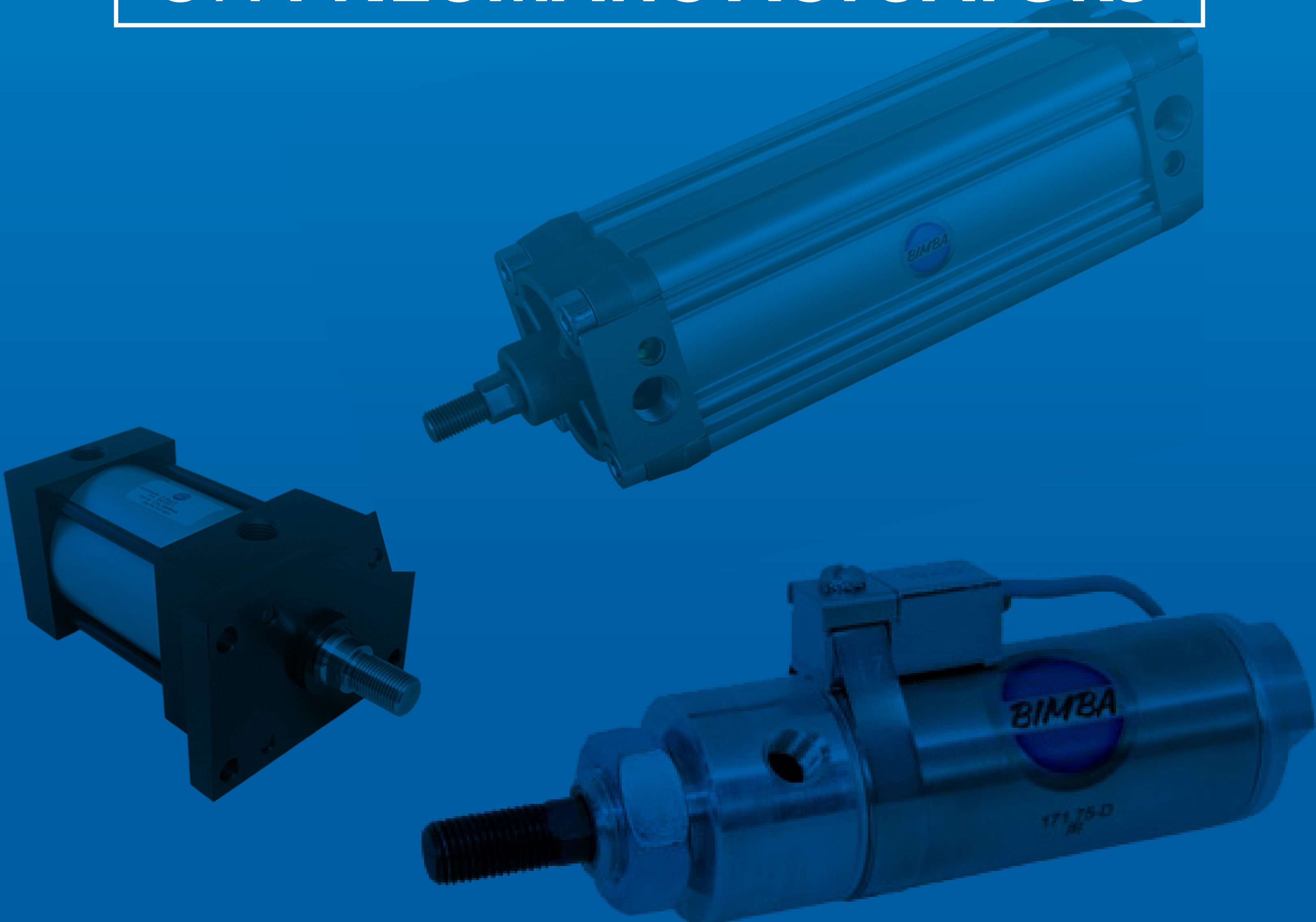
DESIGN GUIDE
ON PNEUMATIC ACTUATORS



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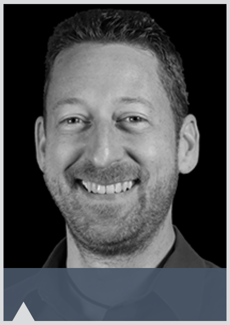
Pneumatic actuators, or cylinders, work to power automated systems, machines, and processes in industrial, medical, laboratory and other challenging applications. They provide either rotary or linear force and motion to move or turn a machine function, or provide the precision and power for pick-and-place systems.

Their operation is simple — compressed air is forced into a cylinder housing to move a piston inside. This piston is attached to an outside machine or device, which converts the energy into use. They are most commonly manufactured to either NFPA or ISO standards.

In this Design Guide, the editors of Fluid Power World provide tips on the different styles available, sizing and selection, and special uses in automation and sensing.

MARY GANNON
Editor



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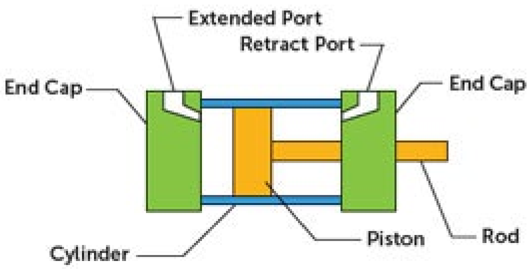
WHAT ARE **PNEUMATIC CYLINDERS?**

Many industrial applications require linear motion during their operating sequence. One of the simplest and most cost effective ways to accomplish this is with a pneumatic actuator, often referred to as an air cylinder. An actuator is a device that translates a source of static power into useful output motion. It can also be used to apply a force. Actuators are typically mechanical devices that take energy and convert it into some kind of motion. That motion can be in any form, such as blocking, clamping, or ejecting.

Pneumatic actuators are mechanical devices that use compressed air acting on a piston inside a cylinder to move a load along a linear path. Unlike their hydraulic alternatives, the operating fluid in a pneumatic actuator is simply air, so leakage doesn't drip and contaminate surrounding areas.



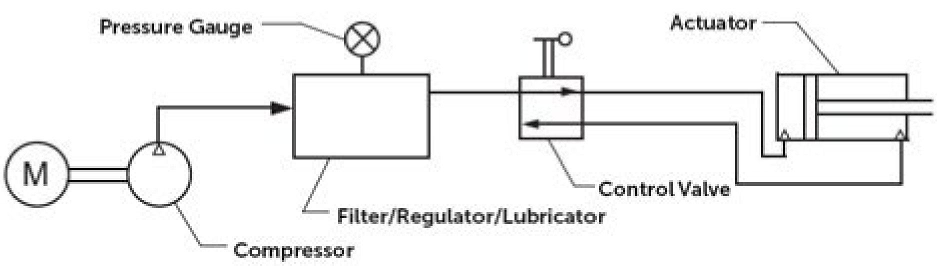
There are many styles of pneumatic actuators including diaphragm cylinders, rodless cylinders, telescoping cylinders and through-rod cylinders.

The most popular style of pneumatic actuator consists of a piston and rod moving inside a closed cylinder. This actuator style can be sub-divided into two types based on the operating principle: single acting and double acting.

Single-acting cylinders use one air port to allow compressed air to enter the cylinder to move the piston to the desired position, as well as an internal spring to return the piston to the "home" position when the air pressure is removed.

Double-acting cylinders have an air port at each end and move the piston forward and back by alternating the port that receives the high pressure air.

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. An on-off control valve is used to direct compressed air into the Extended 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 surface 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. Reversing the valving and the compressed air flow will cause the assembly to retract back to the "home" position.

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WHAT ARE PNEUMATIC CYLINDERS?

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, are compressors, filters, pressure regulators, lubricators, on-off control valves and flow controls. Connecting all of these components 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 desired performance. Undersized upstream components can cause a pneumatic actuator to perform poorly, or even make it unable to move its load at all.

PNEUMATIC CYLINDER SELECTION

When selecting any air cylinder, it's important to properly match the cylinder to the application, particularly in terms of required force. The theoretical force available in the actuator is the piston surface area multiplied by the supplied air pressure. Spring force must be subtracted from this value for single acting cylinders. The actual force applied to the load will be 3% to 20% less due to pressure losses in the system.

When the required piston surface area (A) is known, the bore diameter (d) can be found by the formula:

Stroke length is determined by the required travel of the machine element driven by the actuator. The final selection criterion is the cylinder mounting arrangement, and the resulting configuration.

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. Once the basic actuator size and configuration are known, other options such as end-of-stroke cushions or special seals should be considered. In some applications, position detection switches are required, typically accomplished with a magnetic piston and switches.

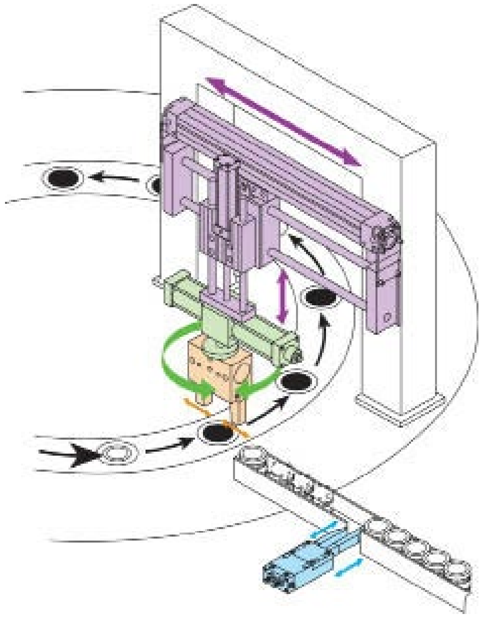
There are many factors such as system contamination, corrosion, minor leaks and wear that will affect the available air pressure and flow used to drive the actuator. An actuator and fluid power system should be sized correctly so as not to waste energy, with a margin added to account for minor reductions in pressure and flow due to the factors listed above.

WHAT ARE **RODLESS PNEUMATIC CYLINDERS/SLIDES?**

Pneumatic cylinder slides or rodless cylinders, are designed to provide power and linear motion while supporting a load. Standalone pneumatic cylinders are suitable for providing power and motion, but are not designed to provide support for a load. Many cylinders have no way of holding the position of the piston rod, due to the rod's ability to rotate. Pneumatic cylinder slides provide the load capability and a stable, non-rotating platform on which to mount tooling or other actuators. This is especially important when a cylinder is moving in a horizontal direction where side load is a major issue—common in automation devices used for picking and placing of parts.

Cylinder slides are popular choices when longer distances of travel are required, or when the overall length must be minimized due to space constraints

Typical uses for these slides include conveyor stops, part ejection and positioning, opening and closing safety doors, gates or curtains. In many of these applications, the need for side load capacity and non-rotating capability is critical.



The idea of applying a load to a linear actuator is very common and there are a number of types of cylinder slides that can be used for these applications. The first basic style of powered slide is commonly known as a "thruster" or cantilever type unit. This type of powered slide is typically powered by a pneumatic cylinder, which is attached to the body of the slide, or may be integral to the slide. In either case, the cylinder piston rod is attached to a tool plate providing power and motion. The tool plate is supported by a bearing mechanism, and together they are able to carry any loads that are attached, rather than transferring the load to the cylinder rod. This type of slide is designed to carry an overhung load known as a cantilevered load.

The second basic type of cylinder slides is called a saddle slide or base slide. In this case, the pneumatic cylinder is attached to a saddle that supports the bearing system on each end of the slide's travel. This type of powered slide can be used for longer travels with less deflection based on the bearing system being supported on each end. Like the thruster style slide, the saddle carries the load verses the cylinder's piston rod.

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WHAT ARE RODLESS PNEUMATIC CYLINDERS/SLIDES?

The types of bearing systems can vary on both the thruster slides and the saddle slides. The most common type of bearing system on cylinder slides uses round shafts with linear bearings. The bearings can be precision reciprocating ball bushings or a variety of composite bushings. The precision ball bushings provide low friction and more 200 million in. of travel life. Composite bushings are typically lower in cost and can be used in harsh environments. These have more friction and do not have the life expectancy of the reciprocating ball bushings.

Other pneumatic cylinder slides use profile rails with reciprocating ball carriage bearings. The profile rail bearing systems provide long life with minimum deflection. These can be incorporated in both thruster and saddle type slides.

There are several considerations when selecting the best type of pneumatic cylinder slides. These include:

Load capacity required. The total payload must be calculated in order to start the selection process.

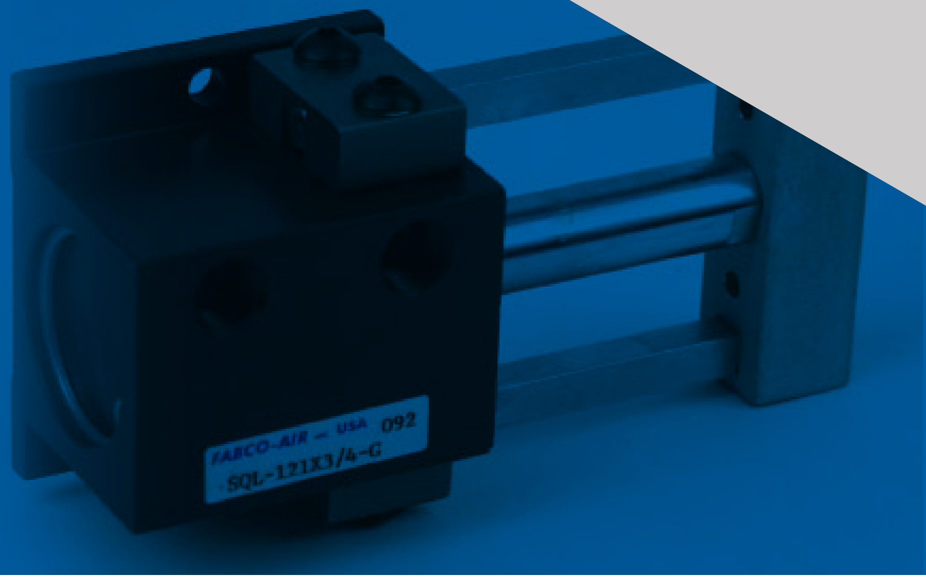
Life required from the slide. The bearing system selected will have an impact on the expected life of the unit along with the required speed and payload.

Speed required. The slide speed is a critical component including the ability of the slide to handle the kinetic energy as the load stops at the end of travel. Cylinder shock pads, cylinder cushions or shock absorbers may be required based on the load and speed of the slide.

Accuracy needed. The amount of deflection will vary based on the bearing system and the payload being carried. This deflection will affect the positional accuracy of the slide.

Many manufacturers of pneumatic cylinder slides provide specification and sizing software to allow the proper selection of the slide required for various applications.

WHAT ARE **COMPACT PNEUMATIC CYLINDERS?**



Compact cylinders have been shortened relative to standard pneumatic cylinders. They may take up to 50% less space than the normal, while still maintaining the capacity to exert the same force as their larger counterparts. Important parameters for the proper selection of a compact cylinder can be broken up into general, dimensional, performance, material, features.

The "Pancake cylinder" was the original compact pneumatic cylinder, invented by Al Schmidt in 1958, to fill a need for force in a tight, enclosed space. The basic intent was to get the most stroke in a short overall length using common machined parts and seals. Through the years, this design has been further developed, with many features and options to satisfy an extreme variety of customer applications. This round body cylinder has a smooth, clean outside diameter for ease of machinery cleaning. Even though initially used for strokes less than 1-in., manufacturing methods have allowed increased strokes to as much as 4-in. Non-metallic rod bushings and piston bearings can accommodate extreme or unforeseen loads to provide long term durability.

Other compact cylinders vary quite a bit. They can be square shaped, offer numerous mounting features and can be placed with adjacent cylinders at a close center-to-center dimension. Piston bearings, materials, hard anodized bore and chrome plated rods can enhance cylinder capability for unexpected side loads and long term durability. Up to 6-in. strokes can be accomplished with extruded body material. Other features may include metric dimensions, extruded sensor mounting, and non-rotating styles.

SELECTING A COMPACT CYLINDER

Application data needed for sizing a compact cylinder and choosing the best component:

- Operating psi, force required (Force = Pressure x Piston Area)
- Stroke
- Preferred mounting, foot print
- Spring return or double acting

Other items to consider:

- Ambient temperature
- Media temperature
- Environment
- Excessive loads other than required axial force
- Load guiding (non-rotating) requirement

HOW TO SELECT A PNEUMATIC ACTUATOR: AN ENGINEER'S GUIDE

Driving linear-motion applications with pneumatic actuators (or air cylinders) is a relatively easy and inexpensive approach. The actuator technology has existed for more than 50 years, but better piston seals and rod wiper seals (of modern materials) make pneumatic actuators more resilient and efficient than ever. These seals reduce leakage and withstand extreme temperatures to let engineers use the actuators in more environments.

Likewise, surfaces with permanent lubrication, servo-pneumatic controls, improved corrosion resistance and air-cushioning features make pneumatic actuators more useful than ever.

To review, pneumatics is the technology of compressed air. However, in some circles, it's more fashionable to refer to it as a type of automation control. Pressurized gas—generally air that may be either of the dry or lubricated type—is used to actuate an end effector and do work. (More after the jump.)

End effectors can range from the common cylinder to more application-specific devices such as grippers or air springs. Vacuum systems, also in the pneumatic realm, use vacuum generators and cups to handle delicate operations, such as lifting and moving large sheets of glass or delicate objects such as eggs. Pneumatics is commonly used in industries that include medical, packaging, material handling, entertainment and even robotics.

By its nature, air is easily compressible, and so pneumatic systems tend to absorb excessive shock, a feature useful in some applications. Most pneumatic systems operate at a pressure of about 100 psi, a small fraction of the 3,000 to 5,000 psi that some hydraulic systems see. So, pneumatics are generally used when much smaller loads are involved.

A pneumatic system generally uses an air compressor to reduce the volume of the air, thereby increasing the pressure of the gas. The pressurized gas travels through pneumatic hoses and is controlled by valves on the way to the actuator. The air supply itself must be filtered and monitored constantly to keep the system operating efficiently and the various components working properly. This also helps to ensure long system life.

In recent years, the control available within pneumatic systems (thanks to advanced electronics and componentry) has increased a great deal. Where once pneumatic systems could not compete with many comparable electronic automation systems, the technology today is seeing a renaissance of sorts.

PNEUMATIC ACTUATOR OPERATION

Many industrial applications require linear motion during their operating sequence. One of the simplest and most cost effective ways to accomplish this is with a pneumatic actuator, often referred to as an air cylinder. An actuator is a device that translates a source of static power into useful output motion. It can also be used to apply a force.

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$$d=\sqrt{\frac{4A}{\pi}}$$

The required travel of the machine element determines stroke length driven by the actuator. The final selection criterion is the cylinder mounting arrangement, and the resulting configuration.

There are myriad pneumatic-actuator configurations available from various manufacturers. The more common ones include rigid nose or tail mount, trunnion mount, rear pivot mount and foot mount. Once the basic actuator size and configuration are known, other options, such as end-of-stroke cushions or special seals, should be considered. In some applications, position detection switches are required, typically accomplished with a magnetic piston and switches.

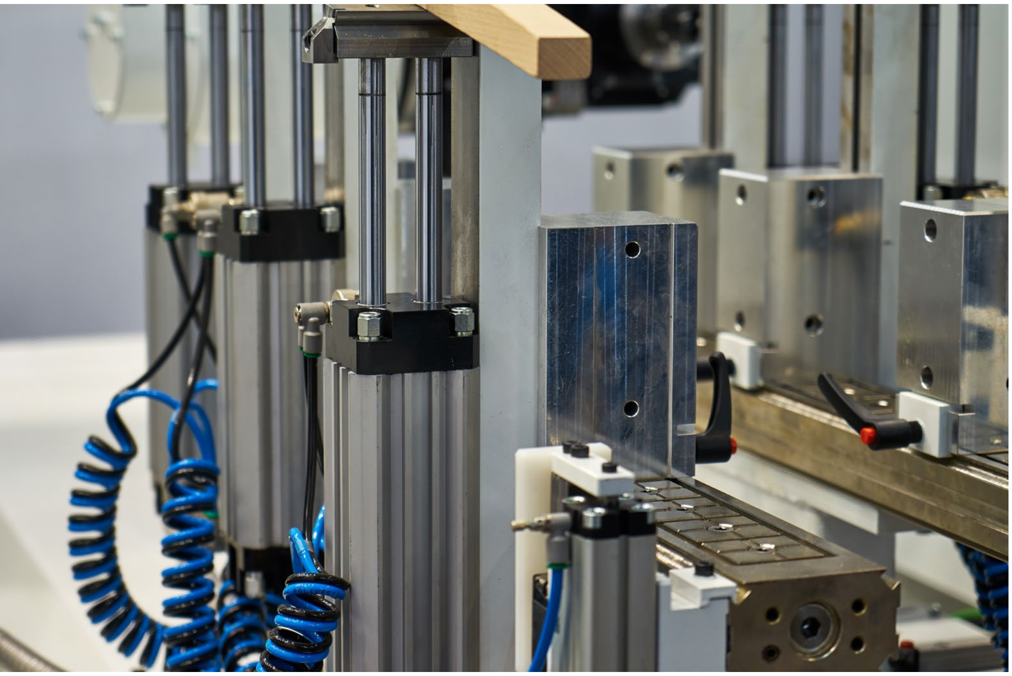
Several factors, such as system contamination, corrosion, minor leaks and wear, affect the available air pressure and flow used to drive the actuator. Engineers should size the actuator and fluid-power system so as not to waste energy, with a margin added to account for minor reductions in pressure and flow.

HOW ARE **PNEUMATIC ACTUATORS USED IN AUTOMATION APPLICATIONS?**

Pneumatic actuators come in an array of permutations for automation. Rod and rodless actuators are the two most common, though rodless are far more common in the U.S. Rodless actuators include bearings to address moment loads in X. Y, and Z. Tip: Avoid undersized pneumatic actuators for applications by accurately calculating application force; subtracting piston-rod area; accounting for the energy to overcome friction; and accounting for unusual application kinematics.

Note that most pneumatic-actuator applications are linear-stroke setups needing two or more position stops. Minimizing stop times in many pneumatic actuators are done by air cushions. Damping seals are another option. Choosing pneumatic actuators over electrical options is common in applications that need motion axes to work without electricity — where sparking poses a problem (as in applications that involve flammable materials for example).

Limitations include lack of total controllability and air consumption, but few actuators outperform pneumatic actuators in applications that need clean operation, low upfront cost, and high force-speed ratios. Even so, pneumatic actuators deliver moderate to high load at 120 in./sec or better. Plus advanced pneumatic actuators have wireless valve controls and sensors for IoT and predictive-maintenance functionality.



ANOTHER VARIATION ON PNEUMATIC ACTUATION: BLADDERS

Bladder actuators are another form of pneumatic actuation for short strokes and constant-force motion. Where appropriate they outperform other systems. In part positioning, footed bladder actuators output consistent lifting force for plates and other wide and flat loads and workpieces. Another application is automatic door seals to work as flood barriers and chamber closures. These inflatable actuators also work in material-handling applications. Such actuators can’t deliver on precision positioning, so only work where designs are forgiving on that parameter. They’re also unsuitable for point-source applications. That said, these actuators are capable of very accurate force control, and strokes can reach a couple inches.

PNEUMATIC CYLINDERS THAT TALK BACK

Air cylinders and actuators are renowned for simplicity, economy and long-time durability in countless motion-control applications. The devices typically provide basic linear motion and perform faultlessly and unnoticed for years.

Increasingly, however, many newer equipment designs and automation systems demand a lot of data — even from components like air cylinders — to operate precisely as intended and quickly pinpoint when something goes wrong. Likewise, engineers sometimes need to enhance control to compensate for widely fluctuating loads or inconsistent system air pressure.

That's because many types of machinery have complex and automated sequences and interactions, for instance ensuring one cylinder completes its stroke before the subsequent action begins. It necessitates monitoring performance to ascertain correct operation, and position sensors can perform such functions.

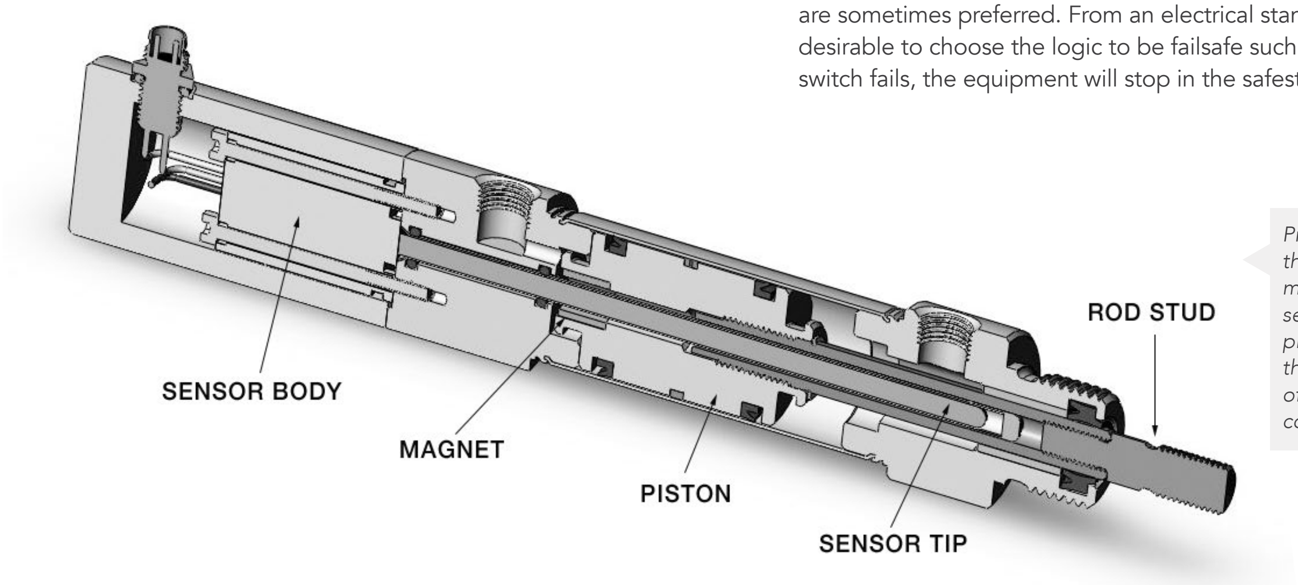
Most cylinders operate to two positions, extended and retracted. By installing position switches for each case, the control system can be configured to alarm if a cylinder has not reached the commanded position when expected. It is also possible to add more switches to indicate intermediate positions. The control system can also be programmed to identify any actions that take longer than expected. This can trigger a warning of a potential breakdown before a complete failure occurs.

Installing sensors on-board an actuator is a reliable and proven method which can be consistently applied throughout a machine. Many cylinders include T-slots or dovetails that readily accept compatible position switches. Users can also secure sensors with mounting bands or adapter brackets.

Two widely available types of position sensors or switches are economical mechanical reed switches and Hall-effect sensors. The latter are a reliable option because they have no moving parts and may also include LEDs to indicate operation status and faults, although they exhibit a small current leakage that could cause issues in some set-ups. Both types also require the internal piston to be magnetic in order to engage the switch and close a circuit.

Mechanical switches operate like relay contacts. Solid-state switches come in PNP (sourcing) and NPN (sinking) varieties, which must be selected to match control-system characteristics. When driving other loads such as relays or lights, engineers must evaluate the switching power and current rating.

It is most common to use normally-open (NO) switches that close when position is sensed, although normally-closed (NC) versions are sometimes preferred. From an electrical standpoint, it is always desirable to choose the logic to be failsafe such that if the wiring or switch fails, the equipment will stop in the safest way possible.



Pneumatic cylinders that use noncontact magnetostrictive sensors can track piston position along the entire length of travel. Image courtesy of Bimba

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PNEUMATIC CYLINDERS THAT TALK BACK

Sometimes a design requires more than just end-of-stroke sensing. In such cases, engineers can specify cylinders with sensors that track piston and rod position along the entire length of travel. These products are ideal for applications that require a high degree of flexibility and adaptability. They're often recommended for automated manufacturing processes that require quick changeover or for mass-customized product assembly.

For example, Bimba Manufacturing, based in University Park, Ill., makes the Position Feedback Cylinder (PFC) that provides continuous position sensing in a lightweight, small bore air cylinder. The PFC contains an internal linear resistive transducer (LRT) mounted in the cylinder rear head. The LRT probe, which has a resistive element on one side and a collector strip on the other, sits inside the cylinder rod. A wiper assembly is installed in the piston. Moving the piston creates an electrical circuit between the resistive element and collector strip. Resistance in the circuit is proportional to piston position, which is used to produce an analog signal that the controller uses to determine a precise position.

Three factors, resolution, linearity and repeatability, determine the LRT accuracy. Resolution is stroke sensitive – the longer the stroke, the less the resolution. It's typically around 0.002 to 0.003 in. Linearity, the maximum deviation of the output voltage to a straight line, is ± 1% of stroke. And mechanical repeatability is ± 0.001 in. So overall accuracy is on the order of a few hundredths of an inch.

The Position Feedback Cylinder Non-Contact (PFCN) is similar to the PFC, except it uses a magnetostrictive sensor instead of an LRT. In basic terms, magnetostriction involves a fixed sensing element, called a waveguide, made of ferromagnetic material that runs the length of the cylinder. A magnet mounted on the piston creates a magnetic field.

Short current pulses generated by the sensor electronics travel along a conductor attached to the waveguide. When the magnetic fields induced by the current and magnet interact, it generates a torsional strain in the waveguide. This mechanical wave travels back to a signal converter in the electronics and is used to determine position — all in a few µsec. It is calibrated to produce exactly 0 V fully retracted and 10 V fully extended.

In practice, the unit senses position as the piston moves back and forth. And it provides absolute position information. Accuracy, the combined effects of non-linearity, repeatability and hysteresis, is ± 0.016 in. maximum anywhere along the stroke.

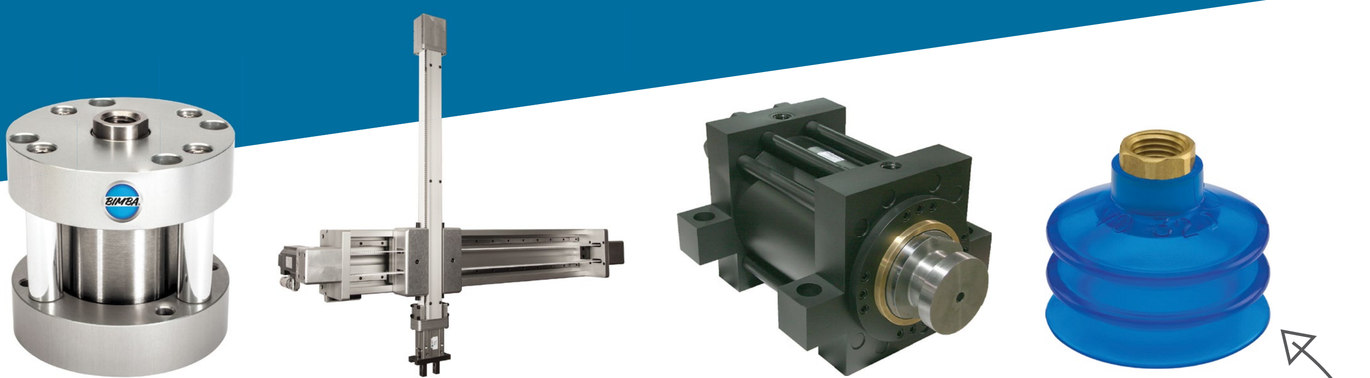
Non-contact operation provides many advantages. The technology is reportedly ideal for applications that involve dirty or moist environments, rapid oscillation over a small increment of stroke, and vibration. In addition, it is relatively immune to airline contamination. This makes the Non-Contact Position Feedback Cylinder a preferred option in many closed-loop pneumatic positioning applications.

Both The PFC and PFCN can operate with controllers like Bimba's Pneumatic Control System, Digital Panel Meter Model, or Electronic Controller, as well as similar units. And for rotating applications, Bimba's Pneu-Turn (PTF) rotary actuator with position feedback is a rotary rack-and-pinion actuator that has a rotary potentiometric feedback transducer attached to the output shaft. It provides continuous shaft position sensing within ±0.5°.

Sensing elements are a good value, especially when feedback is required for critical applications. Yet it must be noted that for the most basic cylinders, the cost to add position switches to both ends of travel may double the final price of the complete cylinder. That's when you consider the added costs due to sizing and selection time, wiring expenses, and controls programming, as well as additional costs should they eventually fail. Thus, adding sensors to every cylinder may not be cost efficient or the best use of project funds.

The bottom line is that used judicially, cylinder feedback control and monitoring elements are a valuable addition to innumerable pneumatic systems.

Pneumatic. Electric. Hydraulic. Vacuum.



Whether it's a standard off-the-shelf cylinder or a cutting-edge custom assembly, Bimba is uniquely positioned to help with your motion control application. That means everything from simple, non-repairable products to the latest in precision mechatronics or end-of-arm tooling applications. If you've got an engineering challenge, Bimba has the solution to keep your application moving forward. From innovative design to unparalleled customer service, it's all about getting you the right solution at the right time.

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