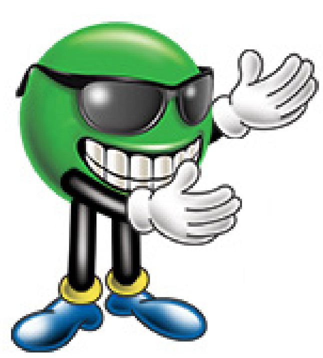
An important question to ask is, "Do I really need lubrication?" Today's pneumatic devices often don't require lubrication, but high-speed pneumatic power tools often do, so check the manufacturers' recommendations. Some devices will need a light-weight non-detergent oil such as SAE 10, ISO VG32, or equivalent lubrication, while some are pre-lubricated and don't require it.

A mist-type air lubricator creates a fog of oil vapor via an oil drip, needle valve and ejector nozzle, and it should be mounted close to the pneumatic devices to be lubricated. Also note that an oil mist does not generally travel uphill, so mount the air prep unit above all valves and cylinders that require lubrication. Routing of hose and tubing should also be carefully considered.

Lubricators are available in a variety of port sizes to match other air prep components. Due to the adjustable lubrication rate, the bowls are also available in several sizes to store more oil as needed. When the sight gauge indicates low oil level, more oil can be added while the ubricator is pressurized.

Proper design of the plant air preparation system including correct specification of all the required components will ensure many years of trouble free operation for the downstream pneumatic components. When in doubt, it's generally best to oversize supply lines, as pressure can also be stepped down at the point of use.

Ok, the supplied air is now prepped and ready for use. But how do you use it? In many cases this air will be the driving force for pneumatic cylinders. These cylinders are used for a variety of motion applications and come in many styles, sizes, stroke lengths, etc. So let's take a closer look at these air cylinders and see what they are all about.



A word of advice when a lubricant is used:

Valves sticking in the *off* position or leaking when *off*, and premature wear of pneumatic cylinders and actuators, are often a sign of dirty or moist air causing seal wear and damage. In some cases, a cylinder could fill with water over time, locking the cylinder. Oil can cause the same results, and oil and contaminates can also clog up valves, especially small pilot ports and mufflers.

Pneumatic Actuator (Air Cylinder) Basics

There are thousands of industrial applications that require a linear motion during their operation sequence. One of the simplest and most cost effective ways to accomplish this is with a pneumatic actuator. Pneumatic actuators are also very clean operating because the operating fluid is a gas, which prevents leakage from dripping and contaminating the surroundings.

This section will discuss the basic construction and function of a pneumatic actuator, the relationship with a fluid power system and the selection guidelines for pneumatic actuators or air cylinders.

Pneumatic actuators convert compressed air into rotary or linear motion. There are many styles of pneumatic actuators: diaphragm cylinders, rodless cylinders, telescoping cylinders and through-rod cylinders.

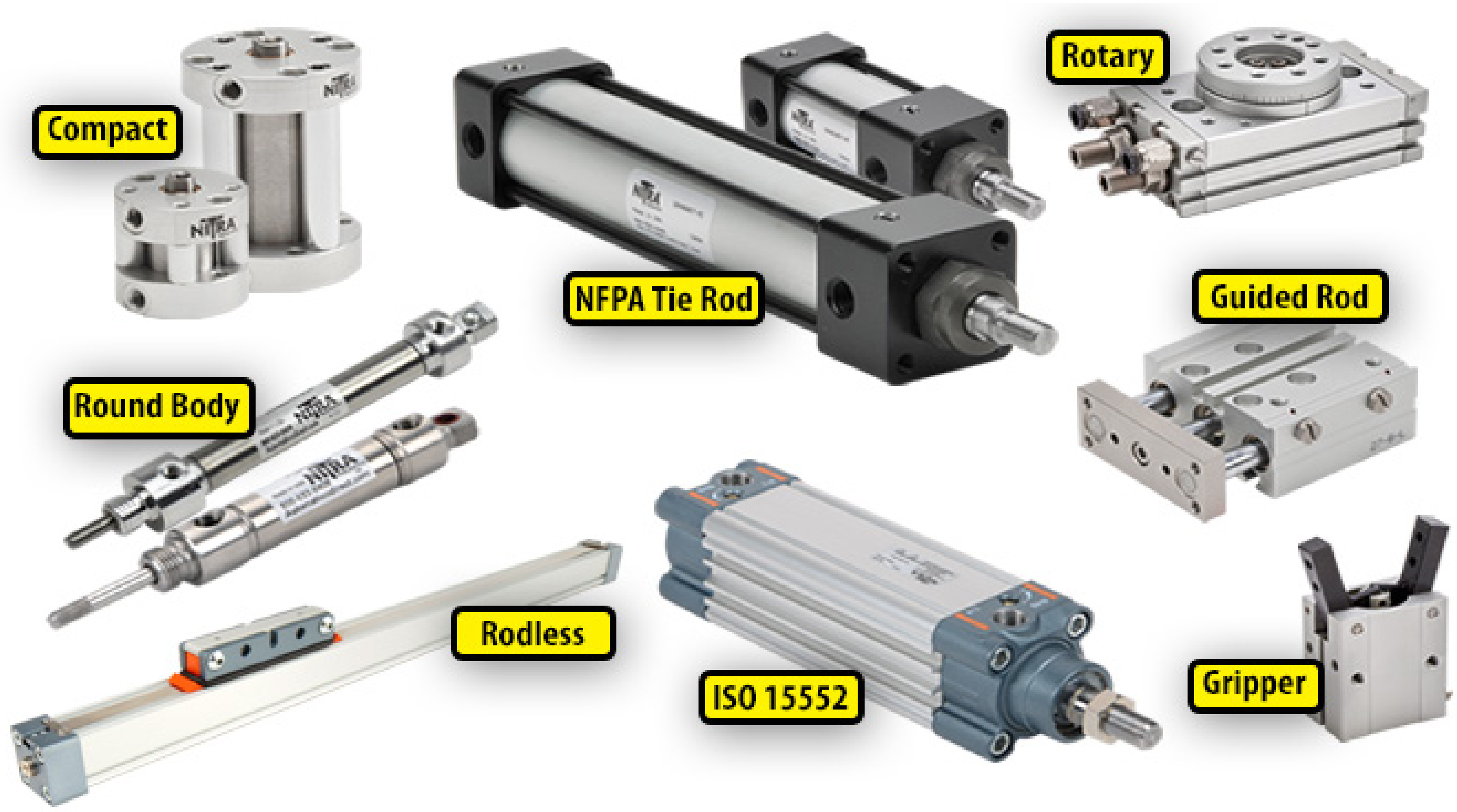


Figure 4A: Pneumatic actuators come in a variety of shapes and sizes

The most popular style of pneumatic actuator consists of a piston and rod moving inside a closed cylinder. Even so, there is a large variety of construction techniques and materials to fit a wide range of applications and user preferences. Body materials can be aluminum, steel, stainless steel and even certain polymers. Construction can be either non-repairable or repairable. This actuator style can be sub-divided into two types based on the operating principle: single acting and double acting.

Single-acting cylinders have a single port to allow compressed air to enter the cylinder to move the piston to the desired position. They use an internal spring or sometimes simply gravity to return the piston to the "home" position when the air pressure is removed. Single-acting cylinders are a good choice when work is done only in one direction such as lifting an object or pressing an object into another object.

Double-acting cylinders have a port at each end and move the piston forward and back by alternating the port that receives the high pressure air. This uses about twice as much energy as a single-acting cylinder, but is necessary when a load must be moved in both directions such as opening and closing a gate.

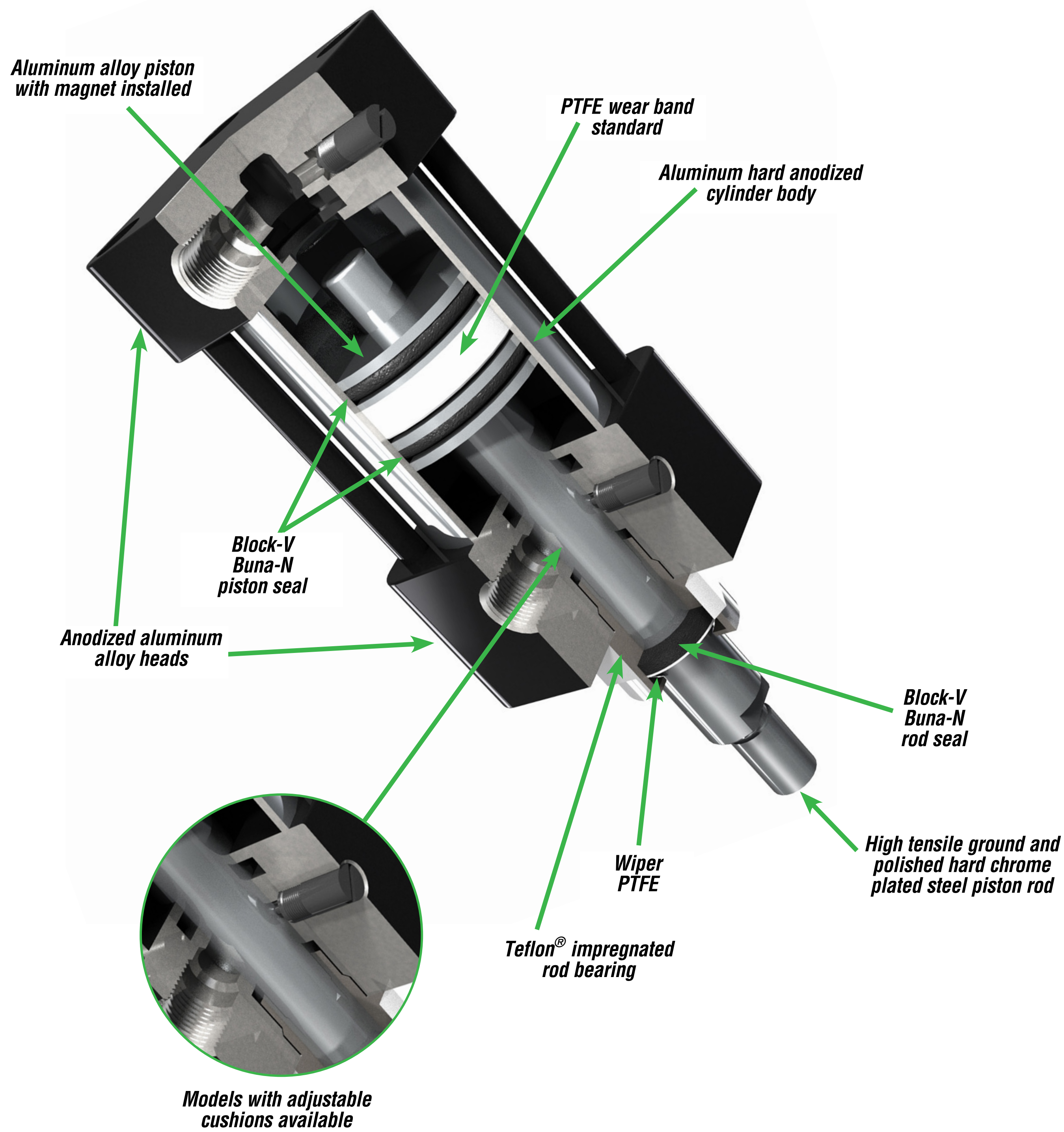


Figure 4B: Shows the primary components that make up a typical double-acting pneumatic actuator

In a typical application, the actuator body is connected to a support frame and the end of the rod is connected to a machine element that is to be moved. A control valve is used to direct compressed air into the extend port while opening the retract port to atmosphere. The difference in pressure on the two sides of the piston results in a force equal to the pressure differential multiplied by the area of the piston. If the load connected to the rod is less than the resultant force, the piston and rod will extend and move the machine element. Changing the valve to direct compressed air to the retract port while opening the extend port to atmosphere will cause the cylinder assembly to retract back to the "home" position.

Pneumatic actuators are at the working end of a fluid power system. Upstream of these units, which produce the visible work of moving a load, there are compressors, filters, pressure regulators, lubricators, control valves and flow controls. Connecting all of these together is a network of piping or tubing (either rigid or flexible) and fittings.

Pressure and flow requirements of the actuators in a system must be taken into account when selecting these upstream system components to ensure the desired performance. Undersized upstream components can cause a pneumatic actuator to perform poorly or even make it unable to move its load at all.

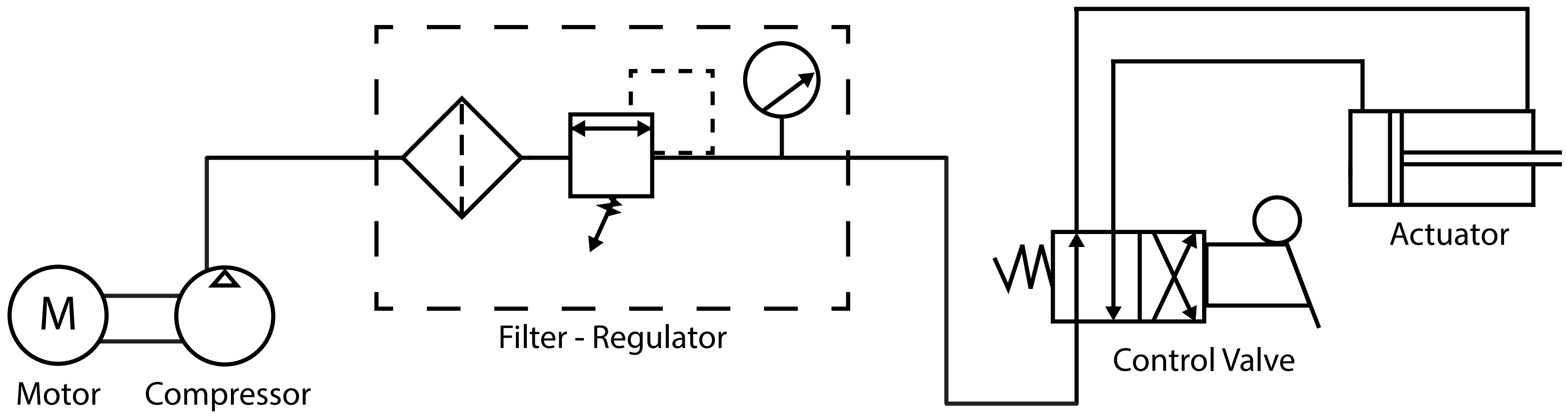


Figure 4C: A typical pneumatic system

The above Figure shows a basic system to power and control a pneumatic actuator. When selecting an actuator it is important to properly match the cylinder to the job.

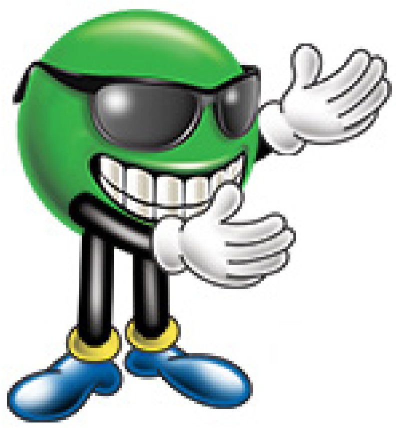
A typical pneumatic system configuration is shown in Figure 4C. The theoretical force available in the actuator is the piston area multiplied by the supplied air pressure. Spring force must be subtracted from this value for single-acting cylinders. The actual force of the actuator will be 3-20 percent less due to pressure losses in the system. A good rule to use when sizing an actuator is to select an actuator that has about 25% more force available than needed for the job, and the following formula can help with determining size requirements.

$$d = \sqrt{\frac{4F}{P\pi}}$$

Figure 4D: Cylinder bore size calculation

When the cylinder force (F) is known, the bore diameter(d) can be found by the above formula. F is the force required (lbs) and P is the supply pressure (psi). Stroke length is determined by the required travel of the machine element driven by the actuator. The speed at which the cylinder can move a load is directly related to the rate that the compressed air can flow through the pneumatic system to the piston to make it move.

This can often be a little tricky to calculate, since as the flow rate increases, system resistance (basically friction of the air moving through pipes and components) will increase in a non-linear fashion. The result is a larger pressure drop from the supply (air compressor) to the cylinder. When the pressure drop is so large that the available pressure at the cylinder cannot move the load, the cylinder will stall. When speed is critical to a machine operation, it may require testing two or three combinations of valves, tubing and cylinders to get the desired performance. Let's look at a practical example of how you would figure out your requirements. See our "Rules of Thumb" for fast cylinder action along with our Interactive Theoretical Speed Table **here**.



For example:

It is desired to move a 200lb load 12 inches at a rate of 20 cycles per minute. Using a 2" bore cylinder, about 64 psi is required to move the load.

Adding 25% gives an operating pressure of 80 psi. At the desired cycle rate and using 1/4" OD tubing (0.156" ID), pressure losses in the tubing are about 1.5 psi per foot.

It can be seen that the tubing run total (extend and retract lines) needs to be less than 10 feet or else the pressure losses due to friction will drop the available pressure at the cylinder below 64 psi and the cylinder will stall.

Once the cylinder stops moving however, the friction losses go away and the pressure builds back up to 80 psi. This situation results in a jerky motion of the cylinder as it moves the load.

Several factors could overcome this problem:

- System pressure can be increased to overcome friction losses
- Larger tubing can be used to reduce friction losses
- Different size cylinder could be tried that will reduce the flow.

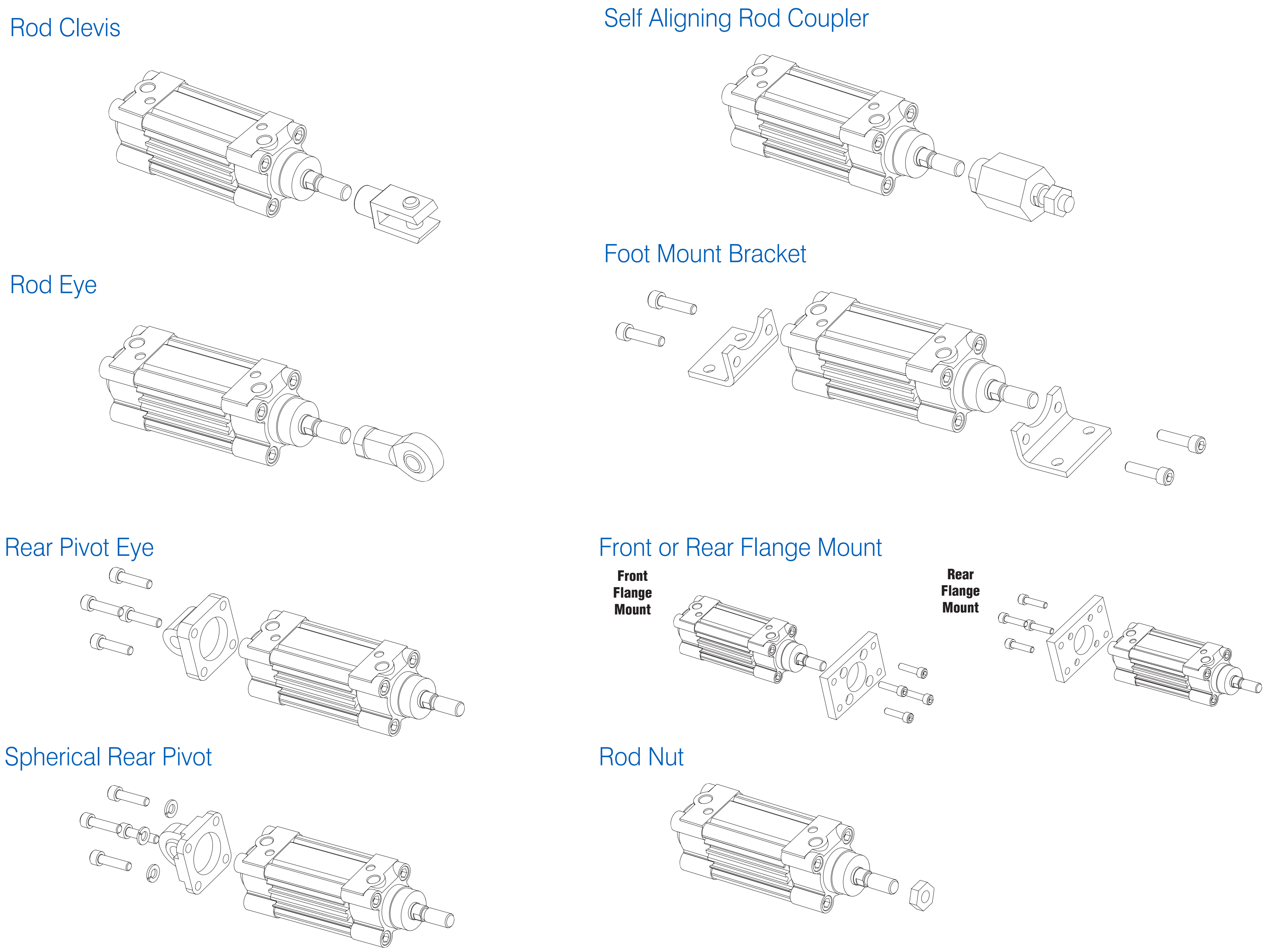
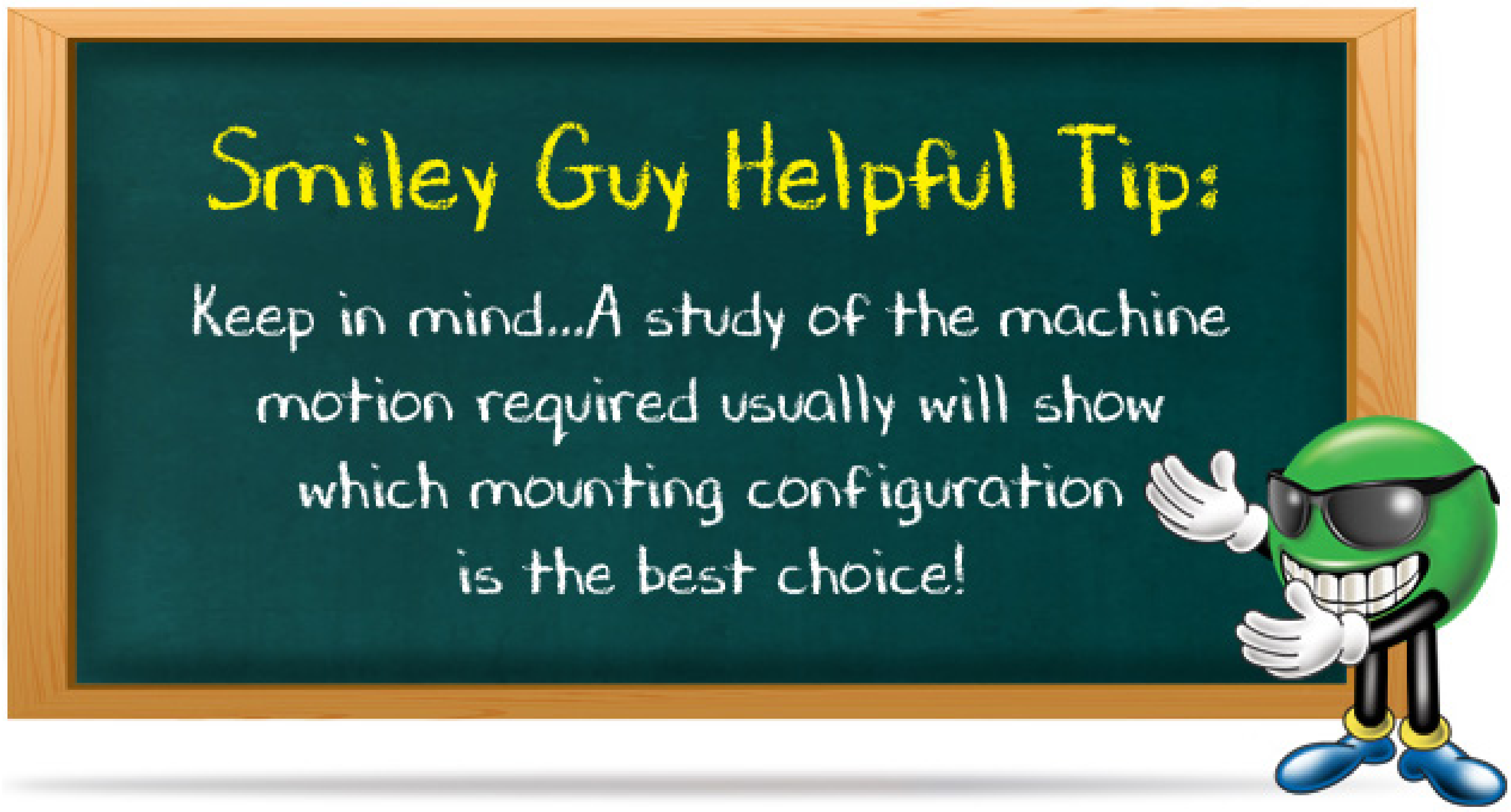


Figure 4E: Cylinder mounting accessories are often sold separately to allow one cylinder to be used in a number of mounting configurations

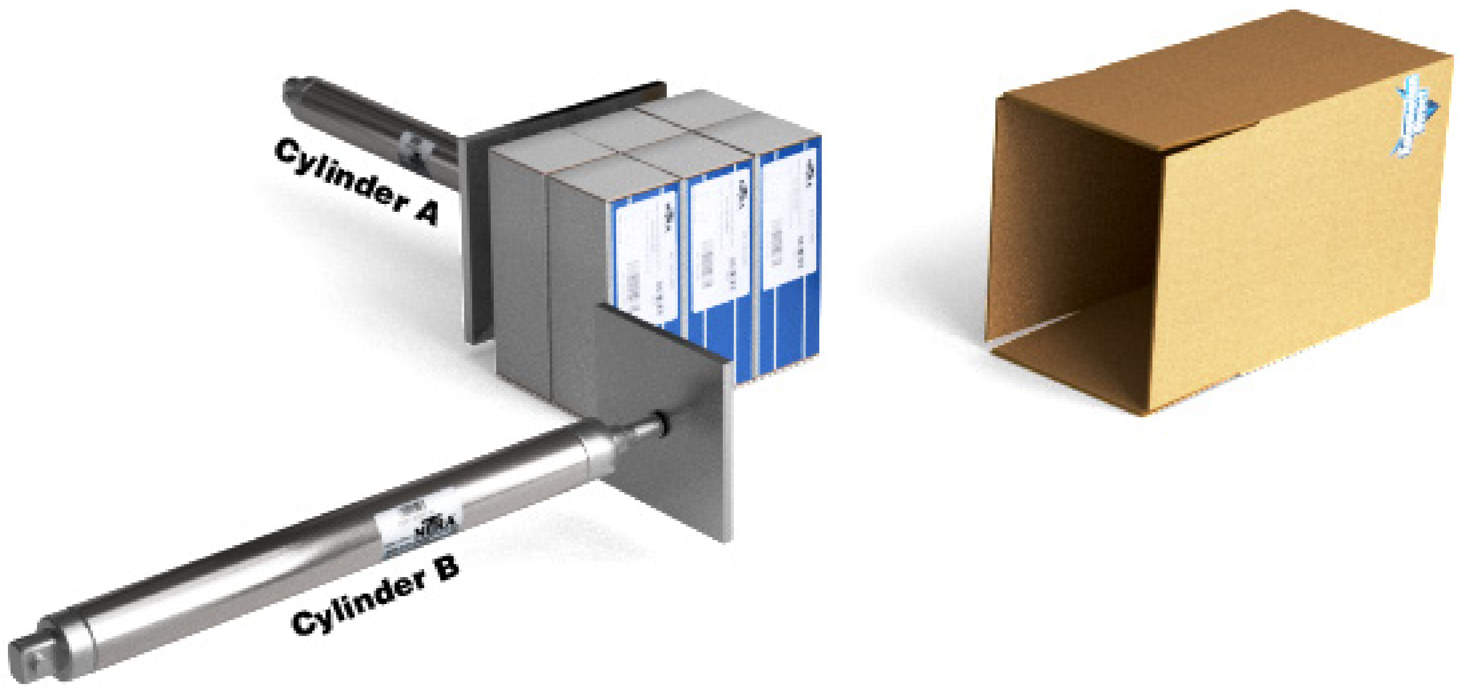
The final bit of basic selection criteria is the cylinder mounting arrangement. There are many different configurations available from various manufacturers. The more common ones include rigid nose or tail mount, trunnion mount, rear pivot mount and foot mount. A study of the machine motion required usually will show which mounting configuration is the best choice .

Once the basic actuator size and configuration is known, other options such as end-of-stroke cushions, magnetic piston (for position detection switches) or special seals should be considered when making the final selection.

Cushions do an excellent job of preventing a piston from banging into the end caps at the end of stroke. Flow control valves can prevent banging also, but at the expense of a slow travel speed. Cushions only slow the travel for about the last half inch of stroke. A cushion is very useful when the design requires a higher cycle rate or speed and also smooth starting and stopping.



Magnetic pistons allow simple magnetic proximity sensors to be mounted on a cylinder which can allow a control system to get feedback on the position of a cylinder. Since most cylinders are either extended or retracted, two proximity switches can monitor the operation of a cylinder. This can be very beneficial for machines that require a sequence of operations. Due to the nature of compressed air systems , the exact speed of a cylinder may vary slightly due to a number of factors outside of the control of the machine's control system such as supply pressure variations, moisture content in the air or ambient temperature. Therefore, a control sequence that begins Step 2 once Step 1 is confirmed complete and so on is a much more robust design.

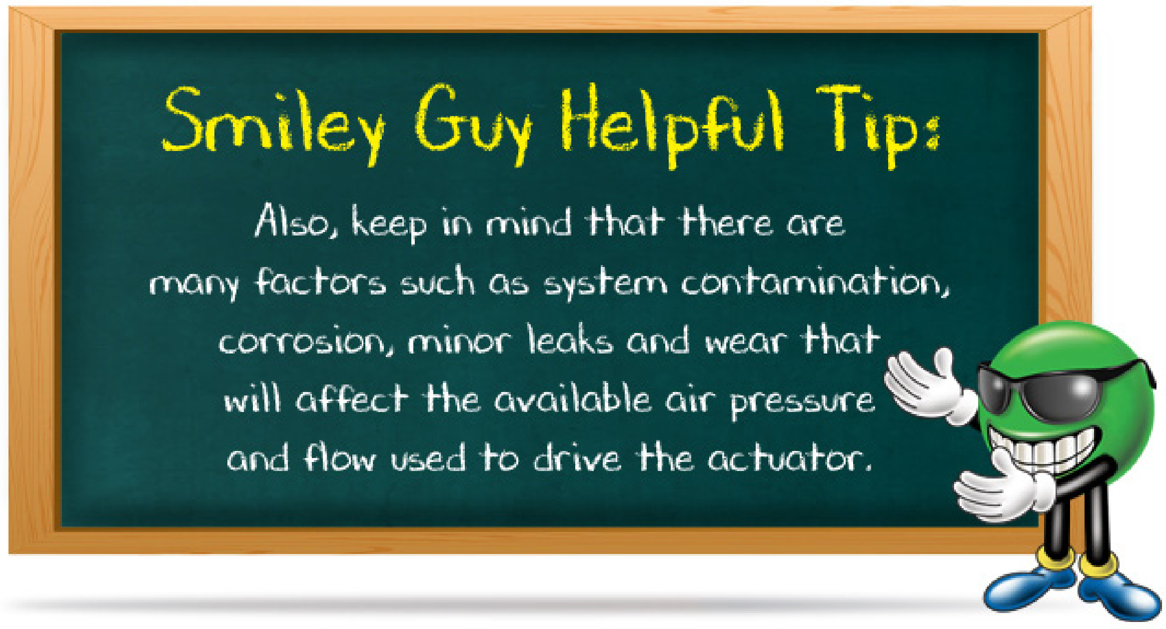


Sequence	Cylinder A	Cylinder B
Position 1	Retract	Retract
Position 2	Extend	Retract
Position 3	Retract	Extend
Position 4	Retract	Retract

Table 4A: Case packing operation example illustrating the importance of position sensors

When it comes to sealing a pneumatic system, remember that environmental conditions such as temperature extremes or corrosive materials may require special seal materials such as Viton. Most manufacturers offer these special seals as an option.

Since pneumatic actuators are at the working end of a fluid power system, producing the visible work of moving a load, pressure and flow requirements of the actuators must also be taken into account when selecting upstream components. Undersized upstream components can cause a pneumatic actuator to perform poorly or even make it unable to move its load at all. So let's now take a closer look at the upstream devices, starting with control valves that feed air to these actuators.



Valves for Pneumatic Cylinders | Actuators

In the pneumatic world, valves are the equivalent of relays controlling the flow of electricity in automation systems. Instead of distributing electric power to motors, drives and other devices, pneumatic valves distribute air to cylinders, actuators and nozzles.

Valve Activation

Pneumatic valves are activated in a variety of ways including manually, solenoid operated and air piloted. In their simplest form, 2-way and 3-way valves can be normally open (NO) or normally closed (NC), terms that refer to their normal states without power applied. Another very common valve is a 4-way valve which switches supply and exhaust between two outlet ports.

Manually activated valves are typically switched open and closed by a foot pedal, toggle actuator, handle, knob or push button. An operator controls the activated position of the valve, and a spring or the operator returns the valve to its home position.

Solenoid operated valves use an electrical coil to control the position of a poppet, plunger or spool to open or close a valve. Typical solenoid control voltages are 12VDC, 24 VAC/DC, 120VAC or 240VAC.

Air piloted valves are operated by an external air source such as a solenoid operated valve in a remote location. The valve can also be internally air piloted, enabling use of a smaller integrated electric solenoid to provide an air pilot signal to control the larger valve spool.

Figure 5A: Three very common types of control valves

Valve Type

With pneumatic valves, the configuration or valve type indicates how air is connected to the device and switched through the valve. This configuration has a strong influence on the device the valve is controlling, and understanding this is critical for specifying the proper valve for the application.

The Pneumatic Circuit Symbols Explained section has the information needed to understand valve configurations, but these symbols must be interpreted. The pneumatic symbol for a valve has three parts: actuation (how the valve is actuated), position (the number of positions and ports) and flow (how the air flows through the device). The actuation methods are on the left and right of the symbol, and can be thought of as pushing the boxes left or right. The number of boxes indicates the number of positions, typically two or three. Flow of supply air or exhaust, for each position, is defined by the information in each box.

Each valve position has one or more flow paths, and the arrows in each box represent flow of air and exhaust. The point where each path touches a box is called a port, and to determine the number of ports, one must count a single box of the symbol. The flow path can also be blocked, indicated by a "T" symbol.

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Valve Port and Position Types

The number of ports and positions define the type of work a valve is designed for, so selecting these options is a critical design decision. A 2-port or 2-way, 2-position valve has one inlet port and one outlet port. This type of valve is on or off, with no way to vent air pressure, unless that is its only function.

The number of different pathways for air to travel in or out of the valve are referred to as "ways" while the different available states are called "positions". Valves commonly used in industrial applications are either a 2-, 3- or 4-way configuration, 2- and 3-way valves have 2 positions while 4-way valves can be either 2- or 3-position.

Common pneumatic valve types

- 2-port (2-way), 2-position
- 3-port (3-way), 2-position
- 5-port (4-way), 2-position
- 5-port (4-way), 3-position

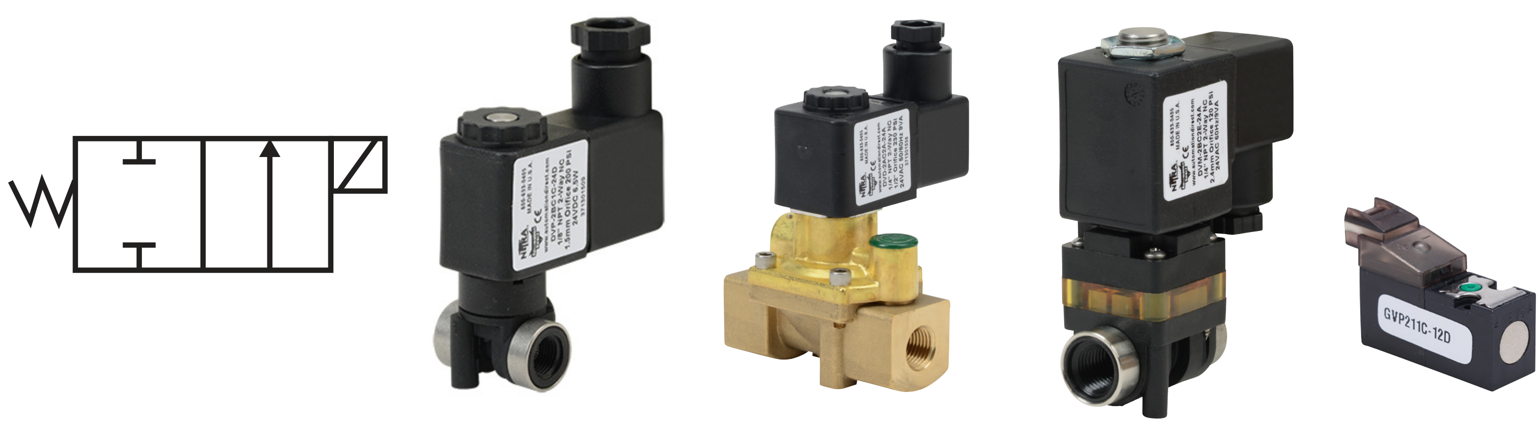
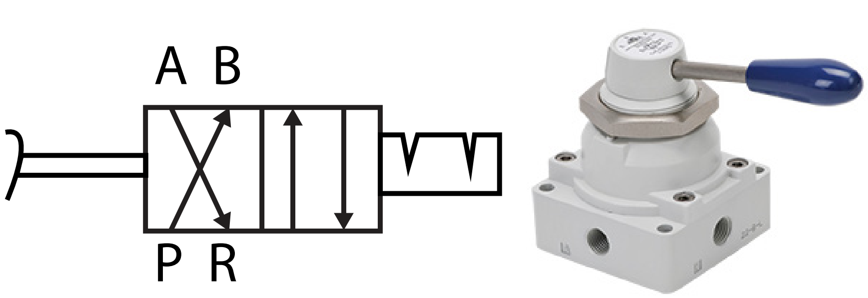


Figure 5B: 2-Port (2-way), 2-position, normally closed solenoid valve, spring return

Figure 5C: 3-Port (3-way), 2-position, normally closed solenoid valve, spring return



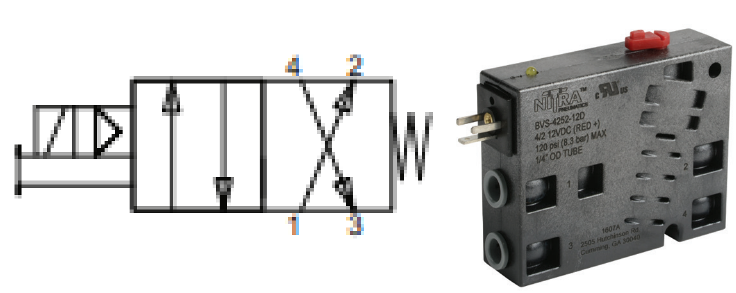


Figure 5D: 4-Port (4-way), 2-position, detented rotary manual valve

Figure 5E: 4-Port (4-way), 2-position, solenoid valve, spring return

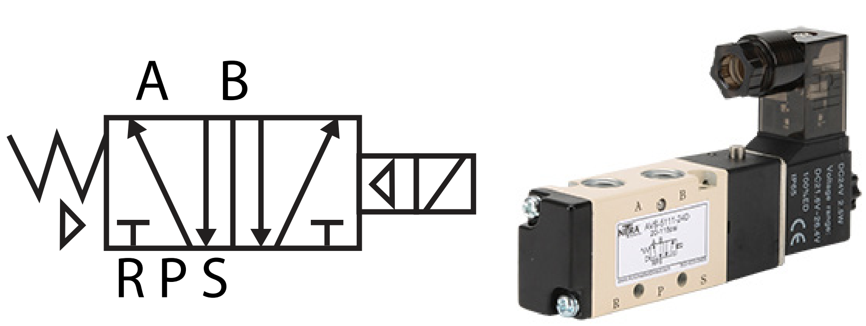


Figure 5F: 4-way (5-port), 2-position, solenoid valve, spring return

Figure 5G: %-port (4-way), 2-position, DOUBLE solenoid valve

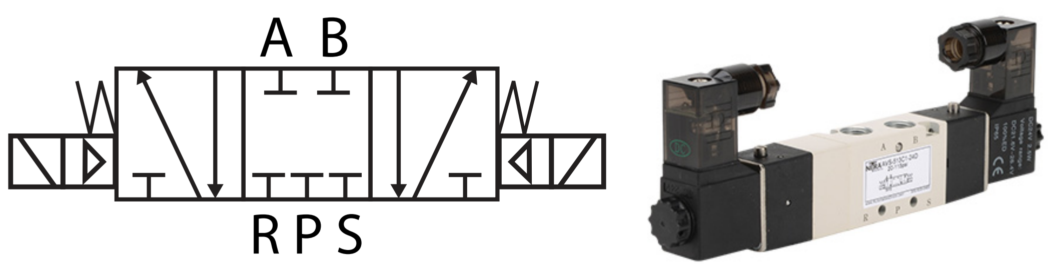


Figure 5H: 4-way (5-port), 3-position closed center, solenoid, spring centering

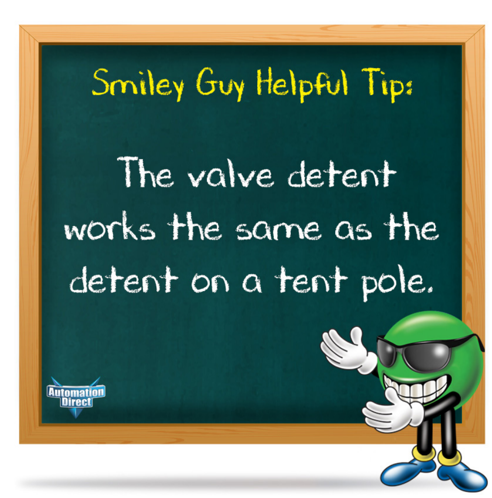
By adding a third port, the 3-port or 3-way, 2-position valve can both supply and exhaust pressure. The three ports are air in, air out and exhaust. While exhausting pressure is important for cylinder movement, this type of valve only works well in applications such as single-acting cylinders with a spring return, or in air blow off applications such as blowing chips in a machining process.

Adding two more ports turns the valve into a 5-port (4-way), 2-position valve. A 5-port valve is technically a 4-way valve since there are two ports open to 'Exhaust'. This is mainly done to simplify valve construction.

This is the most popular directional control valve because it can extend and retract double-acting cylinders, providing a wide range of control capabilities. This type of valve includes an inlet port, two outlet ports and two exhaust ports. In a 2-position configuration, one output is flowing air from the inlet and the other is flowing air to an exhaust port. When the valve is switched, the two outputs are in opposite modes. This is the most common way to extend and retract a double-acting pneumatic actuator, pressurizing one side of the cylinder while exhausting the other.

Keep in mind that 2-position, single solenoid valves have a spring return. So with an energized valve, if the double-acting cylinder it's connected to is extending, that cylinder will retract if electrical power is lost (such as when an emergency stop is pressed) but air remains on. If the emergency stop also dumps air pressure in the system, as recommended, the cylinder will retract once pressure is restored unless the valve is re-energized

If a 2-position, double solenoid valve has a detent feature, the valve spool is held at whichever position it was at the moment the emergency stop was pressed. If the cylinder was at mid-stroke when the emergency stop was pressed, when air is reapplied, the valve will command the cylinder to continue motion to the original energized position, even with both solenoids on the valve de-energized. This motion, due to the maintained valve position, can cause issues. For example, unintended cylinder motion after an emergency stop can damage tooling and should be examined during design.



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3-Position Valves

The 5-port or 4-way, 3-postion valve offers a center position that can be specified to either exhaust or block pressure when neither valve solenoid is actuated. These valves are typically used in applications where it is a requirement to stop a cylinder in mid stroke. They are also used to inch or jog a cylinder, or when air must exhaust during an emergency stop and no cylinder movement is allowed after air is reapplied until a reset button or start button is pressed.

Caution is required when using these valves as there is additional control complexity. Center block 3-position valves can trap air and cause unexpected movement under emergency stop conditions, especially if tooling is jammed. To deal with this condition, all energy including trapped air should be removed when an emergency stop is pressed. Air can also leak out, causing the cylinder to drift or drop.

A 3-position center exhaust valve will dump all pressure to a cylinder under emergency stop conditions or when both solenoids are de-energized. During startup, there will be no air to control air flow to the cylinder, causing very fast and possibly damaging cylinder speeds during the first machine cycle. To prevent this condition, both sides of the cylinder must be charged with air pressure at startup.

Valve Form Factor

The form factor of the valve is often driven by its use. This includes both internal configuration and external design. Common internal configurations include poppet, diaphragm and spool. Poppet valves are usually direct solenoid operated, similar to a gate valve in a 2-way, 2-position application. A pilot piston, accessed from a pilot port, moves the valve stem opening the valve. Diaphragm valves work similar to a poppet valve but physically isolate the operator solenoid from the valve and the working fluid by use of the diaphragm. Spool valves, either direct or pilot actuated, are often used on 4-way, 2- and 3-position body ported valves. These spool valves are pistons with seals that when shifted move along a bore opening or closing ports depending on the position. They provide a simplified way to change flow paths, are easy to actuate and are not affected by pressure.

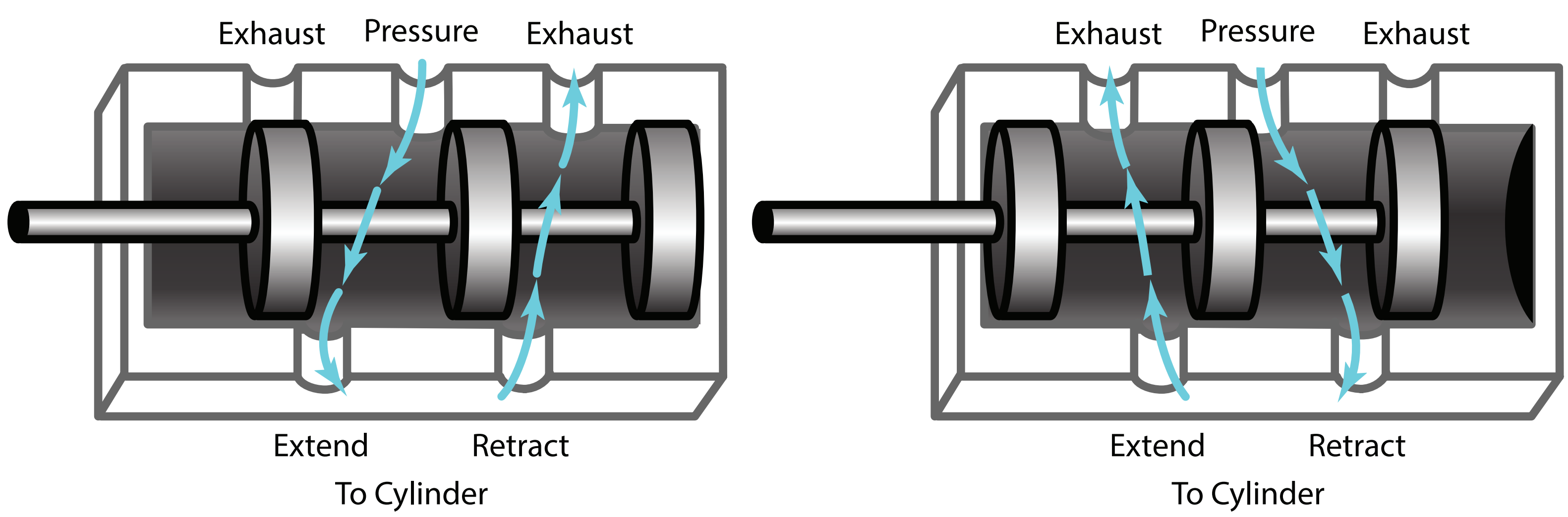


Figure 5G: 4-way valve often used to control a double-acting cylinder

The external form factor of many valves makes them stackable, allowing more valves to fit into a smaller area. Some valves are easier than others to mount individually, and some can be specified to mount either individually or as part of a manifold. Designers may wish to consider compact, modular, manifold-mounted valves in applications with high pneumatic valve counts.

Connecting the Valves

Valves have three primary electrical connection methods: hard wired, modular wired or digital communication. Many valves have a connector built in with removable flying leads, or a DIN style wiring connector.

Modular wiring is typically used with manifold mounted valve configurations. This wiring usually consists of a D-sub connector embedded in the manifold base. This provides an efficient and clean integration option for large pneumatic systems.

EtherNet/IP and other digital communication protocols are becoming a popular way to replace individual discrete wires with a single cable. This is particularly effective when a large number of valves in a small space require activation. This can also reduce cost on the controller side of the system by using a single communication port instead of multiple output modules.

Plumbing Methods

A variety of threaded ports or push-to-connect fittings are available to attach pneumatic tubing to valves.

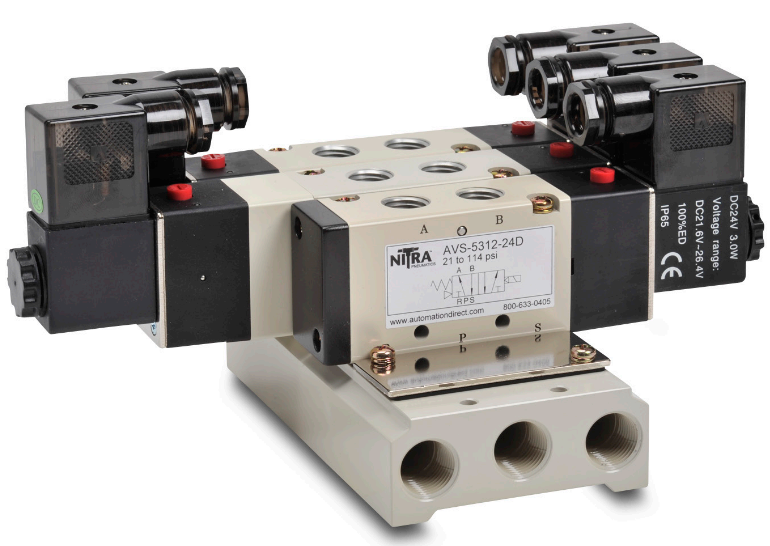
There are typically four ways to assemble and plumb a valve or group of valves: standalone, stacking valves, air manifolds, and modular valves.

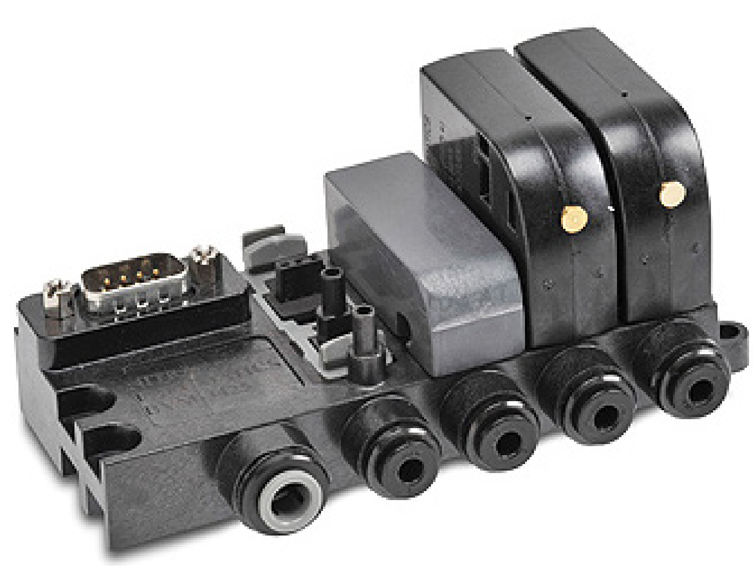
Stand-alone plumbing is often the only way to plumb a single valve, although some miniature valve types may require a single position manifold for mounting and plumbing. When multiple valves are used in a stand-alone configuration each must be plumbed and wired separately - creating unnecessary complexity. In these situations, it may be advantageous to consider one or more of the following options:

A stackable valve, such as the Nitra AVP series, can be plumbed as a single stand-alone valve, but is designed with inlets on both sides, so that it can be assembled into a bank of valves simply by adding an o-ring between adjacent units. A bank of two or more valves is easy to create, and a separate manifold is not required. Inlet air can be plumbed from either (or both) side of the valve bank.

Modular valves are similar to stacking valves, but are not used in stand-alone applications. They typically require a supply/exhaust plate on one side of the bank and an end plate on the other side. A wide variety of valve types can be specified to build the internal section, including 3-way or 4-way styles, and double- or single-solenoid types. Plumbing is greatly simplified, with shared inlets, and push-to-connect fittings built in. As mentioned in the previous section, the electrical wiring is also multiplexed, with clean multi-conductor cabling for the entire bank, or possibly a network connection, with Modbus TCP, EtherNet/IP or other networking technology.

Air manifolds are another way to create a bank of valves. A multi-position manifold is selected, and valves are mounted side-by side. Blanking plates are available to block unused positions and to allow for future expansion. Plumbing is simplified with shared inlet and exhaust ports. Separate control distribution blocks are available for some valve series to multiplex the wiring of valves that are mounted to manifolds.





Pneumatic Tubing & Hose

In today's modern pneumatic systems, there are a variety of choices available to get the air preparation systems, valves and cylinders connected. Most designers use flexible tubing or hose rather than rigid tubing, and many different types of both are available. Fittings offer many choices as well to meet the needs of a wide range of pneumatic system applications.

Tubing and Hose

Flexible tubing is the most common way to connect pneumatic valves to cylinders, actuators and vacuum generators in modern automated equipment, with hose a close second. With any type of tubing be careful to not confuse outside diameter (OD) with inside diameter (ID), and be aware that flexible and rigid tubing are two different types of materials.

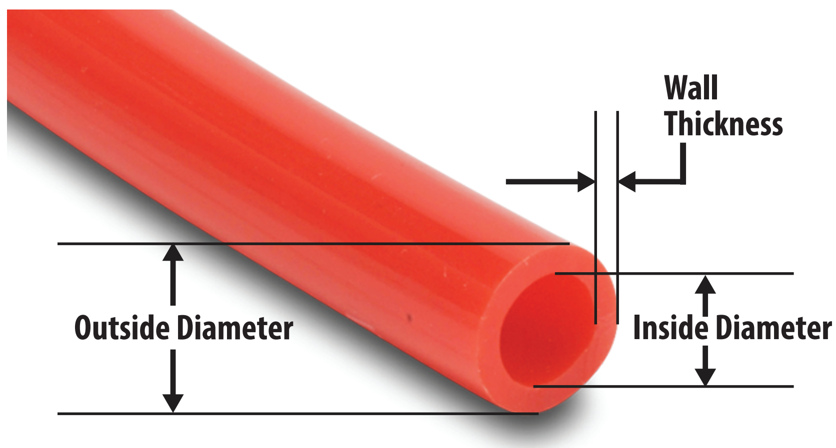
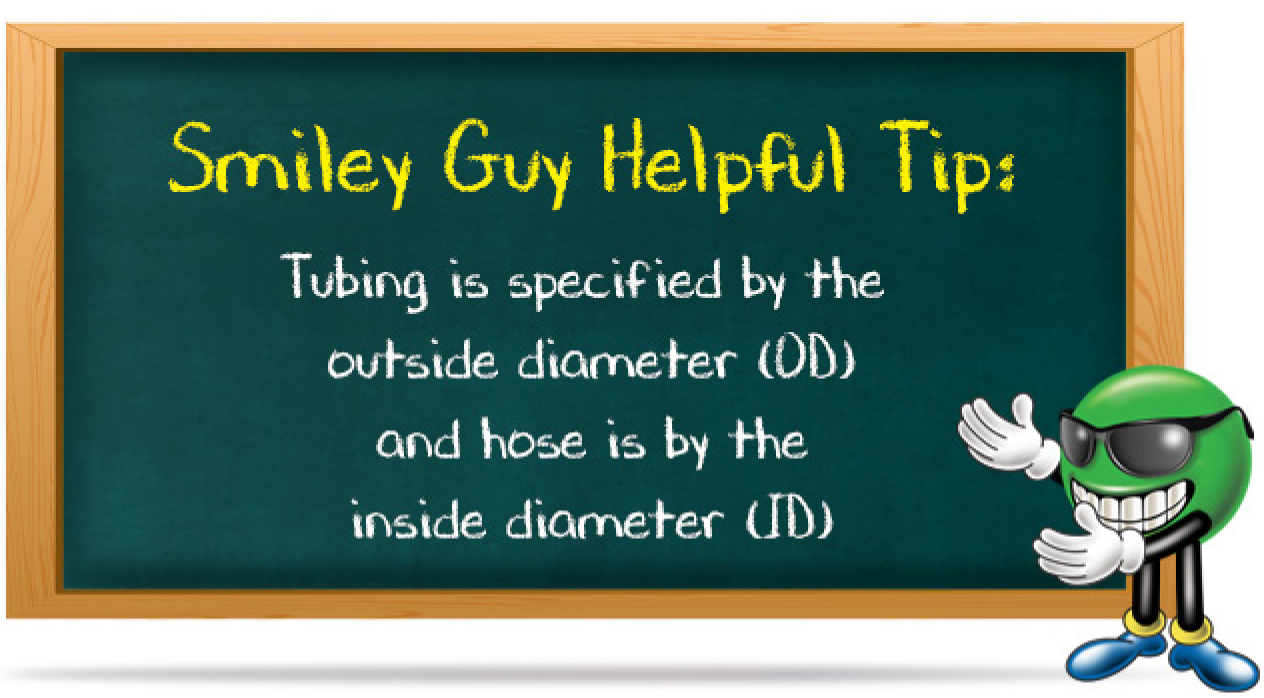


Figure 6A: Important dimensions to know when specifying pneumatic tubing

Figure 6B: Various tubing and hose examples



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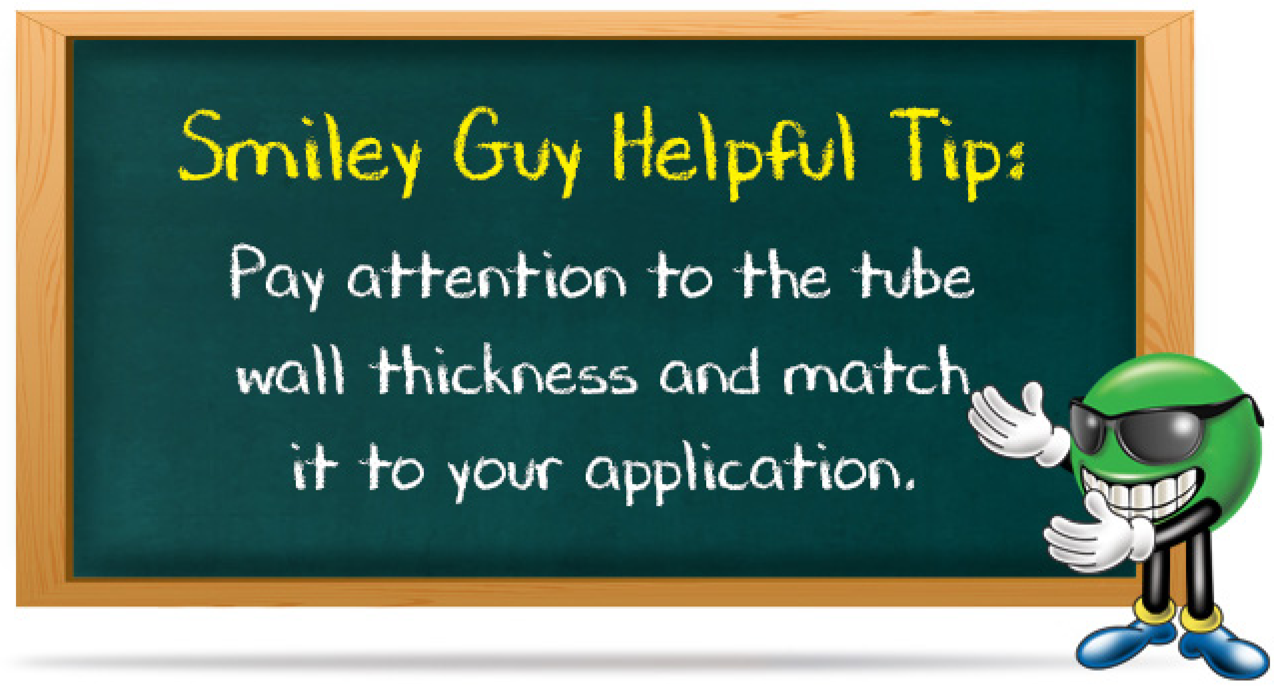
Most tubing used in pneumatic systems is less than 1″ OD with common pneumatic main supply circuits in the 1/4″ to 1/2″ tube OD range, and pneumatic control circuits in the 1/8″ to 3/8″ tube OD range. Pneumatic tubing is available in metric and English sizes, which of course shouldn't be mixed on the same machine.

In automated equipment and machine shop applications, the outside diameter drives the selection and specification process, matching the tubing to the push lock or other fitting.

If more air flow is needed, larger diameter is the obvious choice, but be aware that the inside diameter of tubing is affected by the tube wall thickness, with thick tubing walls reducing ID and air flow.



Hose is sometimes manufactured by adding a nylon braid between the inner and outer layers of tubing and attaching a rigid and a swivel fitting. Whether the hose is rubber or lighter weight polyurethane or other materials, it's strong, flexible and kink resistant—and thus an easy way to connect shop air to blow guns or other pneumatic tools. Hoses are commonly available in 1/4″, 3/8″ and 1/2″ diameters with national pipe thread (NPT) or quick disconnect fittings (QD). Check diameters carefully as hoses are often specified by inside diameter to ensure proper flow for the application.

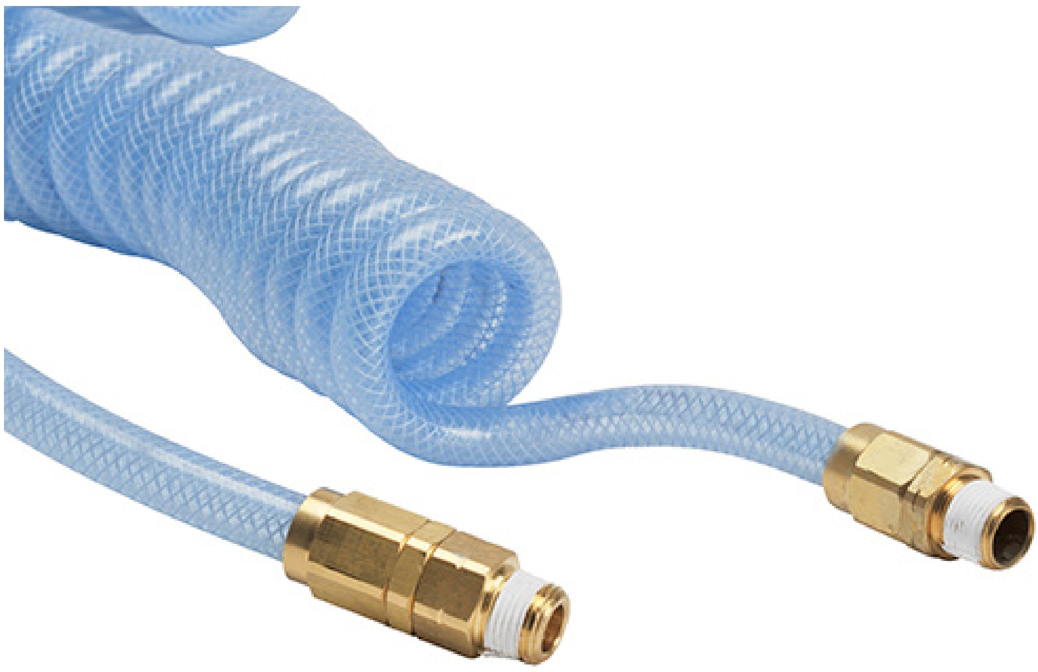


Figure 6C: Reinforced coiled hose is popular to use with pneumatic tools or moving components

Selecting the Right Tubing or Hose Material

There are a variety of materials used to make extruded plastic pneumatic tubing including:

- Polyurethane
- PVC
- Nylon
- Polyethylene
- PTFE
- Hybrid

Polyurethane tubing is strong and has excellent kink resistance compared to other material types. It has a working pressure of 150 psi or higher and is the most commonly used tubing material. It also has tight OD tolerance, and a wide range of push-to-connect fittings are available. A variety of tubing colors and diameters are offered to help identify pneumatic circuits, and UV stabilization is an option for outdoor use.

Polyurethane and PVC tubing are the most flexible of the materials above. Polyurethane tubing is very durable with outstanding memory, making it a good choice for coiled, portable or self-storing pneumatic hose applications. PVC is not as tough as polyurethane, but can be specified for food-grade applications, and is a good choice when high flexibility and low cost are required.

Nylon and polyethylene tubing and hose use harder plastics and are thus less flexible, making them a good choice for air distribution and straight run piping applications. Notable specifications of nylon tubing is its higher working pressure capability up to 800 psi with a temperature range up to 200°F, and excellent chemical resistance.

PTFE tubing has several notable properties including high heat resistance, excellent chemical resistance, and good dielectric properties. PTFE tubing can handle temperatures up to 500°F, is chemically inert, and can be used in applications sensitive to static electricity.

Reinforced hybrid PVC hoses feature a polyester spiraled yarn, allowing use in higher working pressure applications, as well as remaining highly flexible in extreme cold temperatures.