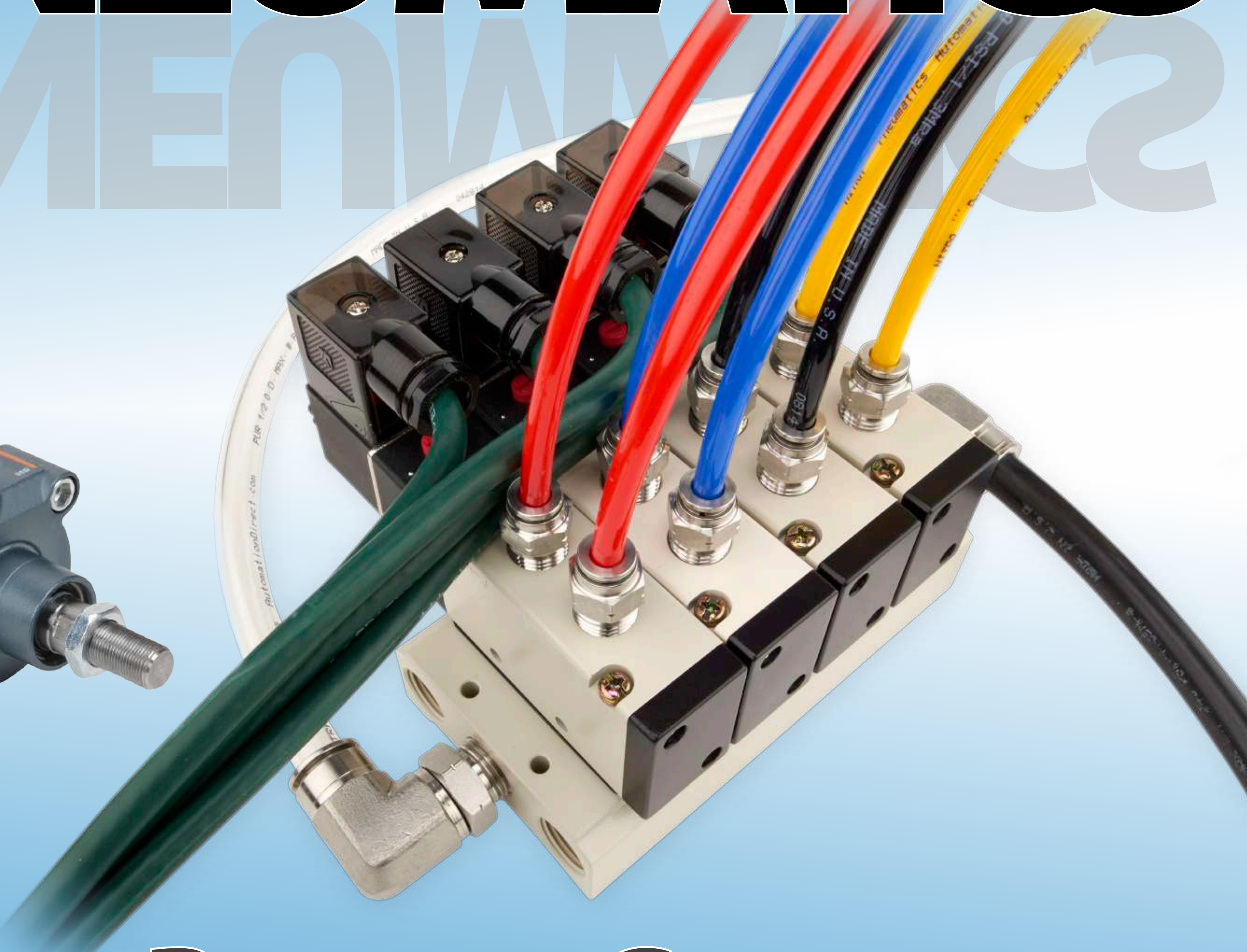
PNEUMATICS



PRACTICAL GUIDE

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ADC-005-Pneu

PNEUMATICS
Practical Guide

TABLE OF CONTENTS

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.

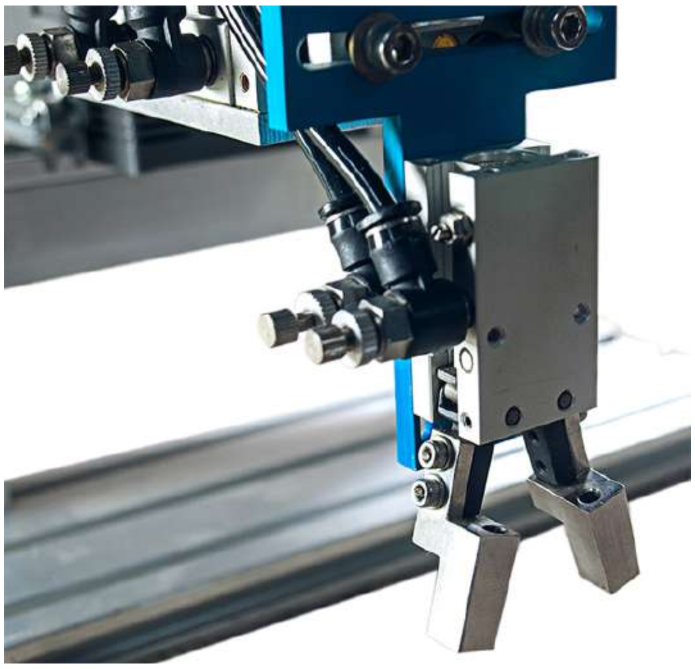


Figure 1A: Pneumatics in action (aluminum pneumatic robot hand)

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.

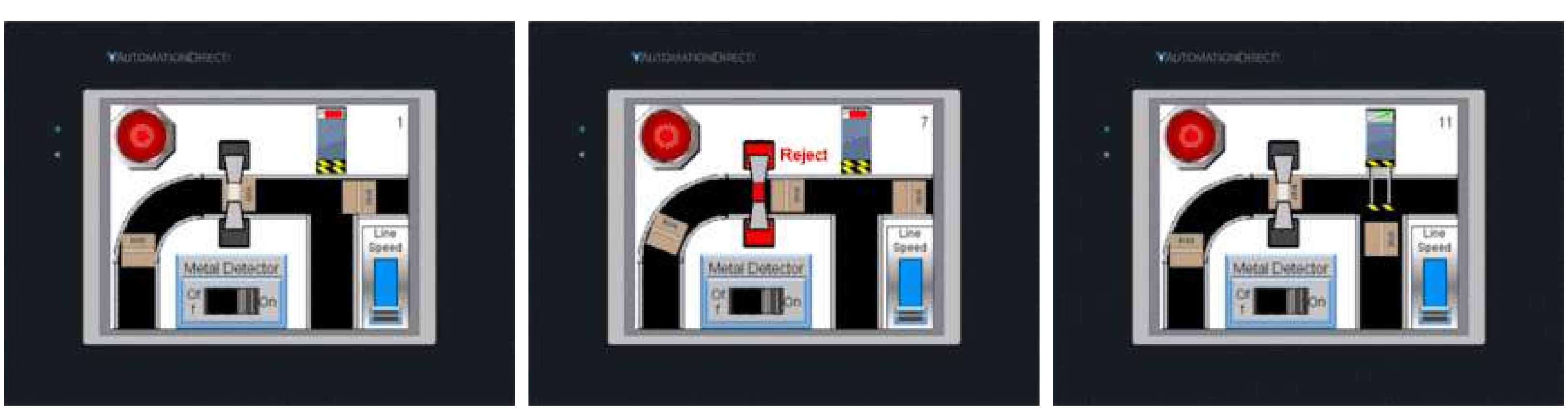


Figure 1B: Simple pneumatics application: Air cylinder powered ram to divert rejects to another conveyor

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

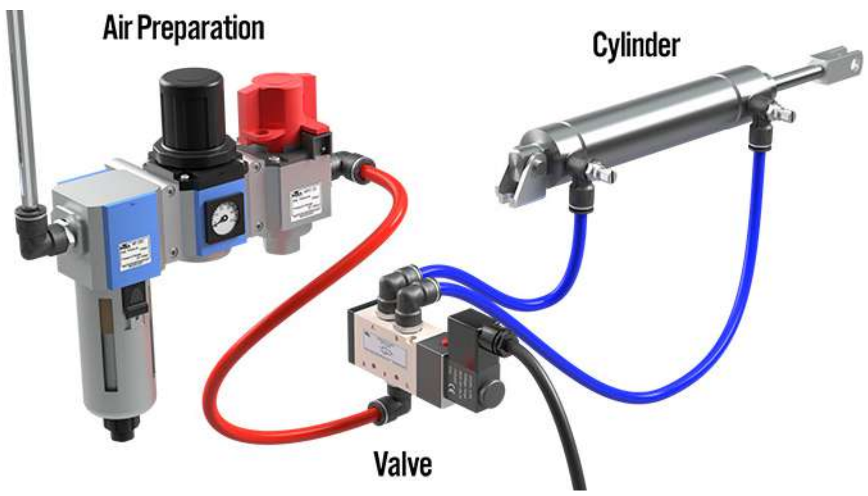


Figure 1C : Basic pneumatic system

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.

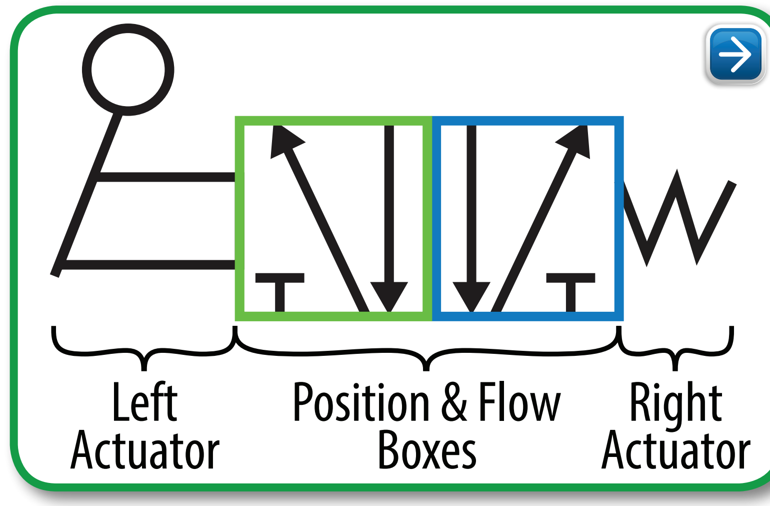


Figure 2A: 2 position, lever actuated, spring return valve

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.

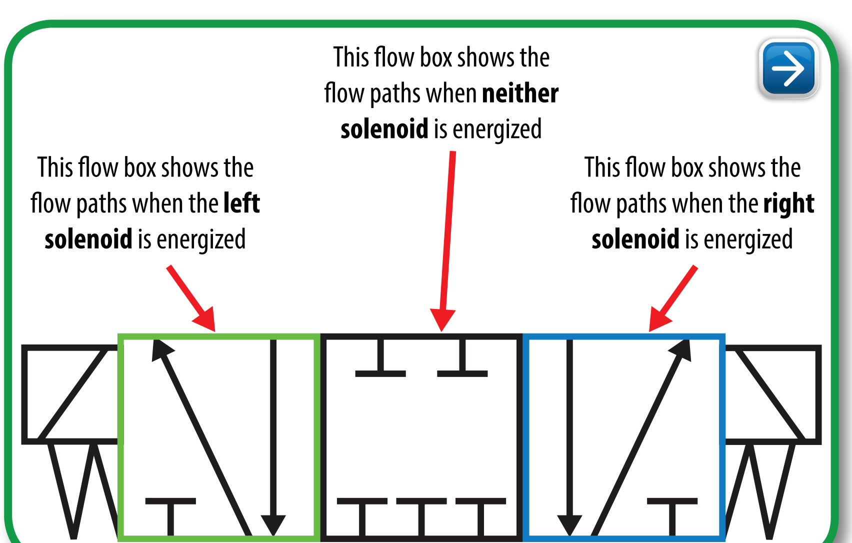
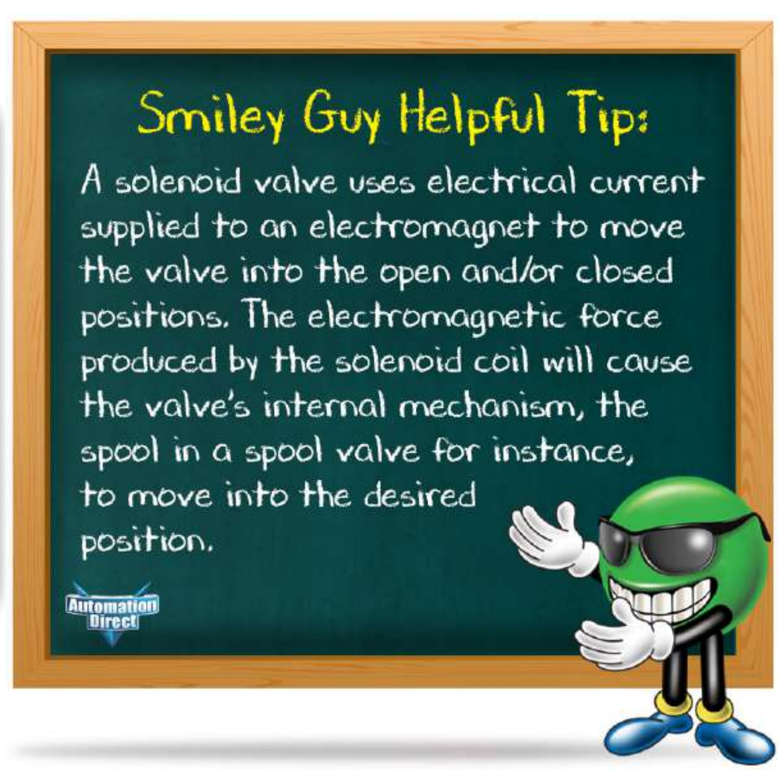


Figure 2B: 3 position, double solenoid actuated, spring return valve



Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Action
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Ports

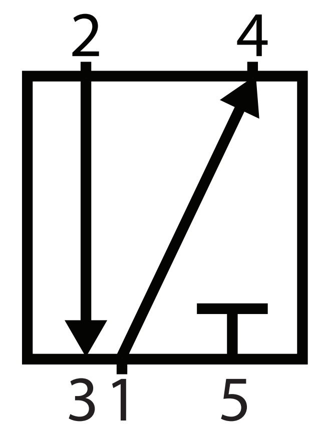


Figure 2C: 5-port valve

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

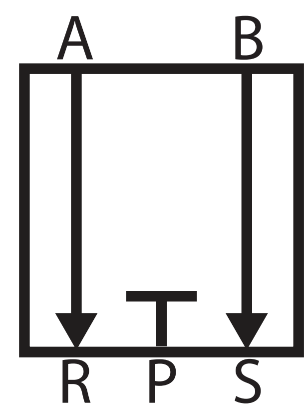


Figure 2D: Port labeling

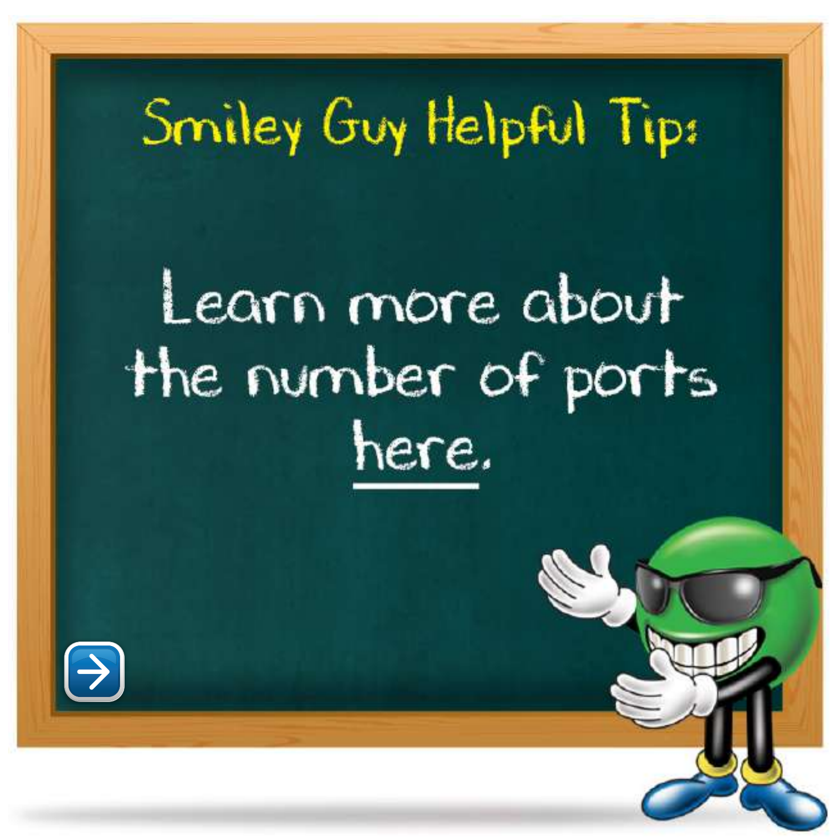
Port labels are typically shown on a single flow box per symbol. Different manufacturers label valve ports with different letters, but the labels at right are fairly standard. "P" represents the pressure inlet port, "A" and "B" are outlets (generally plumbed to the 'extend' and 'retract' ports on a cylinder),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

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.

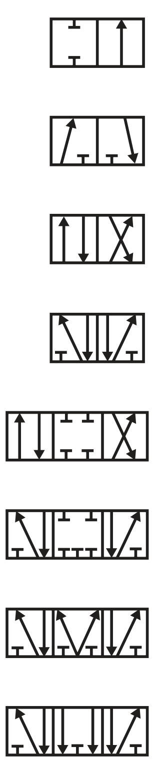
It has five ports, but it is considered a 4-way valve because two of the ports share the same exhaust function. This is a holdover from hydraulics – where the two exhaust paths are joined (internally to the valve), so that only one return port is required, and only one return line is required to get 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.



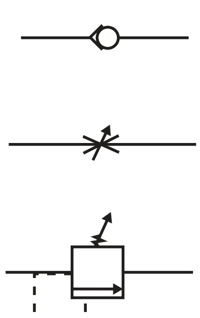
Common Valve and Actuator Symbols

Directional Control Valve Symbols



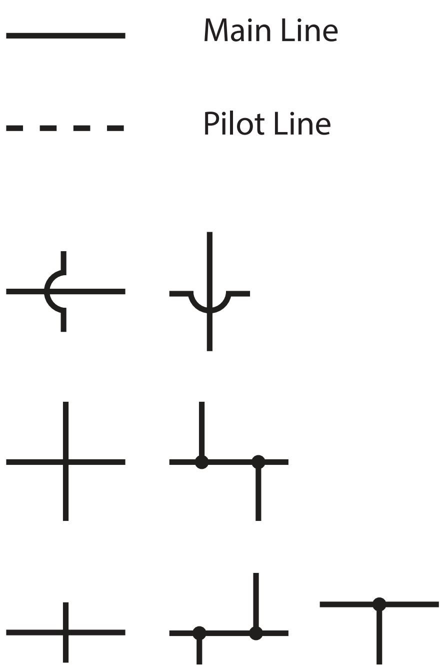
- 2-position, 2-way, 2 ported
- 2-position, 3-way, 3 ported
- 2-position, 4-way, 4 ported
- 2-position, 4-way, 5 ported
- 3-position, 4-way, 4 ported Closed Center
- 3-position, 4-way, 5 ported Closed Center
- 3-position, 4-way, 5 ported Pressure Center
- 3-position, 4-way, 5 ported Open Center

Simple Pneumatic Valves



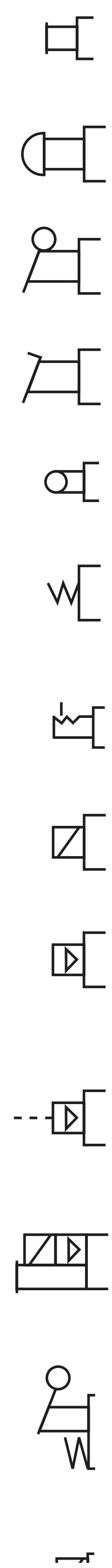
- Check Valve
- Flow Contol
- Relief Valve

Lines



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

Actuator Symbols

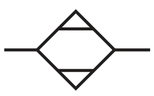


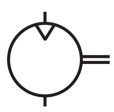
- Manual
- Push Button
- Lever
- Foot Operated
- Mechanical
- Spring
- Detent
- Solenoid
- Internal Pilot
- External Pilot
- Piloted Solenoid with Manual Override
- Lever Operated, Spring Return

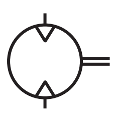
Other Pneumatic Symbols

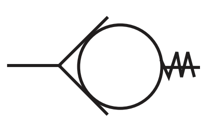
Other pneumatic components also have schematics or symbols, but these generally do not require as much explanation as those for the valves. Here are symbols for other commonly used pneumatic devices: Check out our Interactive Circuit Symbols **here**.

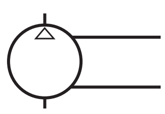

Accumulator

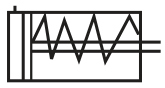

Air Dryer

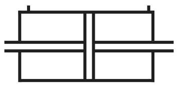

Air Motor (One Direction Flow)

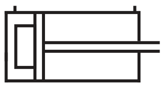

Air Motor (Two Direction Flow)

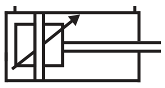

Check Valve (Spring Loaded)


Compressor

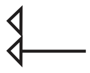

Cylinder (Spring Return)


Cylinder Double Acting
(Double Rod)

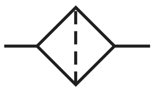

Cylinder Double Acting
(Single fixed cushion)

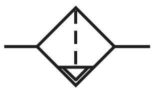

Cylinder Double Acting
(Two adjustable cushions)

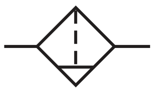

Differential Pressure

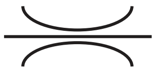

Direction of Flow

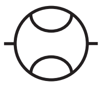
Exhaust Line or Control Line

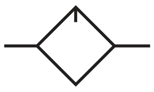

Filter


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.

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.

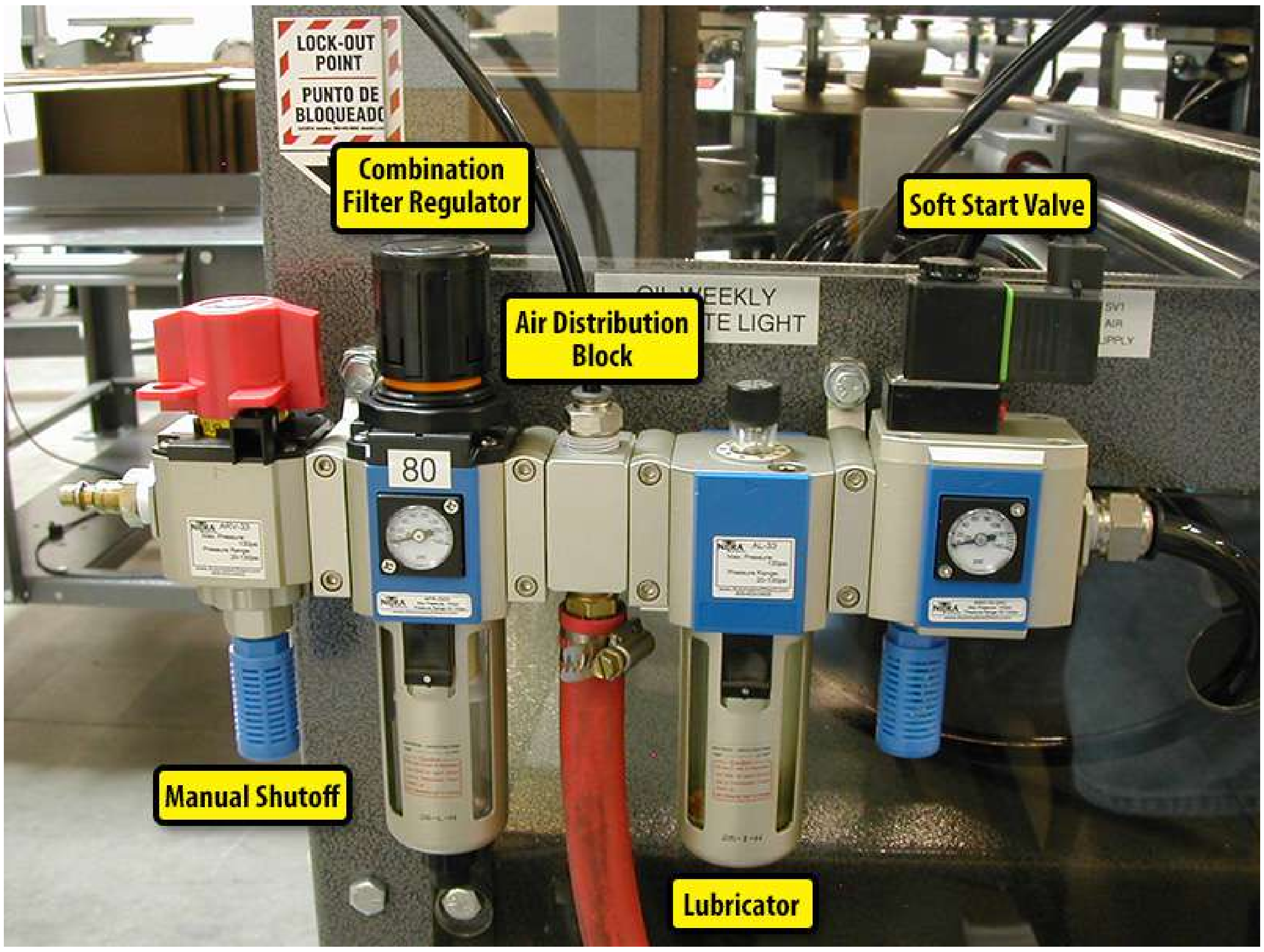


Figure 3A: Air preparation assembly on a machine using pneumatics

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.

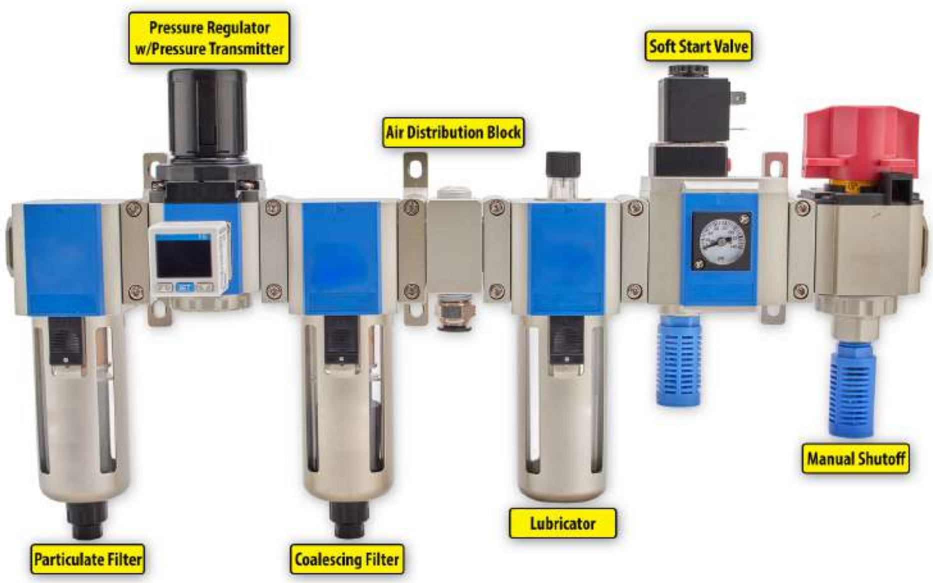


Figure 3B: Air Prep System

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.

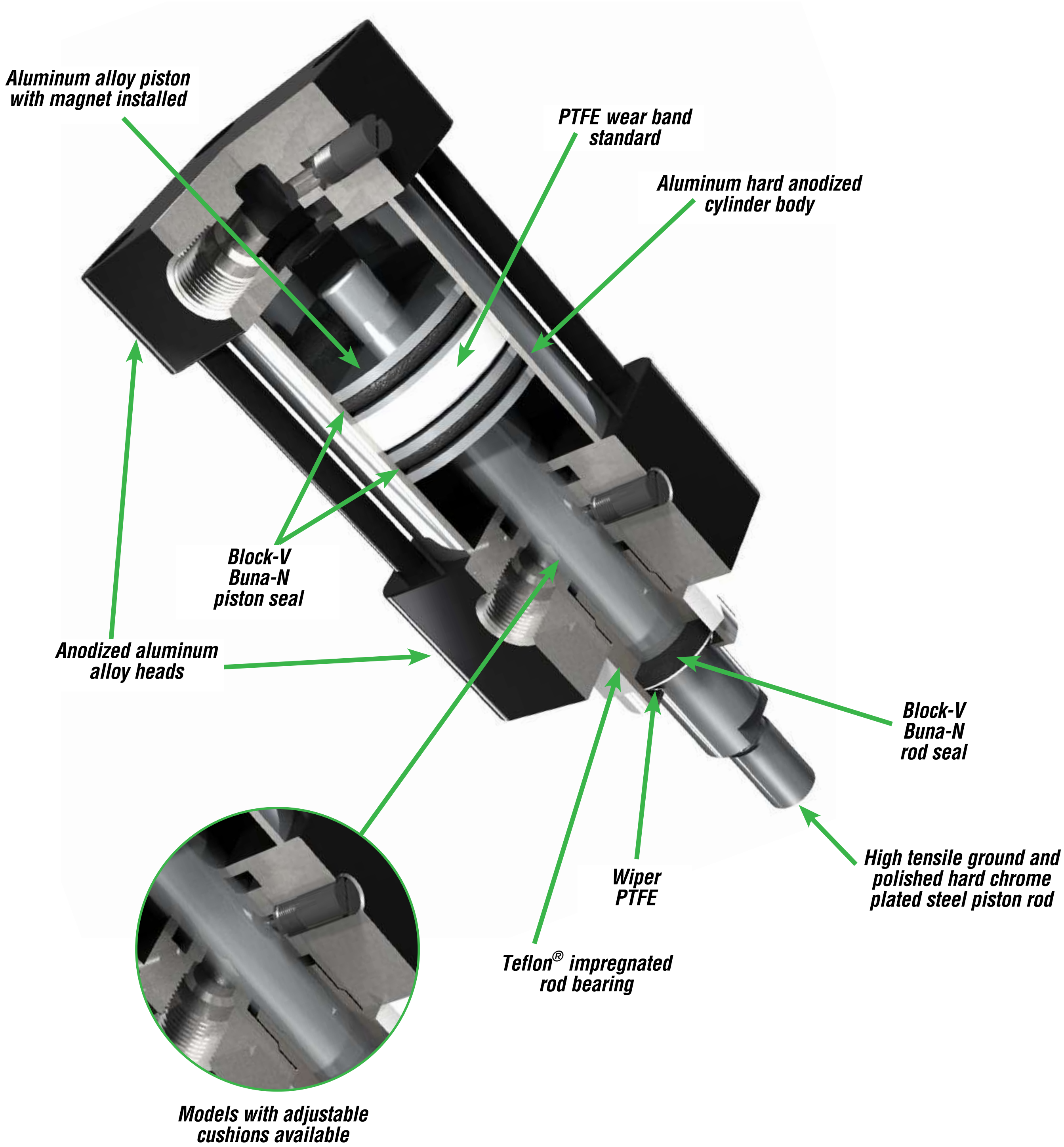


Figure 4B: Shows the primary components that make up a typical double-acting pneumatic actuator

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.

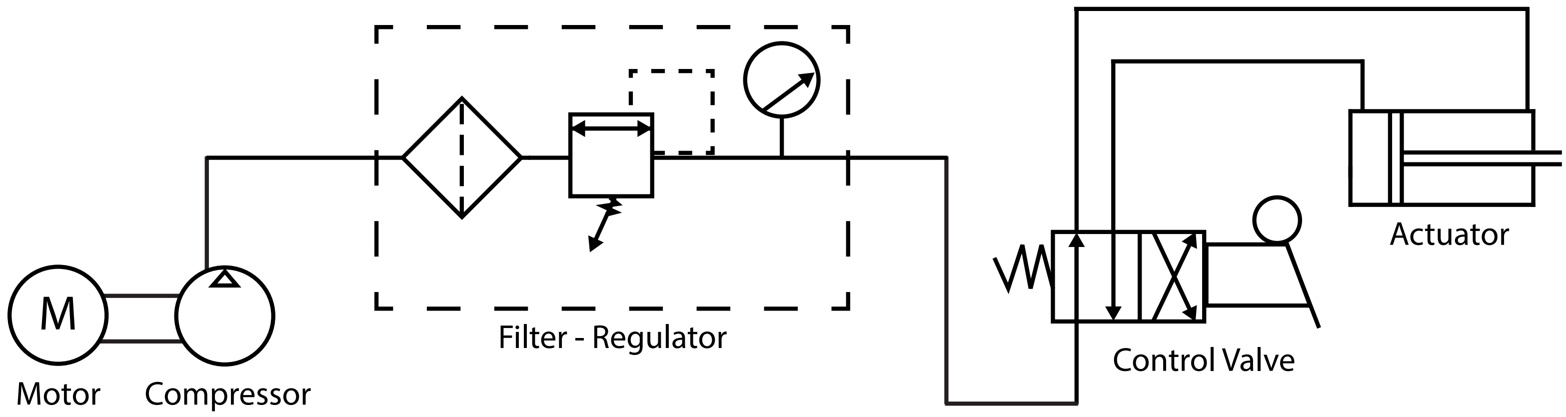


Figure 4C: A typical pneumatic system

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.

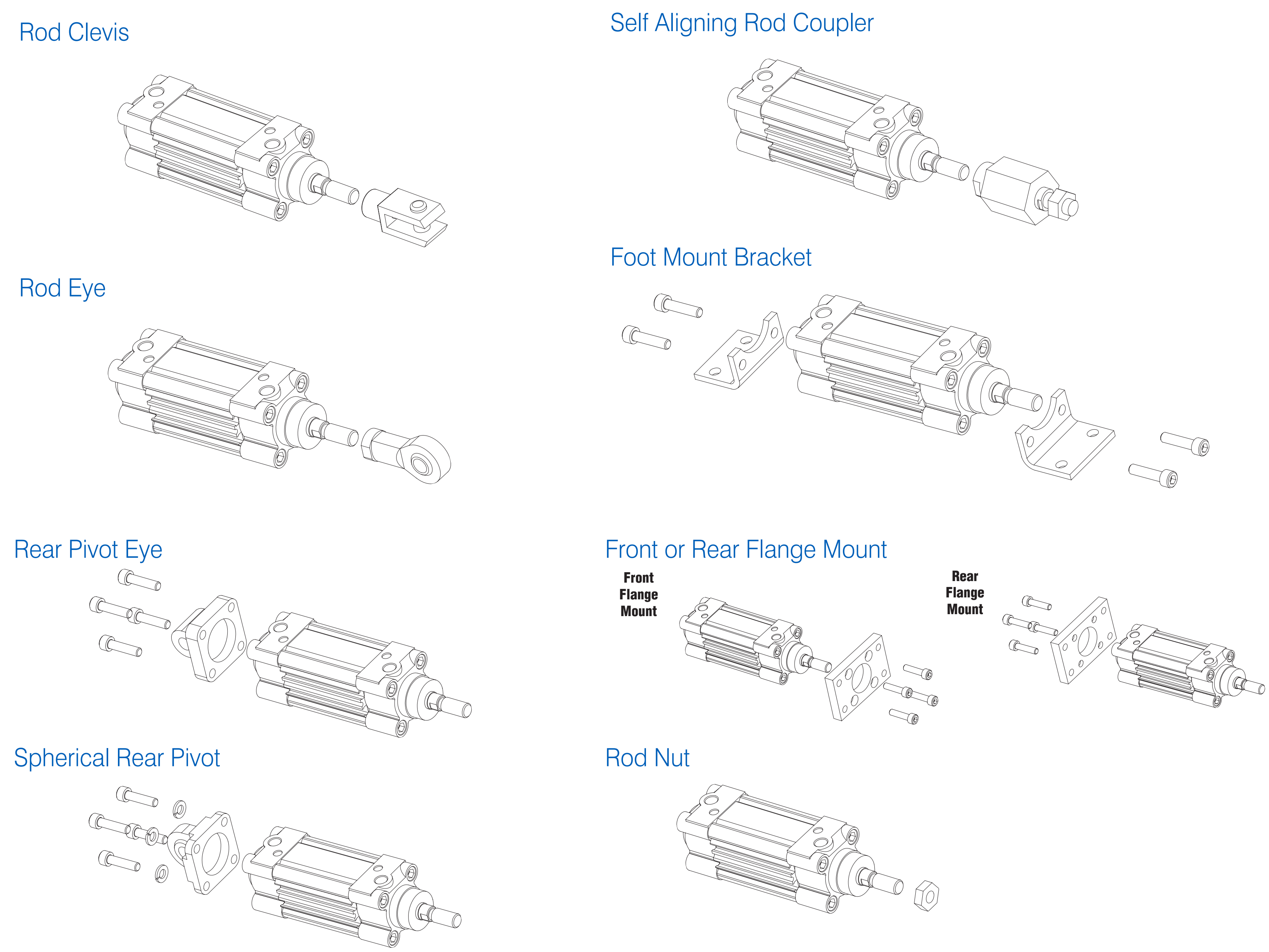
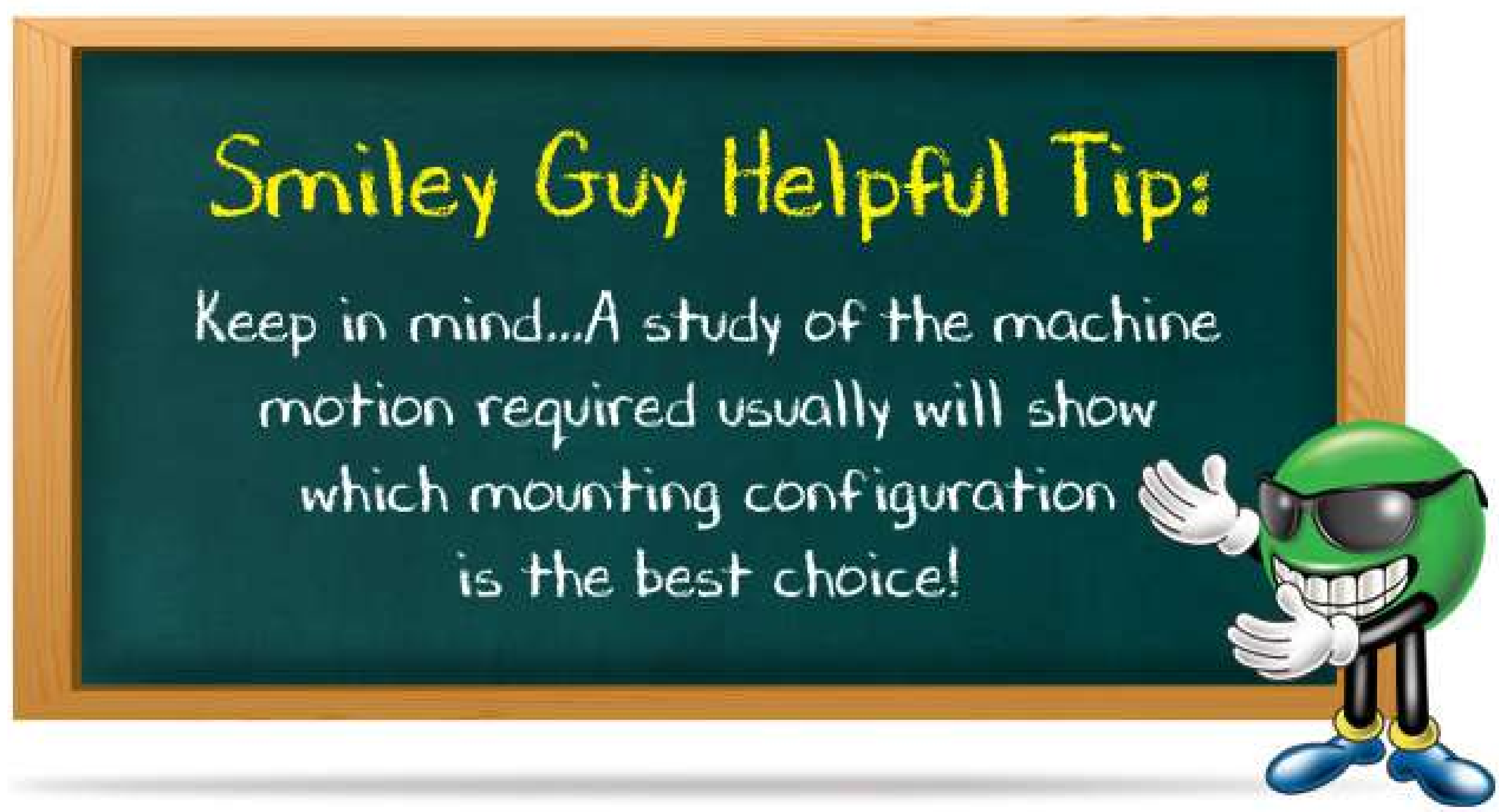


Figure 4E: Cylinder mounting accessories are often sold separately to allow one cylinder to be used in a number of mounting configurations

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.



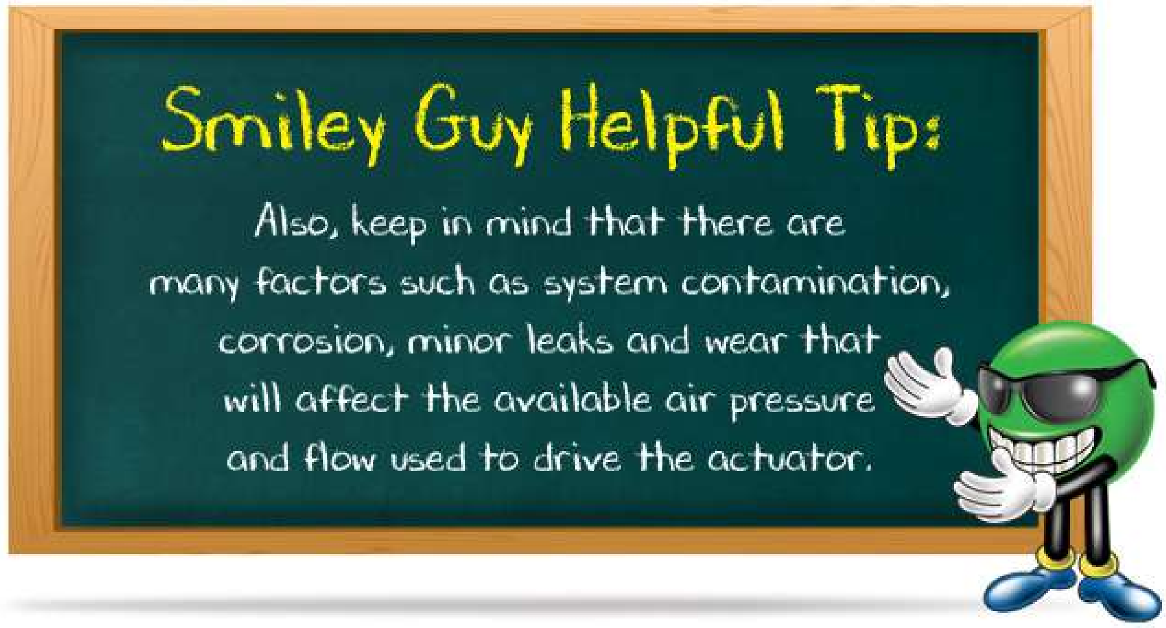
Magnetic pistons allow simple magnetic proximity sensors to be mounted on a cylinder which can allow a control system to get feedback on the position of a cylinder. Since most cylinders are either extended or retracted, two proximity switches can monitor the operation of a cylinder. This can be very 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.

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

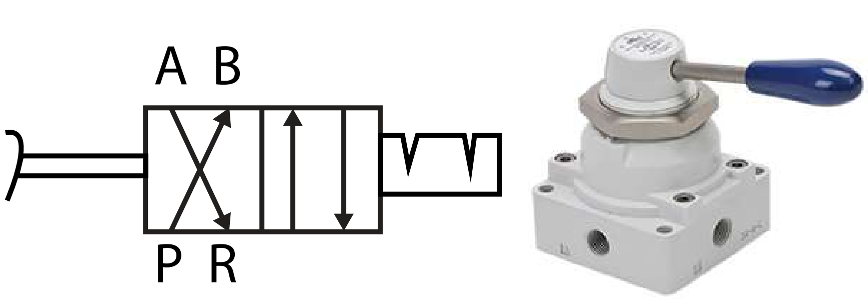


Figure 5D: 4-Port (4-way), 2-position, detented rotary manual valve

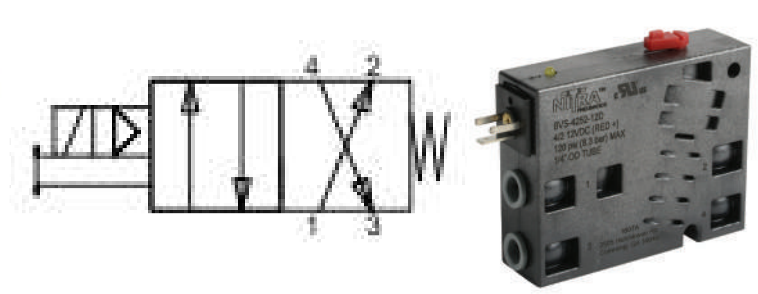


Figure 5E: 4-Port (4-way), 2-position, solenoid valve, spring return

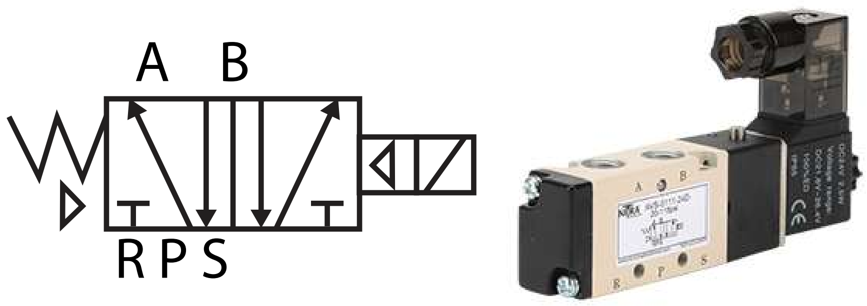


Figure 5F: 4-way (5-port), 2-position, solenoid valve, spring return

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

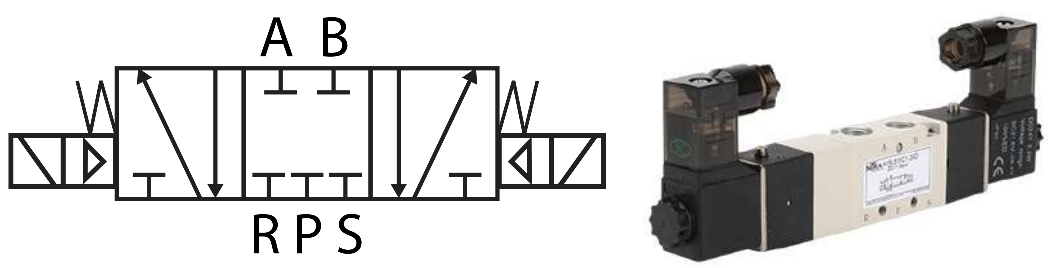


Figure 5H: 4-way (5-port), 3-position closed center, solenoid, spring centering

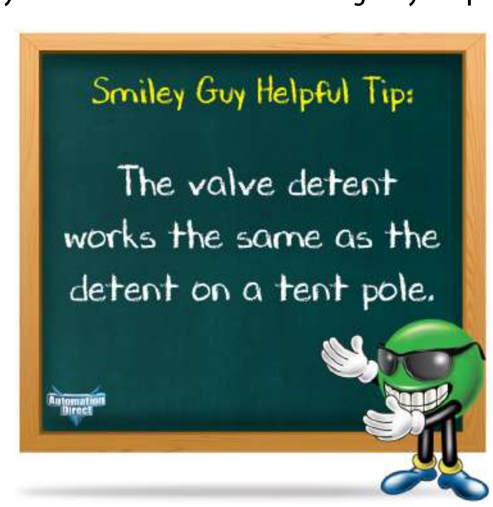
By adding a third port, the 3-port or 3-way, 2-position valve can both supply and exhaust pressure. The three ports are air in, air out and exhaust. While exhausting pressure is important for cylinder movement, this type of valve only works well in applications such as single-acting cylinders with a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



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.

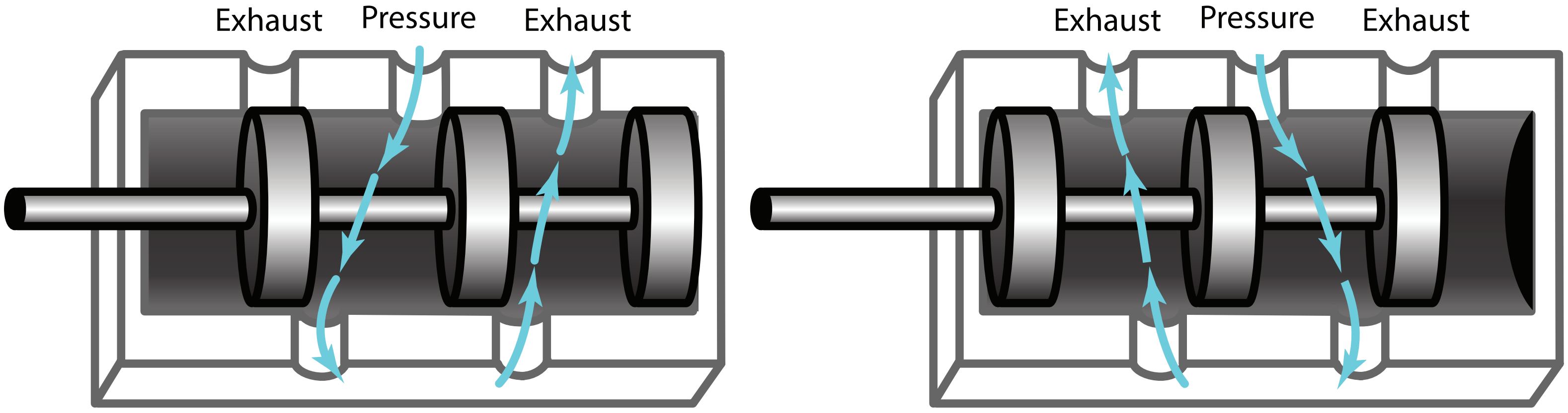


Figure 5G: 4-way valve often used to control a double-acting cylinder

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

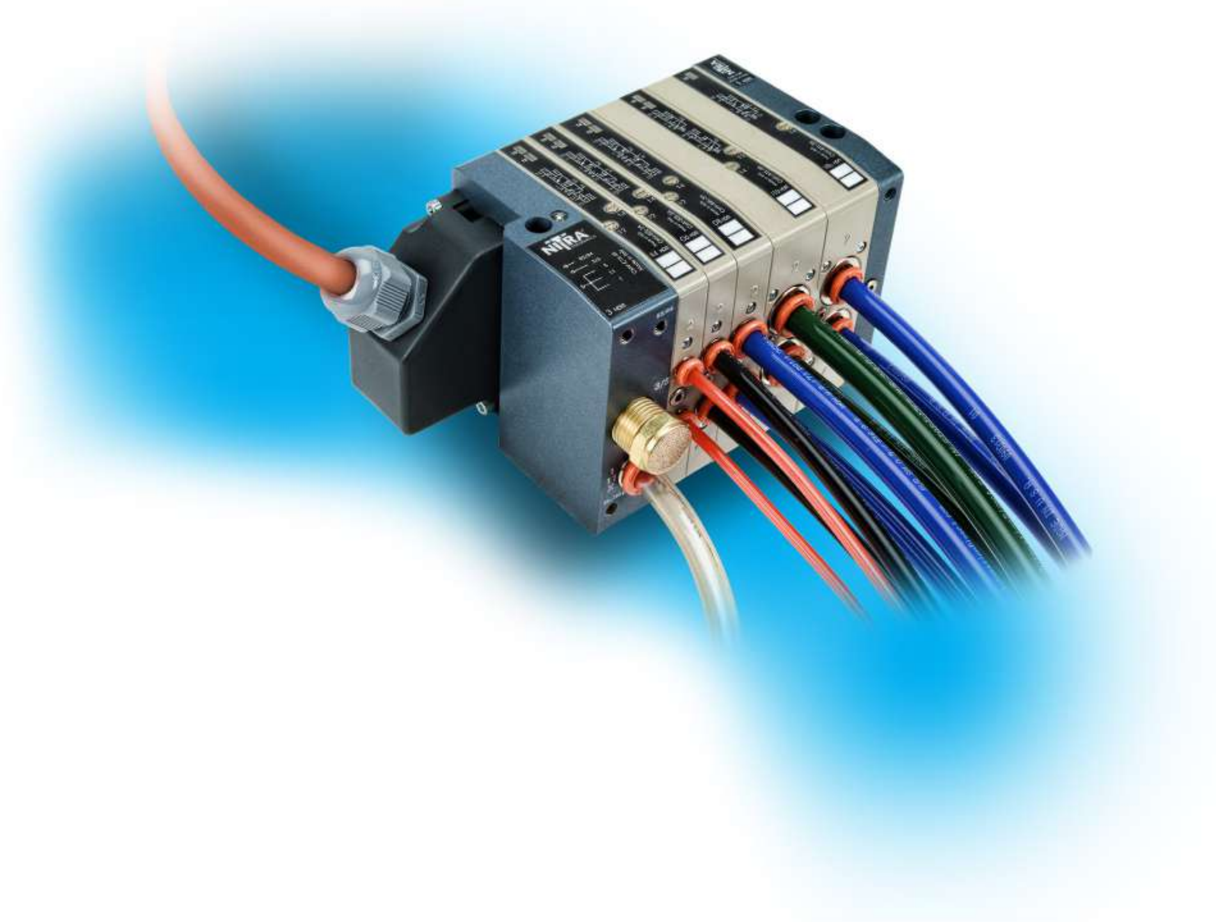
A variety of threaded ports or push-to-connect fittings are available to attach pneumatic tubing to valves.

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.

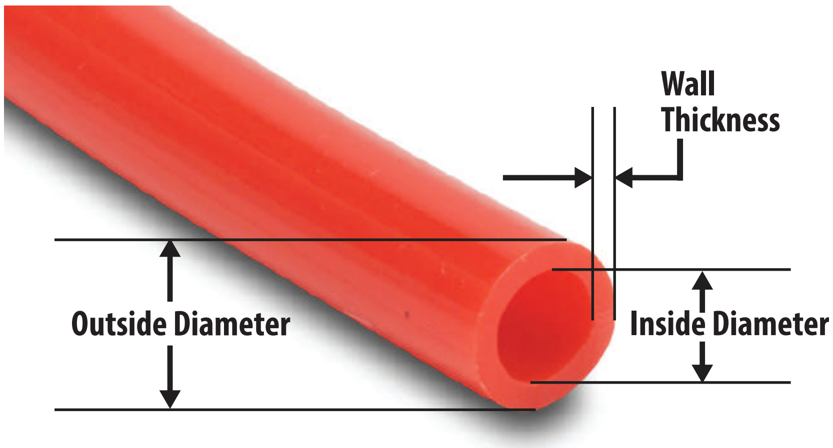
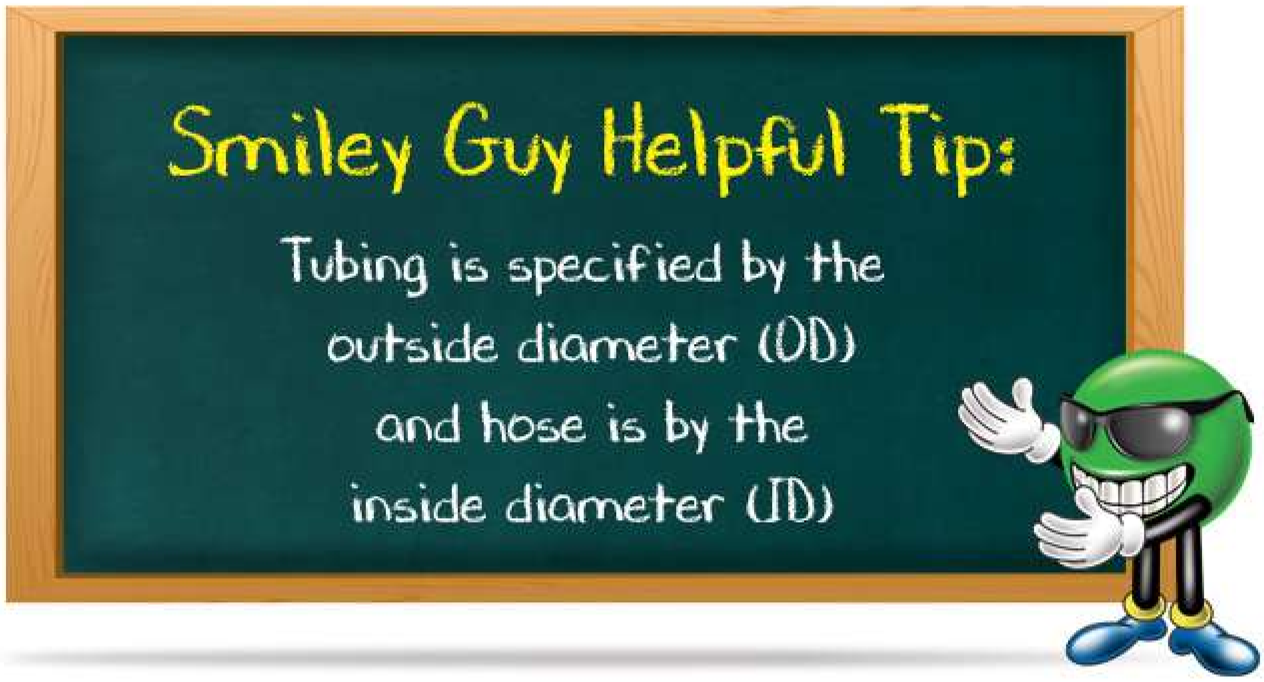


Figure 6A: Important dimensions to know when specifying pneumatic tubing

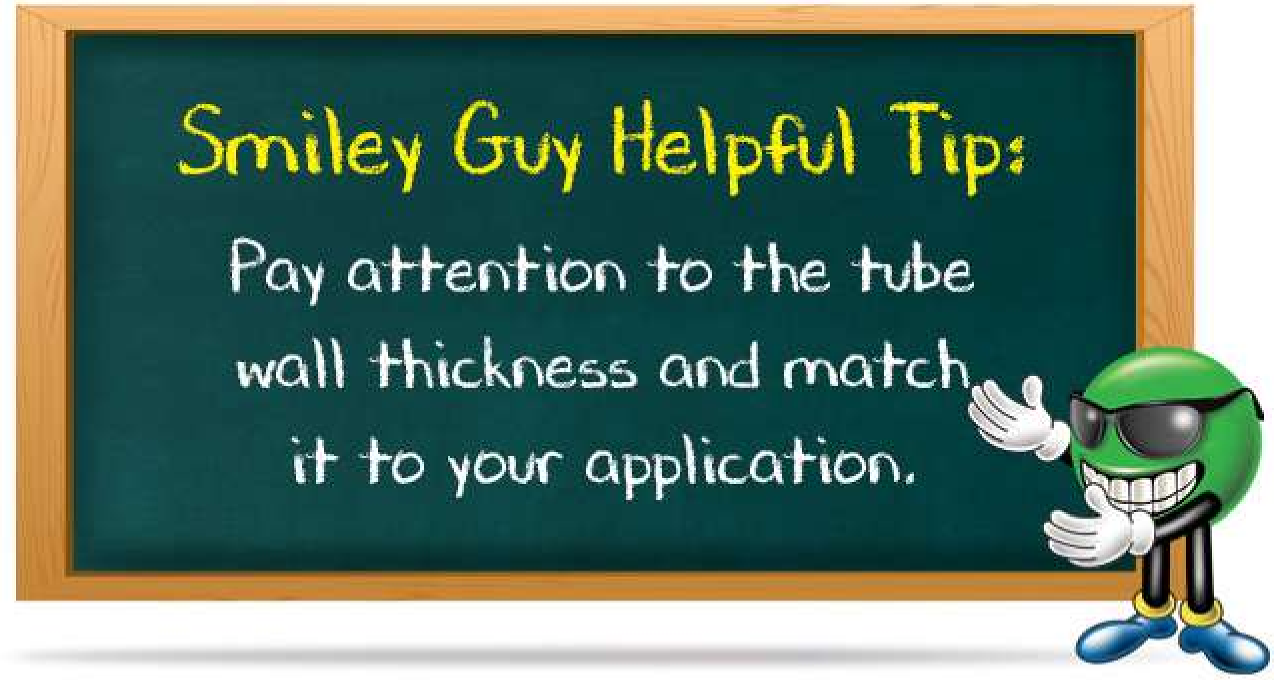
Figure 6B: Various tubing and hose examples



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

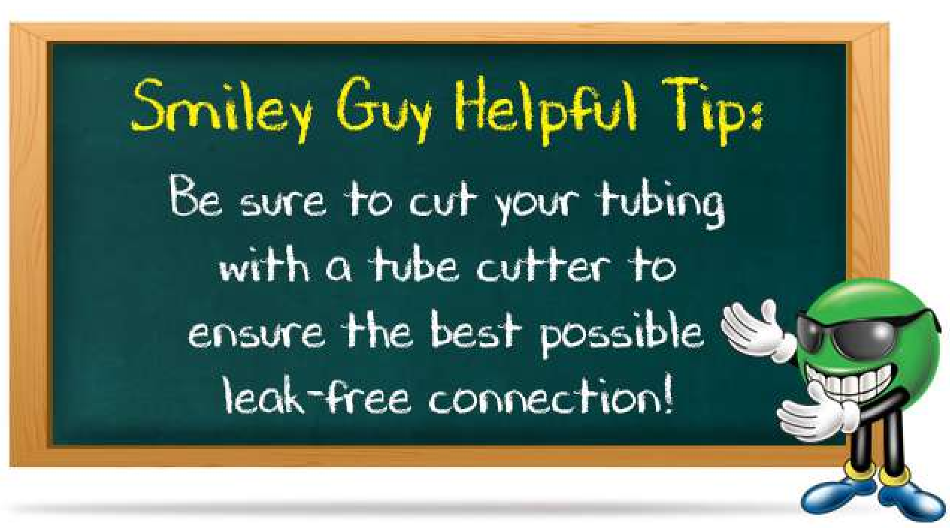
Polyurethane tubing is strong and has excellent kink resistance compared to other material types. It has a working pressure of 150 psi or higher and is the most commonly used tubing material. It also has tight OD tolerance, and a wide range of push-to-connect fittings are available. A variety of tubing 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.



Pneumatic Fittings

Getting Fitted

Fittings for connection to tubing and hose come in a variety of configurations including barb fittings, compression fittings, plastic/brass push-to-connect fittings, all metal push-to-connect fittings such as plated brass or stainless steel, brass threaded fittings, and quick-disconnect air couplings which are mostly used with hose.

Barb fittings are a simple way to connect flexible tubing or hose. The tubing is simply pushed over a barb that is slightly larger than the inside diameter of the tubing. A hose clamp is often added to secure the tubing more tightly. While easy to use, barb fittings have a higher risk of leaking or of the tubing popping off.

Compression fittings use a small barrel-shaped piece called a ferrule that slips over the outside diameter of the tube and is then compressed between a nut and the other half of the fitting. While creating a very secure connection, removing the tubing later can be difficult and often the tubing is deformed to the point that a new tube must be used to reconnect the fitting.

With push-to-connect fittings, flexible tubing is easily connected by inserting the tubing end into the fitting. To release the tubing, the circular release ring is pressed and the tubing is pulled out. This has become one of the most popular fittings for machinery and automation assemblies.

Plastic/brass push-to-connect fittings typically use strong thermoplastic with stainless steel tube- gripping claws, and threaded components made of nickel-plated brass. These fittings provide an excellent solution for most applications. In harsher environments, more expensive all-metal push-to-connect stainless steel fittings are commonly used, and these fittings are also preferred in high temperature and wash-down applications.

Brass threaded fittings are a good choice for miscellaneous connections to many pneumatic devices, but typically don't connect to tubing or hoses. Quick-disconnect air couplings are great for changing tool or hose connections and come in several sizes and materials.

Thread Standards

Pipe thread and tubing OD are two completely different things. A 1/4" tube fitting doesn't necessarily have a 1/4" threaded connection at the opposite end, so specify carefully. There are also several standard pipe threads including:

- NPT (National Pipe Taper)
- BSPT (British Std Pipe Taper)
- BSPP (British Std Pipe Parallel)

NPT is the most commonly used in the U.S. and has a tapered thread. Thread standards should never be mixed on a machine, as a BSPT male thread fitting won't mate correctly with a NPT female thread fitting. Although they will screw together, the thread angle is different and thus won't create a proper seal.

NPT can be referenced multiple ways. MNPT, MPT and NPT(M) all mean the fitting has male threads and uses the NPT standard. Female thread is labeled in a similar fashion, but with an F instead of an M. NPT fittings require thread sealant when installed, such as Teflon tape, but only if not provided with sealant from the factory.

BSPT is sometimes called R-thread and is most commonly used in Europe, but is also sometimes used in the U.S. and Canada. BSPT fittings require thread sealant when installed, such as Teflon tape, but only if not provided with sealant from the factory.

BSPP, also called G-thread, is less common, and a straight thread, but sometimes needed to connect certain standardized components. BSPP threads don't require thread sealant since they have an O-ring for sealing.

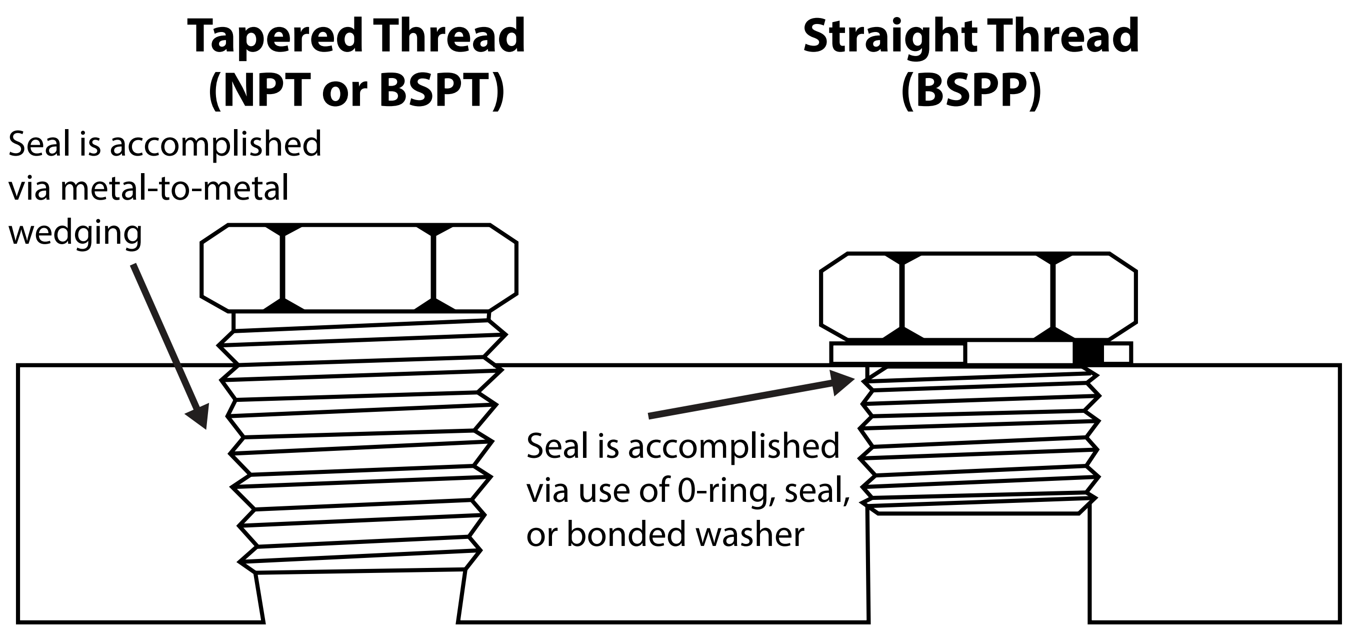


Figure 7A: Comparison of tapered and straight pipe threads

Special Purpose Fittings

Getting tubing connected between valves and cylinders often requires more than just a simple connector or elbow. Several special purpose push-to-connect fittings are available to improve integration and operation of pneumatic systems.

Flow Control Valves

Flow control valves are often used on cylinders to control their speed. Flow control valves provide an adjustable restriction on the flow of air in a single direction, while allowing free flow in the other direction. Two styles are available, inline and threaded types:

Figure 7B: Inline style flow control

Figure 7C: Threaded style flow control

As their name suggests, inline flow controls are installed in the tubing lines, while the threaded versions are attached directly at the cylinder port. Meter-in flow controls meter the air going into a port, while meter-out valves restrict the flow of air as it leaves the port. To control the speed of a double-acting cylinder it is usually best practice to mount a threaded style meter-out flow control at the cylinder port. Metering the air as it leaves the cylinder usually provided the smoothest cylinder action. Use a meter-out flow control on the extend port to control the speed of retraction and use a meter-out flow control on the retract port to control the extension speed. With single-action (single port) spring-return cylinders, a meter-in flow control valve may be required to control the extension speed.

Quick-Exhaust Valves

Quick exhaust valves speed cylinder action by allowing exhaust air from either port to escape directly to the atmosphere without having to flow back through the control valve. They have no effect on the air flowing into the cylinder port.

Figure 7D:Quick-exhaust valve

Mini Shut-off (Hand) Valves

These handy shut-off valves mount inline where ever you need on/off control of air. Choose a 2-way model for simple on/off control, or a three-way design to vent downstream pressure when the valve is in the off position. A lock-out model is even available to prevent enabling of a pneumatic circuit for maintenance or other purposes.

Figure 7E: Shut-off valve

Figure 7CF Locking shut-off valvel

Pressure Regulators / Guages / Indicators

Miniature push-to-connect pressure regulators, gauges, and indicators are small, lightweight, cost-effective, and easily added to existing circuits. Adjust pressure from 15 to 120 psi, monitor pressure from 0 to 170 psi, and even indicate active circuits (>29 psi) all in a minimum amount of space, anywhere on a machine (perfect for secondary branches).

Figure 7G: Special purpose push-to-connect pneumatic fittings

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Action
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Check Valves and Stop Valves

Check valves allow air flow in one direction and block air flow in the reverse direction. Pilot-operated check valves work as a normal check valve until pressure is applied to the pilot port allowing reverse flow. Stop valves block upstream air pressure when the downstream pneumatic tube is removed from the fitting. Models are available with push-to-connect and/or threaded fittings.

Figure 7H:Check valve

Figure 7I:Pilot operated check valve

Figure 7J:Stop Valve

Shuttle Valves

NITRA shuttle valves automatically select the higher of two inlet pressures and direct that flow to the outlet. Models are available in nickel-plated brass or anodized aluminum with push-to-connect or threaded fittings.

Figure 7K: Shuttle valve

Bleed Valves

NITRA bleed valves provide a pushbutton to manually release trapped or excess air pressure from a pneumatic system. These nickel-plated brass valves are available with threaded fittings.

Figure 7L: Bleed valve

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Action
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Are Pneumatic Components Compatible

The industrial pneumatics market is fairly mature. While there continues to be new developments and technologies, many of the tried and true core products have been around for years. One advantage that this can offer to both system designers and end users is often having several brands of components that are interchangeable with each other. This can allow users the opportunity to shop around and look at more than one supplier for the same component.

Competition is almost always beneficial to customers because now factors such as price, availability and service can be considered along with performance when making a buying decision. Check out our Interactive Cross Reference Chart **here**.

Here are examples of a few components that have interchangeable sources:

Non-Repairable Air Cylinders

Type	Mount	Bore	Stroke	NITRA PNEUMATICS (AutomationDirect)	Bimba	Norgren	Parker
Double Acting	Pivot	3/4″	6″	A12060DP	046-DP	RLC06A-DAP-AA00	0.75DPSRx6.0
Single Acting	Nose	7/8″	3″	A14030SN	063	—	0.88NSRx3.0
Double Acting	Double End	1-1/4″	10″	A20100DD	1210-DP	RLE10A-DAD-AA00	1.25PSRx10.0

Table 8A: Examples of a few components that have interchangeable sources

Pipeline Valves

Pipeline Valves	Normal State w/o power applied	Thread Size	Control Voltage	NITRA PNEUMATICS (AutomationDirect)	ASCO
2-way direct acting solenoid valve	normally closed	1/4″ NPT	24VDC	DVP-3DC2E-24D	8262H007
2-way direct acting solenoid valve	normally closed	3/8″ NPT	120VAC	DVP-3DC3F-120A	8263H232
2-way diaphragm solenoid valve	normally closed	1″ NPT	120VAC	DVD-2BC6F-120A	8215B050
2-way stackable solenoid valve	normally closed	1/8″ NPT	120VAC	DVP-2CC1C-120A	8280B002
2-way stackable solenoid valve	normally closed	1/8″ NPT	120VAC	DVP-2CC1C-120A	8280B002

Table 8B: Pipeline Valves

Compact Air Cylinders

Type	Bore	Stroke	NITRA PNEUMATICS (AutomationDirect)	Fabco-Air	MFD Pneumatics	Numatics	Parker	SMC
Double Acting w/ Magnet	100mm	100mm	H100M100MD-M	GND-SA100X100DB	MACQ-100X100-S-T	UND-SA100-100D-B	S100DC7G0100	CDQ2A-100TN-100DZ

Table 8C: Examples of Compact Extruded Body Cylinder

Figure 8A: Compact Extruded Body Cylinder

Compatibility Note

Care must be taken when changing brands to verify any possible differences in performance or dimensions. If you can adapt to some small differences, however, you may often be able to find a less expensive or more readily available component to do the same job as your current one.

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatible?
Chapter 9 Electro Pneumatic Systems in Action
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Electro-pneumatic Systems in Action

Working Together…

In order to perform a task using pneumatics, there needs to be some way to initiate, monitor, and stop the process. This is where a simple pneumatic system becomes electro-pneumatic. Electro-pneumatic systems integrate pneumatic and electrical technologies into one system where the signal/control medium is electrical and the working medium is compressed air. In this type of system, devices like relays, solenoid valves, limit switches, and PLCs can be used to interface electrical control with pneumatic action. There are basically two areas to focus on with the electrical side of an electro-pneumatic system: how to start/stop the process and how to know what the system is doing.

Who's the Boss?

In many electro-pneumatic systems, the device being controlled is an electrically actuated directional control valve. These control valves supply air pressure to devices like cylinders that will extend or retract a rod when pressure is applied or removed. Built-in solenoids are used to open and close these valves and are activated with AC or DC voltage signals. Looking at the conveyor configuration below, notice the diverting conveyor between the two conveyor lines. This diverter is used to return boxes that aren't filled properly and it is pneumatically raised and lowered when the selected boxes are in position. In this example, there are a few different ways to control the solenoid air valve responsible for raising and lowering the diverter.

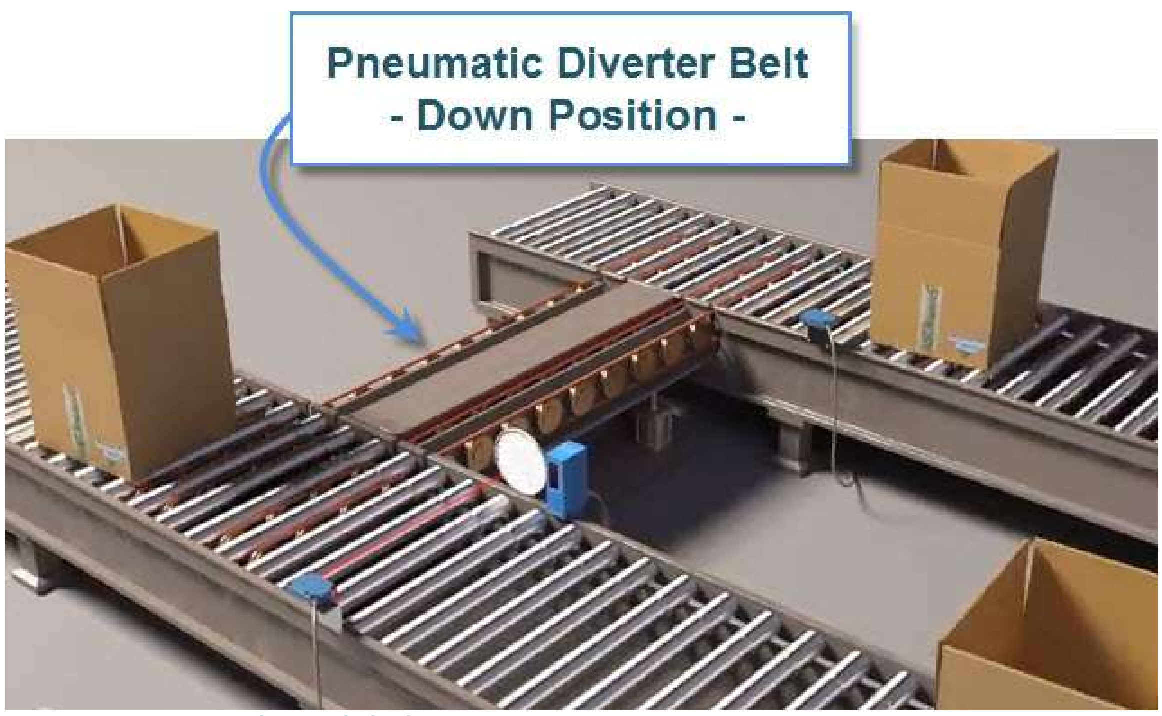


Figure 9A: Pneumatic diverter belt, down position

Figure 9B: Pneumatic diverter belt, up position

The first option is manual control, using a device like a pushbutton. With a single momentary pushbutton and a voltage source, the operator can determine when the belt will raise or lower by pressing the pushbutton and closing the normally open contacts within. Once closed, the supplied voltage will be provided to the solenoid and the control valve will open allowing air flow to the cylinders. The cylinders will extend and the belt will raise into the diverting position. When the pushbutton is released, the air flow will stop, the cylinders will retract, and the belt will lower to its initial position. Although the simplest way to provide electrical control, the manual method requires the operation to be manned at all times.

Figure 9C: Pushbutton examples

Another option for electrical control is the use of relays. When a relay's coil is energized by an electrical signal it will close or open the normally-open or normally-closed contacts within. By connecting the pneumatic control valve to a relay contact and an object detection device, like a photo eye, to the relay's coil, the system will activate the pneumatic action automatically. Once a box is in position and detected by the photo eye, the relay's coil will energize and in return a voltage signal will be sent to the control valve. Once again the cylinders will extend and the belt will raise. Relays are available in both electromechanical and solid state versions and in this scenario, a time delay relay or latching circuit may also be needed to ensure the box has traveled the length of the belt before the belt is retracted.

Figure 9D: Relay examples

In a more complex system with numerous valves, relays may become too cumbersome to install, modify and maintain. This is where PLCs reign supreme. PLCs can not only handle many logical inputs and control outputs, but they can also easily integrate timing functions, sequential operations, alarming, remote visibility, etc. into a pneumatic application. With a PLC, the photo eye is wired to an input module and the control valve is connected to an output module. Logic code within the PLC will determine when to activate the control valve output using the transitions in the photo eye input. Additional code can also be written for latching functions, alarming, data logging, etc. For more information on PLCs and PLC programming, see **The PLC Handbook – A Practical Guide to Programmable Logic Controllers eBook** on our library site.

Figure 9E: PLC example (Productivity2000)

That Makes Sense!

Another important component of electro-pneumatic systems is feedback. Feedback devices inform the operator of system status and whether or not the requested task has been completed, or even attempted. Three important things to know when it comes to pneumatic systems are pressure, flow and position.

Pressure in pneumatics is similar to voltage in electricity. They both represent the potential energy available in the system. The difference in pressure from one point to another is what causes air flow in pneumatics the same way the voltage difference between two points causes current flow in electricity. So, the amount of pressure available is an extremely important component. To measure this pressure, pressure transmitters or pressure switches can be installed in the pneumatic circuit. Some applications, like pneumatic stamps, may also use pressure sensors to detect the optimal pressure applied during the stamping operation.

Figure 9F: Pressure sensor example

Flow is also important as it represents the speed at which cylinders extend and retract. In other words, at a given pressure, flow rate determines the rate of energy transfer (i.e., horsepower) the system will supply. This can be monitored using flow sensors and controlled using flow control valves. Flow switches will inform you if the air flow reaches a set value and flow transmitters will tell you the exact flow value detected. Position tracking in electro-pneumatic systems, like our conveyor, is accomplished by tracking the position of cylinder pistons or the devices they are connected to. Many cylinders have magnets built in to the piston that allow magnetic switches to detect the position of the cylinder. These switches can be mounted directly to the cylinder housing, as seen below, and detect when the piston is fully extended or retracted.

Figure 9G: Typical installation of a position sensor on a cylinder with a magnetic piston

Another option with position detection is to use proximity or limit switches external to the cylinder. Proximity switches will detect position using magnetic, ultrasonic, inductive or capacitive means and limit switches will determine position by physically contacting the device being moved. Various types of limit switches are available, including ones with plungers, levers, rollers, and rods. Looking at the conveyor example, the position of the diverter belt is determined by using a proximity switch mounted underneath the conveyor. When the belt is lowered it moves into the range of the proximity switch. The switch then sends a signal to the controller indicating that the diverter is in its lowered position.

Figure 9H: Proximity sensor example

A limit switch with a plunger could have also been used to determine the conveyor position but limit switches have mechanical components that can wear out over time and in applications with frequent movement, a solid state device is preferred. If you would like more information on object detection devices and how to use them, please visit our **Object Detection video cookbook series**.

Additional Options

There are many other devices available that can make your pneumatic system safer and more intelligent. One example of a safety device in pneumatics is the soft start valve. This valve is used inline with air preparation components and it will slowly ramp up the system pressure to the desired level when its solenoid is energized. This way when a pneumatic system is coming online, the initial pressure will slowly increase in the system ensuring cylinders and other components do not slam into position. The slamming can damage components or injure any personnel unaware that the system is going live. Once the system pressure has reached the set point, these valves become transparent to the system. Also, soft start valves can depressurize the downstream pressure when the solenoid is de-energized. This can be tied to an Estop circuit to automatically dump the downstream pressure when an emergency is present.

Adding an electro-pneumatic transducer to a pneumatic system will also provide more control of system pressure. These devices, often called I/P converters, will take a current signal and convert it to a proportional pneumatic pressure value. I/P converters are used to achieve accurate, repeatable pressure when precision control of pneumatic actuators/operators, pneumatic valves, dampers, vanes, etc. is required.

A recent advancement in electro-pneumatics is the fieldbus-networked valve manifold. This new technology allows pneumatic manifolds to be monitored and controlled over industrial Ethernet networks. When used with PLCs, it allows the controller to more efficiently turn valves on and off without the usual hardwiring, and to gather I/O data from sensors, relays, individual valves, or other I/O devices via communication networks. With Ethernet technology, these manifolds can also integrate an on-board web server, which can make the manifold accessible to any standard web browser. Email capability is also possible and allows the manifold to send email messages containing information like diagnostic data when triggered.

If you would like to see more about the options available for electro-pneumatic systems, please check out our in-depth pneumatic webinar series which explores our available pneumatic components and includes a demonstration on electrical control and monitoring.

Pneumatic System Design Considerations

Pneumatic systems as a whole can be simple, but this simplicity can be deceptive when it comes to selecting components. For instance, there are thousands of types, sizes, and variations of cylinders and valves, from off-the-shelf versions to custom designs. The sheer number of choices can be overwhelming, especially when options such as sensors are added to the mix. So how do you know what is right for your application? Well since every application is different, that's a hard one to answer. But the following section discusses a few considerations that can be helpful when selecting the right components for your pneumatic system. And taking the time to choose the right components for the job will ensure good performance, lower expenses, improve cycle rates, and prolong equipment life.

Compressed Air Supply

Adequate sizing of compressors and feed lines is the first place to start to ensure proper system operation. Consistent plant air pressure with suitable flow allows pneumatic devices to operate as designed, and low or varying air pressure can negatively impact the final product and overall machine sequence. For example, a manufacturing plant was experiencing low air pressure in its facility at the end of the day shift, causing one of the machines to fault due to low air pressure in its pneumatic actuation system. The problem was found to be high volume air consumers nearby, namely blow guns being used to clean machines at the end of each day. Insufficient capacity at the air compressor, or undersized plant air supply tubing and piping is a common issue and one to look out for. If air consumption is a major concern for your factory, check out our Interactive Air Consumption Calculator **here**.

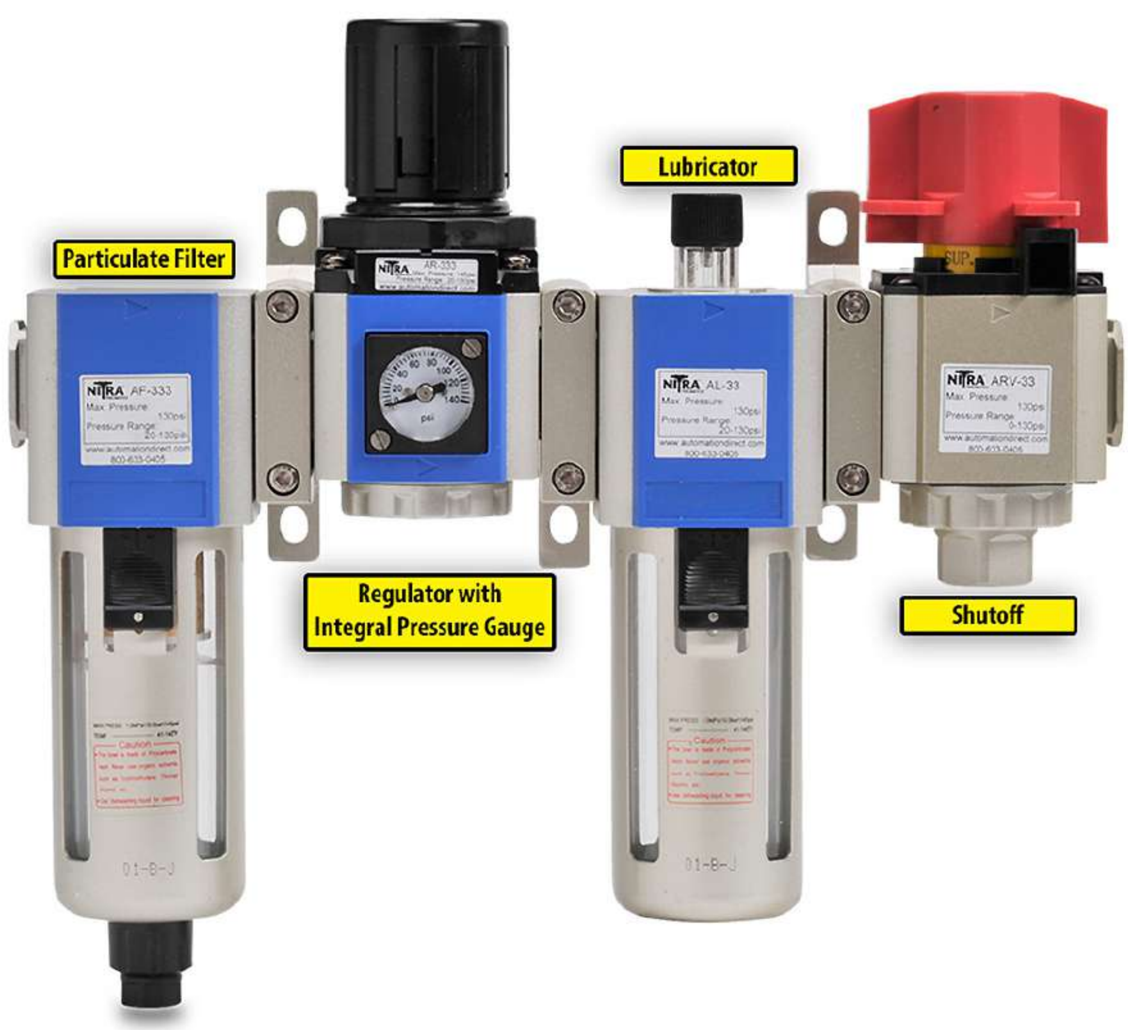


Figure 10A: Basic Air Prep System

Air Flow Control

Once consistent and correct pneumatic system air pressure and flow is established, plant supply air should be connected to a manual, lockable air dump valve at each use point. This lockout, tag-out capability is important for isolating a machine—or a module of a large machine—for changeover, maintenance or tooling changes. A filter regulator should also be installed at the air dump valve. The filter removes dust particles and water that can cause wear and operation problems for pneumatic system components. A regulator is required to throttle to the design air pressure at the use point, typically 60 to 90 psi, as the plant air supply is usually higher, about 100 to 130 psi. Operating at the design pressure as opposed to plant pressure will reduce wear on pneumatic components.

An electric, soft start valve downstream of the regulator allows air pressure to gradually increase at start-up, preventing sudden banging or slamming of cylinders at power up. This is especially important if 4-way, 2-position valves are used because a 2-position valve spool maintains its position after power off and the removal of air. When power and air is reapplied, air will return to the cylinder. If all air was exhausted, no air is available on the other side of the cylinder. This makes speed control with flow controls non-functional. The uncontrolled speed of the cylinder could cause a high-speed stroke, commonly ending with a bang. When soft start valves are correctly applied, a machine will typically return to its home position slowly and smoothly at power up.

Lubricators should be used sparingly and only when necessary. Most modern pneumatic components come lubricated from the factory and do not need oil. However, pneumatic motors on air tools and other equipment do require a lubricator and one should be supplied in these instances.

Cylinder Types

Pneumatic cylinders are a popular way to clamp, position and transfer parts in automated equipment and although there are many types of cylinders, their construction is fairly similar from one to another. If you haven't already, take a moment and review the Cylinders section to get a basic understanding of what cylinders are and how they operate. Understanding the basics helps to know how different applications affect the cylinder and piston rod.

Figure 10B: Typical pneumatic actuators

The first step in choosing a cylinder is deciding whether to use the single- or double-acting version. As mentioned previously, single-acting cylinders use compressed air to move the load in one direction and double-acting cylinders use compressed air for movement in both directions. With single-acting cylinders, air is supplied to only one side of the piston and a spring (or, in some cases, gravity) returns the piston to its original position once air pressure is removed. And while double-acting cylinders use more air (both for the extend and retract), they are well suited for loads that require both pushing and pulling.

In both cases, force calculations can get complicated. In single-acting cylinders with a spring, the spring force opposing the push or pull increases as the stroke progresses. And in double-acting cylinders, push and pull forces are not equal, as rod area must be accounted for in force calculations. Often, manufacturers' catalogs will list push and pull values for both double-acting and single-acting cylinders, with and without springs, in order to simplify these calculations and help with selecting the proper cylinder type. Take a look at our **Interactive Bore Calculator here.**

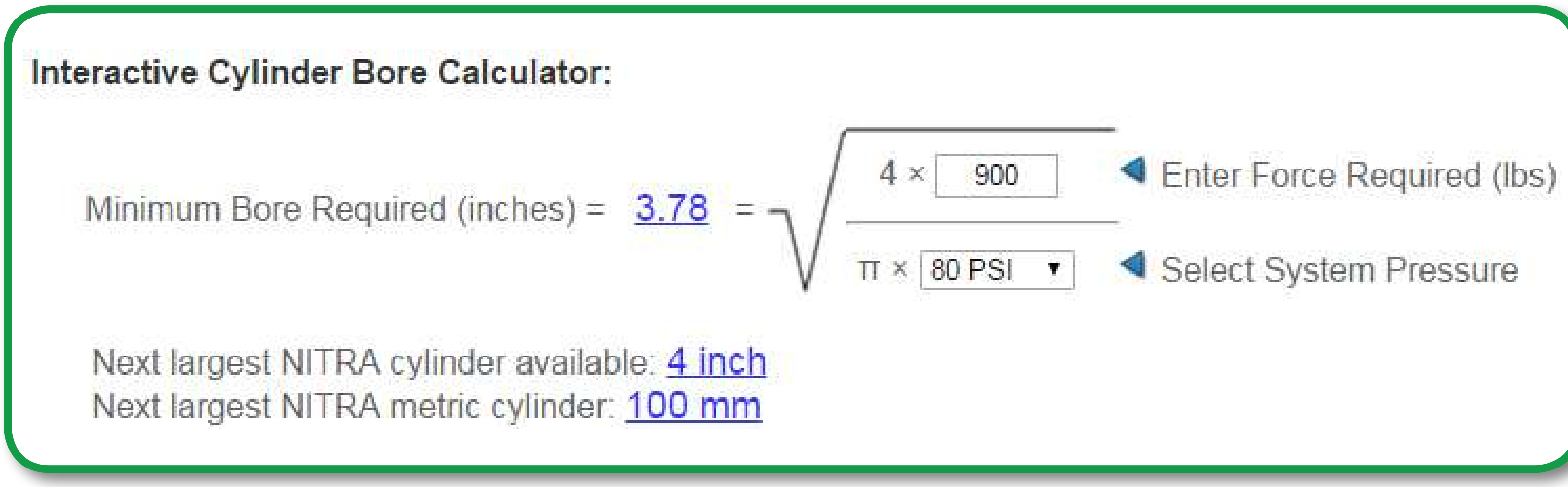
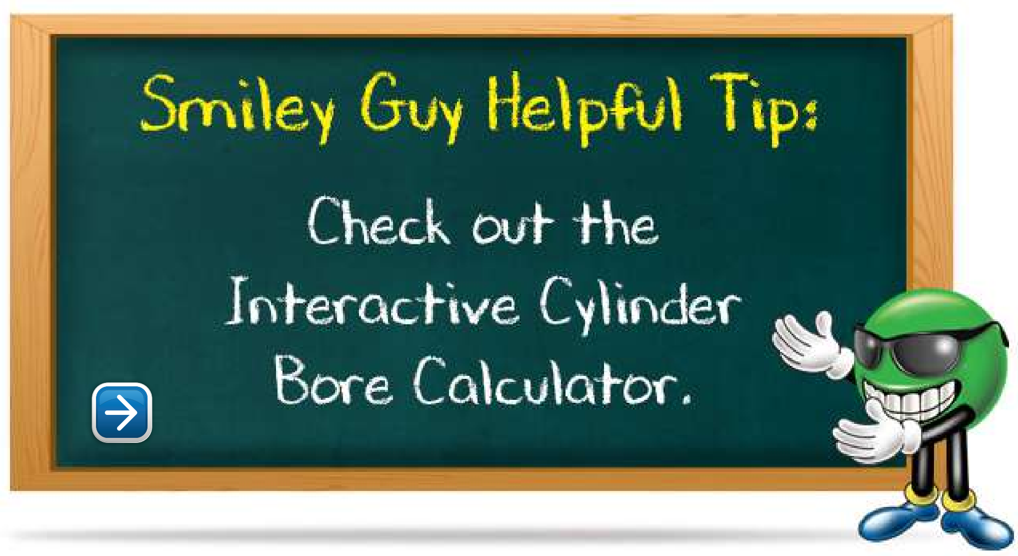


Figure 10C: Interactive Cylinder Bore Calculator



Cylinder Sizing

The load is the primary consideration when determining cylinder type and piston size. The piston area (force factor) multiplied by the air pressure in the cylinder gives the available force. A general rule is to select a force factor that will produce a force 25% greater than the load to help compensate for friction and losses. Pneumatic systems are quite forgiving in terms of oversizing, but using components that are too big adds unnecessary expenses in terms of both purchase price and energy consumption.

The bore size (force factor) determines force at a given pressure. The operating pressure, which in a plant can typically range from 10 to 150 psi, is the first consideration when selecting a bore size. The next step in choosing the bore size is the amount of force that the application requires. Suppliers often provide charts to assist with calculating bore size. If the bore diameter is between sizes, fluid-power experts recommend rounding up to the next size. It's also important to remember the bore diameter squares the thrust delivered. For example, a two-inch diameter cylinder has four times the power of a one-inch diameter unit. Therefore, doubling the bore quadruples the thrust.

In addition to load, designers must also take into account the speed at which the load will move. When compressed air flows through a system, there are pressure losses due to friction against the tube wall, flow around bends, and restrictions in valves and fittings (to name a few issues). Higher speeds result in greater pressure loss as the air must flow faster through the valves, tubing and ports. Attaining higher speeds also requires that the cylinder deliver more force in a shorter amount of time. A force that exceeds the load by 50% or more may be required to reliably move a load at high speeds. For example, a typical air compressor might supply air to a system at 100 psi. In an application with a slow-moving load, the actual pressure available at the piston might be reduced to no less than 90 psi. With that same load moving at a much faster rate, the available pressure could drop as low as 70 psi.

Pressure losses can be remedied by increasing pressure, but this must be done with caution: Too much pressure creates stress on the cylinder and could possibly damage the cylinder, as well as the load. In these instances, it's better to go with a larger cylinder. Also keep in mind that raising system pressure means the compressor must work harder, increasing energy consumption of the overall pneumatic system.

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Acti
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Cylinder Options

Even when a cylinder is sized properly, it may stroke too fast and require use of a flow control, typically by controlling flow of air leaving the cylinder. This also reduces noise problems caused by cylinders banging and reduces rapid exhaust racket. These flow controls are typically mounted directly to the cylinder, but can also be mounted inline near the cylinder, or at the valve if the hose between the valve and cylinder is less than about 3 feet.

Specifying cylinders with built-in cushions can help provide long-term performance in high-speed pneumatic motion applications. The cushions allow a cylinder to stroke at high speed and only slow down near the end of stroke for a quiet, low-impact stop. Adjustable pneumatic cushions are often the best solution, comprised of specially designed end caps with built-in flow controls. Mufflers can also be used to quiet cylinder or valve exhaust noise, and they are often a simple and low cost solution.

Figure 10D: Flow control valves

Cylinder position switches are extremely helpful in sequencing operations and prevent starting the stroke of one cylinder before the previous cylinder's stroke is complete. Using timers to control a sequence instead of position sensors should be avoided in this and most cases. One stuck or slow cylinder during an automated sequence can cause a machine crash, costing much more than the cost of buying, installing and programming end-of-stroke sensors.

Figure 10E: Cylinder switches

Control Valves

Once the cylinders are selected, you should now have a good idea of the flow rate and pressure of compressed air needed. With this information, control valves can be selected. Items to consider in valve selection are size (flow capacity), type and actuation method.

Valve Type

Choosing the right type of valve for the job required is not as difficult as it may seem. For cylinder control, the simplest method is to use a 3 way valve for a single acting cylinder and a 4 way valve for a double acting cylinder. Systems can be much more complex if needed, but let's focus on a basic system for now. The form factor of the valve can vary a great deal and many people have a variety of preferences. It's usually best to make sure the valve has the needed performance characteristics before locking into a particular form factor.

Valve Sizing

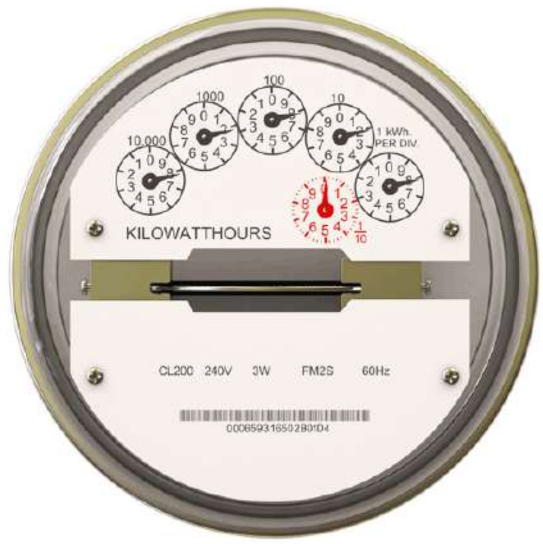
Now that the function of the valve has been determined, look at the required flow capacity. The usual first step is to use the air cylinder bore, stroke and cycle rate to determine a flow rate in standard cubic feet per minute (SCFM). Many valve suppliers will list a flow rate at a particular inlet pressure and pressure drop. Others will list this value as a factor Cv, which has no units. For a more thorough explanation, check out our Interactive Cv Calculator **here**. A simple thing to remember is that a larger Cv value will allow a higher flow rate of air through the valve. Key points to remember in valve sizing are that undersized valves may restrict flow and not allow a system to work properly. Oversized valves often cost more and will use more air. Keep in mind that air consumption is a major portion of the expense for a pneumatic system. If air consumption is a major concern for your factory, check out our Interactive Air Consumption Calculator **here**.

Valve Actuation

How will the valves be operated? Manual valves could be push button, lever or foot pedal activated. The more common method is to use electric solenoids to operate the valve. Solenoids are available in both AC and DC in a variety of voltages to fit just about any need. Match the solenoids up with your electrical control system. In less common situations, an air piloted valve may be required. When air pressure is applied to a pilot port, the valve switches. This is a good way to switch very large valves while using very electrical power – use a small solenoid valve to send air to the pilot port of the large valve.

These are just a few of the many items to consider when designing a successful pneumatic system. Other factors, such as energy efficiency, can affect overall system design as well. But regardless of the design, watch out for the common issues and always be sure to supply, prep and distribute the air properly. When properly applied, your pneumatic devices and actuators will have a long life with limited operational issues along the way, and with minimal required maintenance.

Energy Efficient Pneumatic Systems

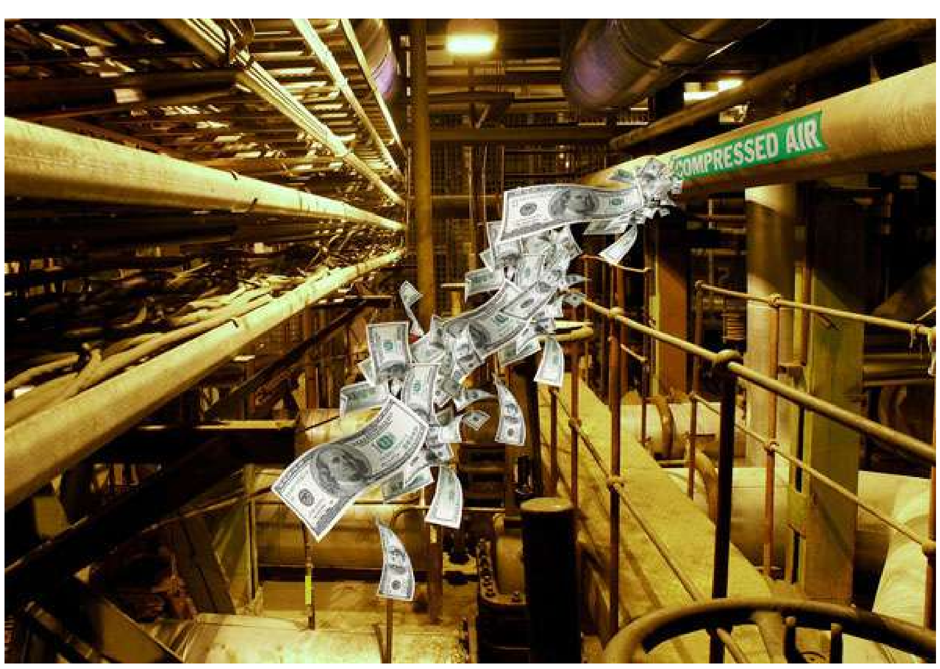


Reducing energy consumption is a priority in almost every manufacturing plant and industrial facility, as no company can afford to throw money away using machines and processes that waste energy. Because pneumatic systems are abundant throughout manufacturing and account for a large share of a plant's power costs, it is extremely important that they run efficiently.

Unfortunately, many users have the mindset that pneumatic systems are inherently inefficient, therefore overlooking opportunities for energy savings. In addition, some manufacturers of industrial equipment and robots tend to focus on ensuring the pneumatic systems perform their intended functions, and in the process neglect efforts to reduce operating costs. Fortunately, there are ways to improve the energy efficiency of pneumatic systems using tactics that range from better engineering decisions in the design stage, to adjustments and maintenance on existing systems. And by optimizing these systems, companies can reduce their compressed-air energy consumption by anywhere from 20 to 35%.

Minimize Leaks

Leaks are common and expensive in pneumatics systems. Statistics from the **U. S. Department of Energy** show the average manufacturing plant loses 30 to 35% of its compressed air due to leakage. The good news is many leaks can be prevented or repaired.



Of the many points between the compressor and the load where leaks occur, valves and seals are two main areas for improvement. Deteriorated seals should be the first area to examine and remedy. Environmental conditions, such as temperature, moisture content and lubrication, all contribute to the leakage rate of a seal. Pneumatic systems in areas with high contamination risk can benefit significantly from an investment in resilient seals like Viton, Teflon or polyurethane.

Another consideration with leakage is proper valve selection. Selecting the best valve for the job can prevent unnecessary leakage and unnecessary cost. Certain valve designs, such as lapped-spool valves with metal seals, have inherent internal leakage that is constant while air is supplied to the valve. Nonetheless, it's important to note that lapped spool and metal sleeve valve air consumption doesn't vary during operation. On the other hand, installing valves with soft seals can significantly lower leakage on the front end, but a soft seal produces hundreds of times more leakage than the lapped spool-and-sleeve valve during an open crossover when the valve shifts. In this case, it is important to look at total air leakage over the whole operation being performed in order to determine which type of valve will optimize the energy usage.

Compressor Enhancements

After fixing leaks, compressors are the next biggest area for improvement. U.S. Dept. of Energy reported that manufacturers spend over $5 billion each year on energy for compressed air systems. This shouldn't be surprising since they form the backbone of the pneumatic system. Manufacturers that optimize their compressed air supply systems have seen significant reductions in their energy consumption. Detailing the methods for increasing compressor efficiency is beyond the scope of this chapter. However, the Dept. of Energy offers guidelines for determining the cost of compressed air in a plant, as well as tips on how to reduce compressor energy usage.

Optimizing Pressure

As compressed air flows through typical circuits, air pressure drops due to changes in demand, line and valve-flow resistance, and other factors. But many of these losses are simply because the distance between the compressor or supply point and the actuator is longer than necessary. Designs that use the shortest tubing possible can reduce energy consumption as well as cycle times. Typically, tubing between control valves and cylinders should be less than 10-ft long. Longer lengths require more pressure so that force, speed, and positioning capabilities aren't compromised.

Another way to eliminate unnecessary consumption is ensuring actuators use only the pressure needed to perform a task. Sometimes, operators on the plant floor increase supply pressure in the belief that it improves performance. However, all this does is waste energy and money. Installing sensors that monitor pressure, and pressure regulators that maintain correct settings, can keep pressure within the minimum and maximum parameters. Many engineers also design systems that deliver more pressure than needed to the actuator. Regulators that control pressure to individual pneumatic cylinders will increase energy efficiency, in many instances generating savings of up to 40%.

Regulate the Return Stroke

Another way to conserve energy is by supplying the correct pressure for an actuator's return stroke. Most applications only move a load in one direction. However, many machines inefficiently use the same pressure for both the working and return strokes.

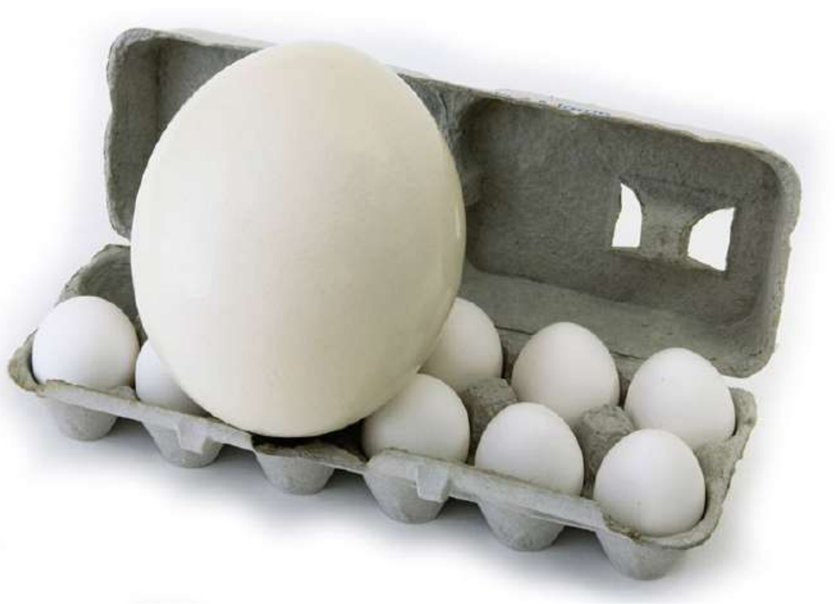
For example, a material-handling system that pushes boxes from one conveyor to another needs high cylinder force only in one direction. The working stroke may demand 100 psi to move a box, but the low-force return stroke only requires 10 psi. Using the same pressure in both directions wastes energy. Reducing the pressure on the return stroke saves 90% of the volume of compressed air. Because that conserves compressed air, a lot of energy is saved over the thousands of cycles that the action is performed. And regulating air pressure not only saves energy, it also minimizes wear on the pneumatic and related components. By reducing pressure for the extract stroke to only what is needed, the machine is not subjected to unnecessary vibrations and shock.

Another option for improving efficiency in processes with shorter strokes is to use a spring return actuator. The control valve in a spring return actuator ports the pressure (using the compressed air) for the working part of the stroke, and then exhausts the air. For the return stroke, the spring—or sometimes merely the weight of the mechanism—takes the cylinder back to the starting position.

A typical case where single-acting, spring-return cylinders can reduce energy demand involves presses. In this type of application, a cylinder pushes two items together such as a bearing into a housing, or a plug into a hole. The job demands a significant amount of force to press the parts together, but only a small amount to retract. This makes it a good candidate for energy savings by eliminating the return-stroke air consumption completely since the spring return can provide the force needed for retraction.

Proper Sizing

It's important to take the time upfront to correctly size the pneumatic system's components because each component's size affects other parts of the system. Buying smaller control valves may save money on the purchase price, but they will be more expensive over time. Smaller control valves will require the air compressor to work harder simply to get the proper pressure to the actuators, creating a long-term demand for more energy.



Another common problem comes from oversizing the cylinders more than necessary. Some oversizing is necessary to compensate for pressure fluctuations and air losses; however, components that are far too large account for one of the biggest energy losses in a pneumatics system.

For instance, a 3-inch cylinder requires more than double the volume of air of a 2-inch cylinder. However, this much extra capacity may not be needed. To avoid grossly oversizing, it's important to remember most loads and speeds require only 25% additional capacity to ensure correct operation. By selecting the right amount of oversizing, cylinder efficiency can be improved by as much as 15%. When factoring in the number of cylinders that will operate thousands of times over their life span, the savings from right sizing becomes significant.

To assist with the many calculations and considerations that go into properly sizing components—such as if the load is rolled or lifted—there are software packages, online calculators, and even an iPhone app that can assist with component sizing. By spending a little more time understanding the system's true requirements, the savings can be substantial.

Hit the 'OFF' Switch

Shutting down a machine when it's not working seems like an obvious way to save energy. While some elements of a system, such as air bearings, can require pressure even when the machine is off, the required compressed airflow is usually much less than that needed during normal operations. However, many installations have no automatic way to reduce or stop airflow to idle machines. Reduced staffing often means that manufacturers can no longer send maintenance workers to manually turn off air to specific machines. Or sometimes workers don't understand that an idle machine requiring pressure only needs a fraction of the pressure required during operation. These facilities can benefit from an automatic air reduction control package to lower the air pressure to necessary levels when the machine isn't working. Typically, the cost of these devices is recovered within a few months.

Save Energy, Save Money

In the past, businesses were mainly concerned only with their pneumatic systems performing their job correctly. Little thought was put into correctly sizing components and making sure that only the pressure required was used. However, today's businesses can't afford to waste energy in any area of the plant. The good news is that with some time dedicated to determining the actual requirements of the pneumatic system and selecting the right components, plants can expect improvements in both energy efficiency and productivity.

Pneumatic Actuator vs. Electromechanical

In materials handling and assembly there are many ways to move an item from one location to another. Conveyors are one way and are widely used, but they can only move objects in a fixed path, limiting their use in more precise manufacturing applications. When more accuracy is required than a conveyor can deliver, such as when the part orientation or alignment needs to be changed, a pick-and-place system is often used. The most common pick-and-place systems employ either pneumatics or electromechanics, with hybrid electro-pneumatic systems also an option in some applications. The question then becomes what system is the best for each application, taking into consideration multiple factors including cost, complexity, performance and maintenance.

Picking the Right Pick-and-Place

In regards to complexity and performance, one should consider the amount of movement(s) that must be performed, the required accuracy of the placement, the weight of the objects to be lifted, the shape of the parts, and the distance they must travel. In general, jobs with complicated movements requiring a high level of accuracy need more expensive electromechanical pick-and-place systems. If the application has a fixed travel path and doesn't need repositioning or multiple positioning, a pneumatic pick-and-place system is often the best choice.

Hybrid systems use electrical components at the front end, and a pneumatic end effector to handle the part or object. These systems are more expensive than pneumatic solutions and less costly than electromechanical systems, and can be the best option for some applications as they combine the economy of pneumatics with the speed and accuracy of electromechanical systems.

When Pneumatics are Better

Although initial cost is often the driving force for using pneumatic pick-and-place systems instead of electromechanical solutions, it's not the only reason, as seen in the Table below.

Advantages of Pneumatic Pick-and-Place Over Electromechanical Systems
• Much lower initial cost
• Higher force density
• More compact in most cases
• Use a safer energy source, compressed air as opposed to electricity
• Better for wet or corrosive areas
• Simpler installation, particularly with respect to programming
• Easier to maintain due to overall simpler operation
• Familiar learning method for younger students

Table 12A: Advantages of Pneumatic Pick-and-Place Systems

Pneumatic devices have a greater force density than many electromechanical solutions, which enables them to be a smaller and lighter, lowering space needs and energy costs. They can also be installed without complex components like controllers, as their operation is simpler with a single path of travel. In applications with contaminates, such as possible splashes, electromechanical systems pose more danger and are more likely to fail. Furthermore, electromechanical pick-and-place systems for these types of applications usually require specialized certifications and have a relatively small pool of vendors, thus making them quite expensive.

Pneumatic systems are not only safer in wet or corrosive environments, they can also withstand numerous cleanings. The pneumatic devices can be mounted close to the process while the associated electronics are housed in a cabinet well away from possible damage, simplifying installation and maintenance. Moreover, since controls for a pneumatic system are typically smaller than servo drives, internal space requirements in the control cabinet are reduced.

Build or Buy?

When the decision is made to implement a pneumatic system, the next choice is to buy an off-the-shelf system or to build one using cylinders, valves and end effectors. A preconfigured system will be in operation faster as it comes with all components pre-assembled and tested. Designing and building a custom system will take more time up front, will cost less in terms of purchased parts and will result in an optimal fit for the application.

Custom pneumatic pick-and-place systems can be built in a variety of configurations using standard components, which are assembled to produce different linear and rotary motion actions. A basic system can be built using primarily off-the-shelf components at a very reasonable cost. Nevertheless, designing a pick-and-place system requires a certain amount of engineering skill.

Pneumatic pick-and-place systems rely on cylinders for mechanical movement in either a linear or rotary direction. Round body cylinders are the least expensive option but they require mechanical guides that are usually custom machined for the particular application. As such, they may be the best choice for a company that can perform machining in-house. For those without in-house machining capabilities, guided-rod extruded-body cylinders are a good choice even though they can be up to five times as expensive as their round body counterparts.

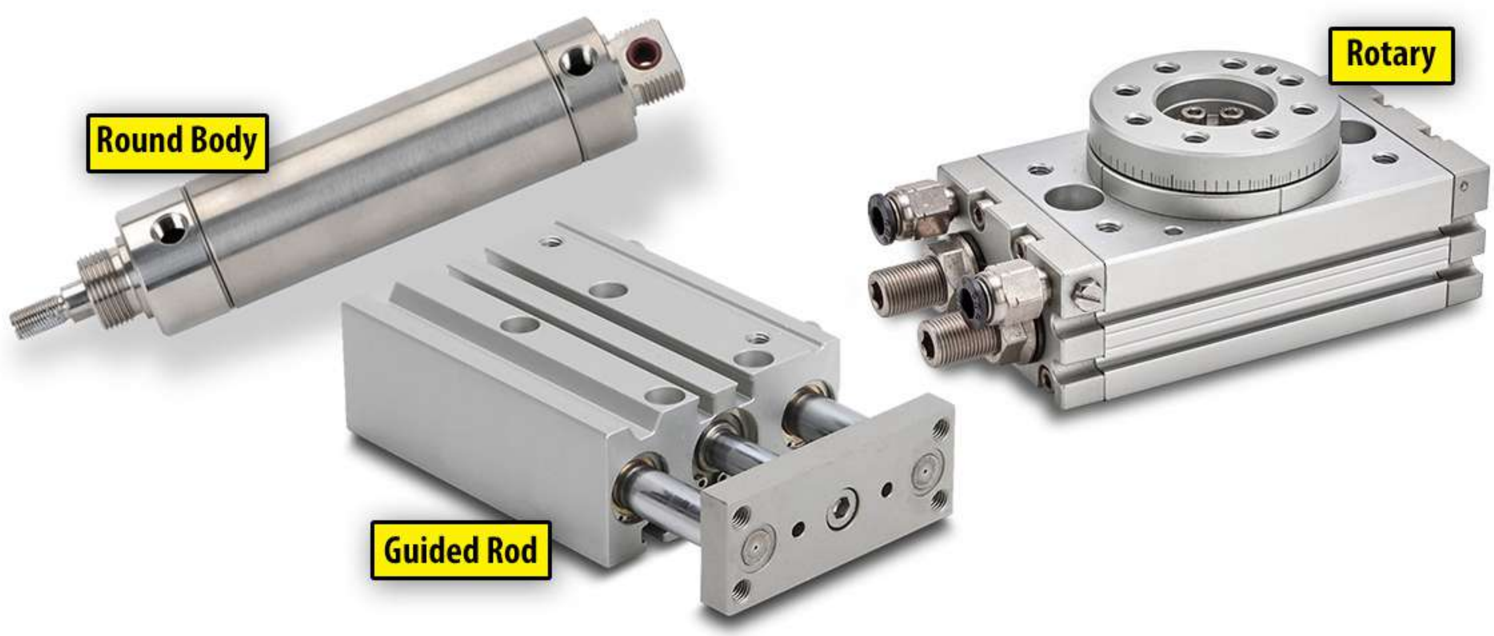


Figure 12A: Guided cylinders can simplify installation in a pick-and-place application

Rotary actuators are used with cylinders to perform non-linear, twisting movements; they can flip, tilt or turn a part or an object. For example, a rotary actuator is used on one end of a vertical axis, with a gripper on the other end. This enables the actuator to move parts in an arc motion, instead of moving the object up and across in separate movements. It should be noted these actuators typically don't rotate more than 270 degrees.

Readily available pneumatic cylinders are generally limited to about 2500 pounds of available thrust, but multiple cylinders can be combined into a very powerful pick-and-place system. These cylinders and other components come in a wide range of materials: nickel-plated brass, aluminum, steel and stainless steel. Designers should select the appropriate material depending on loads, environmental conditions and cost constraints.

Stroke Length Considerations

The stroke length determines how far the pneumatic device can move. Single-acting cylinders have limited extension resulting from the space needed for the compressed spring. Therefore, single-acting cylinders are best suited for applications that only need approximately 6 inches (150 millimeters) of stroke length or less.

Since double-acting cylinders don't use a spring return, stroke lengths for this design are generally available up to 24 inches (600 mm) in most popular bore sizes. For travel distances longer than 24 inches, there are a number of different rodless cylinder designs that work very well in pick-and-place systems.

Speed Control Concerns

While pneumatic pick-and-place doesn't offer the speed control and wide range of motion found with electromechanical systems, they can deliver an often acceptable level of speed control by using valves. Flow control or needle valves are used to control the speed of the pneumatic pick-and-place device by regulating the air flow to the actuator. Overall system sizing of valves, tubing and actuators will have an effect on achievable speed range, and greater care should be used if speed is critical.

Grippers and Vacuum Device Deployment

The end effector that picks up the object in a pick-and-place system can be pneumatic grippers or vacuum suction cups both of which are usually lighter, smaller and less expensive than electric grippers.

Figure 12B: Pneumatic powered options for placing product

Pneumatic grippers work well for applications requiring high speeds or a high gripping force. While they don't offer the force and positioning attributes of electric grippers, pneumatic grippers can be adjusted by using a control valve or an analog proportional pressure valve to change pressure and thus gripping force.

The initial cost of suction cups is low, and they come in a variety of sizes. Suction cups are a good choice for delicate products, such as food and glass, and for flat objects like paper and sheets of metal. While they work for some high-intensity applications, the operational cost of the required vacuum generators may be prohibitive for systems with just a few cups. For inexperienced users, suction cups can also be tricky to implement. Selecting the right size and amount of suction is often more of an art than a science, and determining the size and suction of the cups is often an exercise in trial and error unless considerable experience has been gained in similar applications.

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Acti
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Reducing Total Cost of Ownership

One of the complaints about pneumatic pick-and-place is relatively high operating costs compared to electromechanical systems because they use compressed air. Most pick-and-place systems will operate in settings where compressed air is already being used for other purposes, and several steps can be taken to mitigate air usage. One way to reduce costs is by mounting the pneumatic control components near the point of operation to minimize air line lengths. Locating the valving close to the actuators and using appropriate cylinder and valve combinations can reduce the required air volume by up to 35 percent. In addition, using modern components that are made to reduce leakage and utilizing improved lubricants that operate across a wider temperature range, will extend the life of actuators and valves in your system which in turn reduces the costs of maintenance and replacement. If you would like more tips on making your pneumatic system energy efficient, see the Energy Efficient Pneumatic Systems chapter in this eBook.

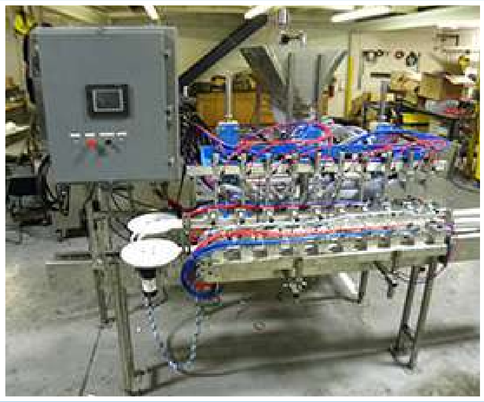
The Choice is Yours

There are some misconceptions and outdated ideas about pneumatics that can needlessly drive up the cost of pick-and-place by relegating users to higher priced electromechanical systems. When just two positions per axis of motion are required, and when very high speed and extreme precision aren't required, pneumatic pick-and-place systems will usually be a simpler and less expensive option. And while pneumatic pick-and-place systems have been used for decades, over time they have been improved with technological advances making these time-tested systems a viable choice for many applications.

Application Stories

Want some examples of what people are doing with pneumatics? You're in luck, we have a full collection of Application Stories on our application stories on our **website**. For your convenience we took the time to list some of our favorites on the next few pages. You can see a preview below and then pick the ones that look the most interesting to you. Just remember that there is a lot more where these came from.

Pneumatics Improve Ridgeline Machine's Equipment



Riada Equipment Solves Difficult Packaging Problem

DIY Pneumatic Saw Clamp

DIY Halloween

Pneumatics Improve Ridgeline Machine's Equipment

Ridgeline Machine Design, LLC (RMD), founded in 2012, is primarily a packaging machinery producer, and the company's owners have over 40 years experience designing and building custom machinery. RMD builds packaging machinery for a variety of applications for product placement into AFM, FOL, HSC, RSC cases or trays, and they have also branched out into robotics and machinery for consumer cooler production.

Ridgeline Machine made extensive use of pneumatics when building a low-cost, small-footprint, portable traymaker to replace a manual process for one of their customers.

Some of the packaging equipment they design and build includes wraparound side-, end- and bottom-loading case packers in many configurations. RMD also builds case erectors, bag-in-box equipment, case sealers and traymakers.

Engineered Equipment

RMD has hundreds of installations in several industries including baking, food, dairy, personal care, chemical and others.

RMD designs packaging equipment for products such as coffee, construction adhesives, aerosol, spices, and cartoned and canned food. Their equipment handles products housed in configurations such as chipboard trays and cartons, corrugated trays, plastic bottles, gable-top cartons, fiberboard caulking tubes, semi-rigid bags, and steel or plastic cans and tubs.

Their packaging equipment typically handles from 10 to 50 cases per minute depending on the application, and they offer a case sealer capable of speeds of up to 114 cases per minute. RMD equipment typically has an open design for easy operation, quick maintenance and simple adjustment.

For example, one of their case erectors builds regular, slotted-case, all-flaps-meet boxes with hot melt closure, and it can be adjusted for a wide range of box sizes using just two hand wheels. Another example is a case packer used where case sealing with pressure-sensitive tape is needed. This flexible machine can be changed over in 15 minutes or less. Some case erectors are designed for many SKU changes and can change over in two minutes.

Their bottom-load case packer works well for applications where a traditional drop-case packer is a poor choice due to possible product breakage during the loading cycle. The machine's design provides a gentle bottom-up feature which results in greatly reduced shock to the product as it's placed into the case.

Leading motion technologies employed in their machines include pneumatic, servo pneumatic and pure servo, each controlled by various PLC platforms. RMD uses the latest 3D software from SolidWorks to design their equipment.

Figure 13A: Ridgeline Machine Design's Model 25 Traymaker was designed and built in partnership with their customer to fulfill specific requirements in terms of space and cost savings

Putting Experience to Work

For one particular project, RMD started with a list of specifications from a manufacturer of custom door locksets and hardware based in the western U.S. RMD set out to meet these specs using pneumatics in a creative design. Pneumatics was selected as the motion control technology for this application due to its low cost, both up front and over time. It is simpler than alternatives such as electromechanical or servos, easy to understand and maintain, and straightforward to control and troubleshoot.

The Model 25 automatic traymaker was developed in partnership with their customer for this project; the machine assembles trays at a rate of 18 per minute with minimal floor space required and at an affordable price (Figure 13A).

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Acti
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Traymaker specifications from the client included a small footprint, portability, low cost, easy operation and simple maintenance. The customer also required a finished tray table with 50-count storage.

Because the machine is portable, it operates from 120 VAC to simplify power connection, and to improve safety. Competing machines typically require 208-230/460 VAC, and are quite a bit more expensive. A small portable footprint is needed due to limited floor space and the need to move the traymaker often. Low cost was another requirement, and one of the reasons AutomationDirect hardware was chosen.

The customer needed to automate an operation which traditionally required their plant personnel to make the trays by hand. The production rate was only four trays per minute, and the new machine assembles trays at a rate of 18 per minute, a significant improvement. The automated machine also freed up four workers who are now performing other tasks to further improve the customer's production processes.

The traymaker discharges each tray on its side to help the trays stack better (Figure 13B), whereas most traymakers on the market discharge the tray upright. RMD's older model traymaker had the tray blank move horizontally before set-up, while this new model has it traveling vertically. This required mechanical reorientation of much of the infeed assemblies.

Figure 12B: Tray output - the completed tray is positioned at the machine output on its side for easy stacking with other tray

Traymaker Ready for Productio3

The RMD Model 25 traymaker has a small footprint of approximately 7'H x 5'L x 3'W without the discharge table. The discharge table is 6'L x 4'W. The traymaker is controlled with a wide variety of AutomationDirect hardware including power distribution components, motors, drives, and safety relays and switches. AutomationDirect also provided an extensive pneumatic system starting from the main plant connection, proceeding to the flow controls, solenoids, tubing, fittings and cylinders.

Much of the product handling and assembly operations are pneumatic. The traymaker includes vacuum pick-off of tray blanks, vertically positioned to save space. The singulated tray blanks are fed into the system using an AC drive powering a motor and a worm gearbox which drives the tray blank feeding wheels.

The vertical, wheel-delivered tray blanks are fed downward to the assembly area, and are then set up by a pneumatic cylinder pressing the blank through tooling. The formed trays are then pneumatically offloaded to the discharge table.

Figure 13C: Air valves and a manifold provide fluid power to the cylinders that feed, assemble and stack the trays.

Pneumatic Assembly of Trays

The traymaker pneumatic components start with a 3/8-inch size filter, regulator and lubricator feeding a bank of valves operating a mix of round, compact and tie rod cylinders. Air preparation provides the required high air flow, and also filters and lubricates the air coming to the machine. The air prep system includes an electric dump valve to relieve the air supplied to the control valves when a door is opened or an emergency stop is pressed. There is also a manual lockable valve on the inlet, providing the required lockout/tagout functionality when servicing the equipment.

Air valves (Figure 13C) control all cylinder and vacuum generator operation. The valves are sized for worst case flow for any function on the traymaker. In this case, 4-way valves were specified to control all the cylinders, as their Cv rating of 0.89 is sufficient for the cylinders to operate and maintain proper speed. A 3-way valve was selected to operate the pneumatic vacuum generator for the same reason.

RMD prefers to use manifolds to feed air to the pneumatic control valves, and utilizes an 8-station unit on this machine for that purpose. To ensure a high flow air supply, ½" tubing is used to supply air to the valve manifolds. Plastic silencers on both ends of the manifold reduce noise and ensure minimal restriction of exhaust air.

The valves were wired using solenoid cables which include built-in surge suppression and an LED to show when power is present to the solenoid. Surge suppression improves the life of the PLC outputs by eliminating voltage spikes, and the LED indicator clearly shows valve status which simplifies and speeds maintenance.

Pneumatic Cylinder Details

The pneumatic cylinder configurations were specified based on space constraints and required motion. In places where the cylinder is producing rotational motion, either by moving a lever or pushing a rack turning a gear, the machine uses tie rod cylinders with built-in cushions. For other low power or supplemental motion, the machine uses either round-body (Figure 13D) or compact cylinders.

Pneumatic cylinders provide all the motion required to feed, assemble and stack the trays (except for the vertical tray blank feed wheel motion, which is electromechanical). All cylinders critical to the assembly/setup of the tray include magnet resistance sensors along with magnetic pistons in the cylinders. The sensors provide error-proofing of cylinder end-of-stroke motion for each step of the machine assembly sequence.

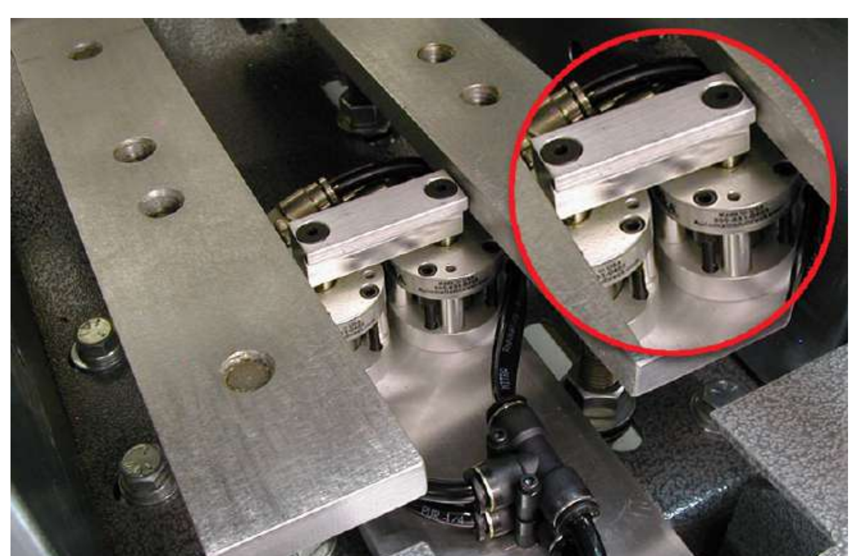


Figure 13D: Compact cylinders. These Compact cylinders were selected for their small size, and are some of the many pneumatic cylinders controlling mechanical motion in the traymaker

The Nitra® pneumatics from AutomationDirect work as well as their more expensive competition, and RMD has used them in lubricated and non-lubed applications with great success.

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Acti
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Supplier Selection

RMD chose AutomationDirect as a primary supplier of the traymaker automation, power, pneumatic and other components. They were selected for the affordability and quick availability of the wide variety of products required for this application. AutomationDirect's technical documentation is available 24/7 on their website, and phone support is available without a support contract. Other factors leading to their supplier selection included the free customer support forum, free 2-day shipping and free programming software.

The traymaker is controlled by an **AutomationDirect CLICK C0-00DR-D PLC** with expansion I/O and terminal blocks for field wiring. A bulkhead programming port with outlet on the control enclosure door simplifies compliance with arc flash regulations as it allows changes to be made to the controller software without opening the door (Figure 13E).

AutomationDirect also provided the power distribution hardware including a non-fused disconnect switch, branch circuit protection circuit breakers, and a rotary motor protector switch to disconnect power from the motor drive.

Operator control buttons include a selector switch, pushbuttons and an E-stop mushroom pushbutton. To sense the product, background suppression photoeyes and cylinder position sensors were used.

The end result shows that, with strong customer buy-in, you can build a reliable machine using the affordable products provided by AutomationDirect. Other factors valued by this and other customers include simple operation, low maintenance and industry-leading customer support.

Figure 13E: Control enclosure. Like the rest of the machine, the control panel is fully portable

Riada Equipment Solves Difficult Packaging Problem

Riada Equipment is based out of Winder, GA and has been solving problems for cleaning product, food & beverage, textile, cosmetic, lubricant, and glue & adhesive customers since 1984. The company offers new bottling equipment, and also re-manufactures existing customer equipment.

Handling and filling oval shampoo bottles required innovative design of custom machinery.

When asked where the exotic company name came from, owner Ross Adair said it was just his last name turned backward. How clever. When a long-time customer ran across a difficult bottling application, they turned to Riada to solve it, calling on that very cleverness.

The difficulty in this particular customer's case centered on uniquely-shaped shampoo bottles. The oval containers precluded stacking, and also conveying bottle-to-bottle. Instead, each bottle had to be indexed and then clamped individually for the filling sequence. To accomplish this, Riada decided to use a programmable logic controller and associated system components from **AutomationDirect**.

Controlling Machine Motion

The machine entry section consists of a set of DC motor-controlled round spacing wheels that move the bottles onto the machine belt conveyor for filling. Running at a speed slightly less than the belt conveyor, the feed wheels space the bottles at the correct distance for the fill nozzles and bottle clamps. The belt conveyor speed is regulated by an AutomationDirect GS-2 series AC drive.

Round-body style entry and exit pneumatic gate cylinders are also supplied by AutomationDirect, and they control the overall 10-bottle group container flow into the machine, and out of the machine to downstream operations.

As the bottles enter the machine, they are counted by an AutomationDirect MVP series retro-reflective photo eye. If the machine is set up for a ten-bottle run, then ten bottles are counted on the way in or the cycle is halted. The bottle count is decremented as bottles exit the machine, and the machine cycle is halted if the total count doesn't reach zero.

A set of AutomationDirect NITRA brand E-Series rod-guided pneumatic cylinders is located at each of the ten fill stations and is used to clamp and hold the bottles. This dual-rod design translates the force of the air into precise linear motion and minimizes any side-to-side movement. This is critical to the clamping sequence as it minimizes clamp-settling time.

An AutomationDirect MV2-series photo-eye at each station individually detects the presence of a bottle and controls the clamping sequence. Since space in the dispensing area is at a premium, the MV2 diffuse type photo eye was used at each station to sense the presence of a bottle. This type of sensor eliminates the need to mount either a reflector or receiver on the other side of the sensing line.

AutomationDirect NITRA brand pneumatic equipment is prevalent throughout the machine. An AFR series filter-regulator provides the machine with clean air at the right pressure, and Riada added a 3rd party receiver tank to provide excess capacity and minimize any drops in air pressure regardless of the real-time air load, ensuring consistent cycle times.

Manifold-mounted AutomationDirect AVS-5 series 5-port 4-way solenoid valves provide the air control function required by the double-acting pneumatic cylinders. MLA series air header manifolds were added at the machine front and rear to distribute air with minimum piping runs, with the result being higher air pressure and more consistent cycle times.

Jump to Chapter
Chapter 1 Why Use Pneumatics?
Chapter 2 Pneumatic Circuit Symbols Explained
Chapter 3 Understanding Pneumatic Air Preparation
Chapter 4 Pneumatic Actuator (Air Cylinder) Basics
Chapter 5 Valves for Pneumatic Cylinders
Chapter 6 Pneumatic Tubing & Hose
Chapter 7 Pneumatic Fittings
Chapter 8 Are Pneumatic Components Compatibl9
Chapter 9 Electro Pneumatic Systems in Acti
Chapter 10 Pneumatic System Design Considerations
Chapter 11 Energy Efficient Pneumatic Systems
Chapter 12 Pneumatic Actuator vs. Electromechanical
Chapter 13 Application Stories

Dispensing Operations

Filling the customer's containers with product is the primary job of the machine. All equipment with surfaces touching the product meets FDA specification, including the stainless steel metering cylinders, and the shut-off stopper cylinders at each nozzle.

Supplying the force to move those cylinders are AutomationDirect D-series NFPA tie rod cylinders. At the rear face of each tie rod cylinder are threaded rods and handles. Each rod travels through customer-supplied holes, and penetrates the rear face of the tie rod cylinder to provide a stop for its piston.

Manually adjusting the rod length varies the stroke of the tie rod cylinder, which in turn varies the volume dispensed by the stainless cylinder, a very simple yet effective design. Different color pressure and exhaust tubing separates the lines to facilitate tracing for troubleshooting.

Control and Operator Interface

The entire machine sequence is controlled by an AutomationDirect DirectLogic DL-06 programmable logic controller. This brick style unit contains both the CPU and sufficient I/O to meet the machine requirements. An AutomationDirect six-inch EA9 series color touch-screen C-More human-machine interface (HMI) allows for flexible machine product and cycle time setup. The HMI is used to set up various timers and variables for the filling process. It's also used to control machine start and stop, minimizing the need for pushbuttons.

Besides operating screens, a maintenance screen is included. This screen allows operators to run the machine dry for testing various components and operations. Typical dry runs include clamping and unclamping of bottles, raising and lowering fill heads, and running the machine through its entire sequence without dispensing any product.

Test and Results

Shop test was performed at the Riada facility in Winder, Georgia. Minor PLC program changes during shop test were done remotely by Riada's systems integrator, Systems & Controls of Lenoir City, TN. The integrator's PC was connected remotely to Riada's shop floor PC running DirectLogic programming software. The connection was made over a wireless plant network at the Winder location. Successful shop test and product run-off with the customer allowed Riada to receive final sign-off prior to shipment, a critical milestone.

The machine has been running for two shifts a day since November 2014 without interruption. Due to these uccessful results, the customer ordered and Riada delivered clamping systems for two of the customer's existing machines.

DIY Pneumatic Saw Clamp

Many years ago my father was working on a new shop behind his house. The insides were left for us to finish. We needed to build work benches, shelves and racks. To save money, he bought the longer 2x4 sized lumber and we'd cut it to whatever size was needed. This worked out great but the extra-long boards were unruly and a challenge to cut by one person because of the length. We didn't have a nice chop saw setup that is so common now with the nice outriggers and side supports. We basically made a saw with an old Black and Decker work bench. The kind with the clamp built into the table top.

After many cuts using one hand on the saw and one hand trying to balance the board, I knew there had to be a better way. I started using the manual clamp that came with the saw but its range was pretty limited and it was better suited for thinner material than a 2x4. I remembered a pneumatic cylinder that I had grabbed out of a junk pile and thought that I might be able to make an automatic clamp with it. I found a piece of steel to mount the pneumatic cylinder to and then used a section of rod for the post. The rod had to be turned down by a friend on a lathe so it would fit in the clamp mount on the saw.

When I first used the pneumatic clamp on the saw I was amazed at how much force it had. I was able to place a 14 foot board under it and it would lift it and keep it perfectly clamped on the saw. When you're trying to cut off 2 feet of a 14 foot board, that's a big deal.

It was so useful for my dad and me that I wanted to revisit the project and share it on my website Neo7CNC.com and the Neo7CNC YouTube channel. I started documenting my very first DIY CNC machine build years ago and posted the videos on YouTube. With each new CNC machine or contraption I built, interest on the channel kept growing. I've continued to share my machines, experiences and information ever since. I really enjoy inspiring others to make things (CNC or not) and the interaction with viewers and sharing of knowledge is a huge bonus. Since randomly finding a pneumatic cylinder doesn't translate very well to my viewers, I wanted to find a source for most, if not all of the needed components for this build.

AutomationDirect.com was my first choice. With a great selection, good prices and fast shipping, it was a no brainer. I've used them many times over the years. Not just for pneumatic parts but also for buttons, enclosures, sensors and much more. I was able to find just about everything from them. The only other items needed can be found at most local hardware stores.

To see how pneumatics was used in the saw clamp application or if you're interested in DIY projects and CNC machines, please stop by the **Neo7CNC.com website and YouTube channel**.

DIY Halloween

When you think of Halloween you probably have in mind something creepy, scary, or horrifyingly haunting to use as your Halloween props. But how do you give it that something special, that "scream factor"? That's where AutomationDirect comes in…

Thanks to products from AutomationDirect you can create something to scare trick-or-treaters.

Check out our video series on automating Halloween props. This series has been quite a hit with viewers and we've kicked things up a notch or two with a classic horror movie-style piece. Hopefully our recent DIY Halloween Prop video will scare…I mean…inspire you.

Each video on this page explains how to build a DIY Halloween pneumatic creation step-by-step. The best part about using a pneumatic component is its ability to automate endless types of props from a bone shaking skeleton, to a crazed zombie or even open and close doors and few dresser drawers. Happy haunting!