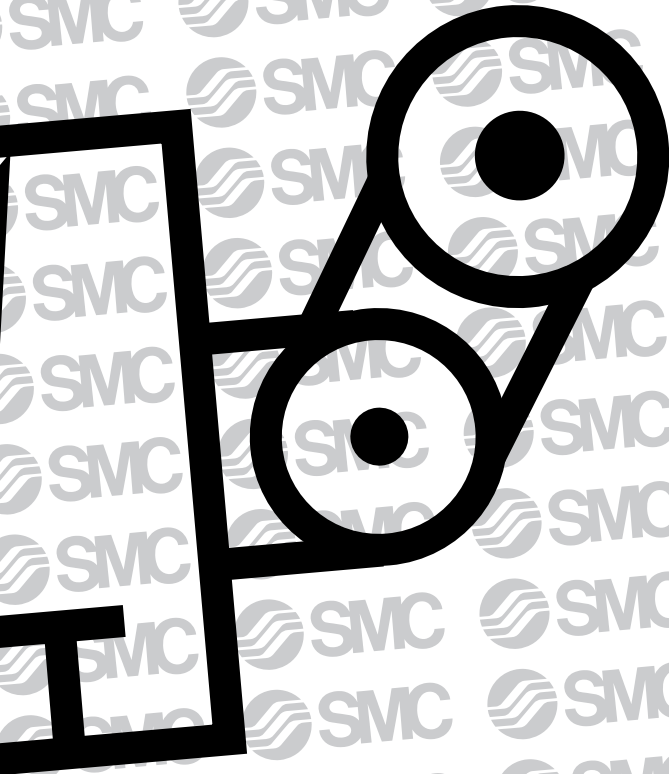


The *Pneu* BOOK



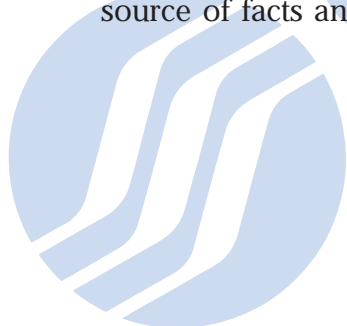
# WELCOME TO THE PNEU BOOK

**T**he Pneu Book is produced by SMC Pneumatics (UK) Ltd and is available to all those with an interest in the theory, development and application of pneumatics technology.

The Pneu Book will comprise of a regularly updated series of issues, each of which will be divided into sections for ease of reference, covering a range of subjects. For example, the first issue, supplied with this pack, starts the ball rolling by looking at the techniques used for sizing valves and cylinders and by providing a guide to basic terminology. Future issues will cover areas ranging from circuit design and symbols, to vacuum theory and cylinder efficiency.

The Pneu Book is intended to provide an informative and interesting reference file, for use when designing or modifying pneumatic systems, or when specifying particular types of components.

We hope that you will find The Pneu Book to be a valuable source of facts and ideas.



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**INTRODUCTION**

# SIZING PNEUMATIC VALVES AND CYLINDERS

**V**alve and cylinder sizing represents possibly the most important element in the design and specification of any pneumatic system. Carried out correctly, it will ensure that capital and operating costs are minimised, while maximising system performance, reliability and efficiency.

## Cylinder Sizing

Cylinder applications can be categorised as either:

STATIC, i.e. clamping, pressing, etc. or  
DYNAMIC i.e. load moving.

In both cases the principle factors which must be considered when calculating the correct cylinder bore size are:

Amount of thrust required.  
Available air pressure.  
Efficiency of the cylinder.

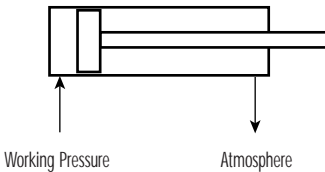
# Cylinder Thrust

Cylinder thrust is a function of:

- Piston diameter
- Applied air pressure
- Frictional resistance (efficiency)

Required cylinder thrust is generally derived from a known clamping pressure (static) or the force required to move a particular load (dynamic) and is expressed in units of pounds force (lbf), kilogram force (kgf) or newtons (N).

In the case of dynamic applications, consideration must also be given to the decaying pressure on the side of the cylinder piston open to atmosphere.



In order to regulate cylinder speed, the decaying pressure on the side of the cylinder's piston open to atmosphere, should be approximately 1.5 bar and can be considered to work against the cylinder.

To determine the correct size of cylinder, it is necessary to use the formula:

$$\text{Thrust} = \text{Pressure} \times \text{Area} \times \text{Efficiency}$$

Pressure in this instance being the available air pressure, expressed in units of bar,  $\text{N}/\text{m}^2$ ,  $\text{lbf}/\text{in}^2$  or  $\text{kgf}/\text{cm}^2$ , and area being the piston area in units of  $\text{m}^2$ ,  $\text{cm}^2$  or  $\text{in}^2$ . (One bar equals approximately  $1 \text{ kgf}/\text{cm}^2$ ).

Cylinder efficiency varies between manufacturers, being dependent upon both cylinder construction and the seal technology employed. The general efficiency of cylinders designed with lip

seals is considered to be 80% whilst more sophisticated and technologically advanced designs can be as high as 97%.

Example 1: Determine the size of cylinder (D) required to move a load of 150 kg, given an air pressure of 7.3 bar (7.3 kgf/cm<sup>2</sup>). Assume an efficiency of 90%.

Thrust = Pressure x Area x Efficiency ( $\mu$ )

therefore,  $150 = (7.3 - 1.5) \times (\pi D^2 / 4) \times 0.9$

Transposing this formula then gives:

$$D^2 = (150 \times 4) / [(7.3 - 1.5) \times \pi \times 0.9]$$

$$D^2 = 36.6$$

$$D = 6.05 \text{ cm}$$

The result is directly equivalent to the diameter of the cylinder required, measured in centimetres. In practice, however, cylinders with the exact calculated bore size are not usually available. It is therefore necessary to specify a cylinder with the next standard bore size. In this case, a 63mm cylinder would be selected.

Clearly, with a larger bore cylinder, a decrease in working pressure can be tolerated; the difference between available air pressure and required system working pressure being the maximum permissible system pressure drop.

The basic formula used above can also be developed to encompass the extending stroke on a single acting cylinder and the retracting stroke on a double acting device.

← Note

The available pressure of 7.3 bar was reduced by 1.5 bar to allow for decaying pressure on the side of the piston open to atmosphere.

The example uses an efficiency of 90%.

For the extending stroke on a single acting cylinder:

$$F_E = P \times A \times \mu - F_S$$

Where:

$F_E$  represents the extending cylinder thrust

P = available pressure

A = piston area

$\mu$  = efficiency

$F_S$  = the spring force at the end of stroke

For the retracting stroke on a double acting cylinder:

$$F_R = \pi(D^2 - d^2)/4 \times P \times \mu$$

Where:

$F_R$  represents the cylinder thrust to retract

D = piston diameter

d = piston rod diameter

P = available pressure

$\mu$  = efficiency

Example 2: Determine the size of a cylinder operating at a pressure of 6 bar (600000 N/m<sup>2</sup>), which would be capable of generating a clamping force of 1600N.

Based on the extending stroke formula:

Note 

In this case, no allowance needs to be made for decaying pressure on the side of the piston open to atmosphere since when clamping, the piston will be static and this pressure will be zero.

Thrust = Pressure x Area x Efficiency ( $\mu$ )

$$F_E = P \times \pi D^2/4 \times 0.9$$

therefore,

$$1600 = 600000 \times \pi D^2/4 \times 0.9$$

Transposed to give:

$$D^2 = (4 \times 1600)/(600000 \times \pi \times 0.9)$$

$$D = \sqrt{0.0038} \text{ m} = 0.0614 \text{ m}$$

therefore,

$$D = 61.4 \text{ mm}$$

Again, the next standard size of cylinder would be 63mm.

Once these formulae are understood, it is possible to produce a chart on which the theoretical thrust of any given cylinder bore can be shown against any given air pressure. See Figure 1A.1 below.

Cylinder Bore	Piston Rod $\bar{E}$ (mm)	Effective Piston area (cm <sup>2</sup> )		Working Pressure p in bar									
				2	3	4	5	6	7	8	9	10	
20	8	3,14	OUT	6.4	9.6	12.8	16.0	19.2	22.4	25.6	28.9	32.0	
		2,64	IN	5.4	8.1	10.8	13.4	16.1	19.1	21.5	24.2	26.8	
25	10	4,91	OUT	10.0	15.0	20.0	25.0	30.0	35.1	40.1	45.1	50.1	
		4,12	IN	8.4	12.5	16.8	21.0	25.2	29.4	33.6	37.8	42.0	
32	12	8,04	OUT	16.4	24.6	32.8	41.0	49.1	57.4	65.6	73.8	82.0	
		6,91	IN	14.1	21.1	28.1	35.3	49.1	49.3	56.4	63.4	70.5	
40	16	12,56	OUT	25.8	28.4	51.6	64.4	77.3	90.1	103.1	115.9	128.9	
		10,55	IN	21.6	32.4	43.2	53.8	64.9	75.3	86.6	96.9	107.6	
50	20	19,62	OUT	40.0	59.9	80.0	100.0	120.0	140.0	160.1	180.1	200.1	
		16,48	IN	33.6	50.4	67.2	84.0	100.8	117.6	134.4	151.2	168.0	
63	20	31,15	OUT	63.5	95.3	127.1	158.9	190.6	222.3	254.1	285.9	317.6	
		28,01	IN	57.1	85.6	114.8	142.8	172.2	200.0	229.6	257.1	285.5	
80	25	50,25	OUT	102.5	153.7	205.0	256.1	307.3	358.6	409.8	461.0	512.3	
		45,33	IN	92.5	138.7	184.9	231.2	277.4	323.5	369.7	416.0	462.2	
100	30	78,50	OUT	160.1	240.1	320.2	400.2	480.3	560.3	640.4	720.4	800.4	
		71,44	IN	145.7	218.5	291.4	364.2	437.0	509.8	582.7	655.7	728.5	

Figure 1A.1

**Note**

If cylinder stroke is excessive and working pressure is near to maximum, final cylinder selection should be made in consultation with manufacturers representatives since rod buckling forces may need to be considered.

This chart does not take cylinder efficiency into consideration since this will vary between manufacturers.

Values should, therefore, be multiplied by the efficiency factor to obtain usable thrust.



The graph below, Figure 1A.2, allows an efficiency factor ( $\mu$ ) to be obtained for various cylinder bore sizes where the supply pressure is known.

**SIZING PNEUMATIC VALVES & CYLINDERS**

**Note** →

The data shown on this graph applies to cylinders produced by SMC Pneumatics. Manufacturers of other cylinders should be consulted to obtain efficiencies for their designs.

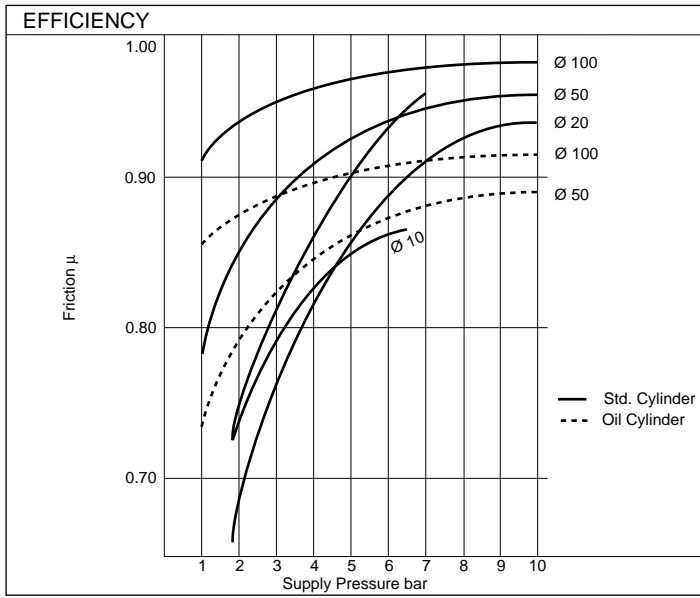


Figure 1A.2

## Air Consumption and Air Flow

The difference between air consumption and flow rate can sometimes be confusing since both are specified using the same units.

Air Consumption is defined as the amount of free air (compressed volume expanded to atmospheric pressure) used by a system during a given time period whilst Air Flow is the rate at which the air is consumed, i.e. a system which operates once every minute and consumes 100 litres of free air has a consumption of 100  $l_N$ /min, however, if the same system only takes 1 second to operate and is at rest for the remaining 59, the flow of air into the system is at the rate of 6000  $l_N$ /min.

It is flow rate that is of prime importance when considering the size of control system components required to power a cylinder at a given speed.

← Note

$l_N$  represents normal  
litres

# System Sizing

Traditionally, valves have been specified by matching their port size to that of the cylinder in use. Also, tube fittings and tube are often selected by appearance rather than functionality in mind. This method is however, highly speculative and provides no theoretical proof that the correct components have been chosen. Instead, it is necessary to use the required flow rate, the working pressure and the acceptable pressure drop across the system, to establish an accurate value for the coefficient of flow, measured in Cv or kv.

A **Cv** of one is equal to a flow rate of one US gallon of water per minute, with a pressure drop of one psi. A **kv** of one is equal to a flow rate of one litre of water per minute, with a pressure drop of one bar.

Most manufacturers now state either a Cv or kv figure for their components. In some instances, however, this may be shown by a value labelled S, which represents the flow section in mm<sup>2</sup> of an orifice in a diaphragm, creating a similar relationship between pressure and flow.

Cv, “Coefficient of velocity, Flow factor” differs from country to country and also from industry to industry. Because of the slight difference in definition, exact conversion cannot be made, however, SMC uses the table shown below.

Cv Value	kv (l/min. system)	S (effective sectional area-mm <sup>2</sup> )
1	14.3	18
1.2	17.1	21.6
1.17	16.7	21.0
0.070	1	1.26
0.0556	0.793	1

**Note** → S values can be converted to Cv by dividing by 18 (approx.) and to kv by dividing by 14.3

For each case, a formula is available to calculate the air flow under given conditions of pressure.

$$\text{For cv: } Q = 400 \times C_v \times \sqrt{[(p_2 + 1.033) \times \Delta p]} \times \sqrt{[273/(273 + n)]}$$

$$\text{For kv: } Q = 27.94 \times k_v \times \sqrt{[(p_2 + 1.033) \times \Delta p]} \times \sqrt{[273/(273 + n)]}$$

$$\text{For S: } Q = 22.2 \times S \times \sqrt{[(p_2 + 1.033) \times \Delta p]} \times \sqrt{[273/(273 + n)]}$$

$C_v, k_v$  = Coefficients of flow

$S$  = Equivalent flow section in  $\text{mm}^2$

$Q$  = The standard flow rate of the valve in litres/min

$p_2$  = Outlet pressure required to drive the cylinder

$\Delta p$  = Permissible pressure drop

$n$  = Air temperature in  $^\circ\text{C}$

At normal working temperatures, the calculation:

$\sqrt{[273/(273 + n)]}$  is so close to 1 that this part of the formulae can be ignored.

Example 3: Consider the problem outlined in example 1.

The problem can be expanded to include an operating time, i.e., it has been determined that the 150 kg load must be moved a distance of 200 mm in 1 second.

We calculated a theoretical piston diameter of 60.05 mm and recognised that, since a cylinder of this bore did not exist, we would select the next standard bore size, i.e. 63mm.

It is necessary to first calculate the minimum system operating pressure.

Remember:- Thrust = Pressure x Area x Efficiency

therefore, Pressure = Thrust / (Area x Efficiency)

In our example:

$$P = 150 \times 4 / (\pi \times 6.3^2 \times 0.9)$$

$$P = 5.35 \text{ kgf/cm}^2$$

Since our previous calculations assumed a decaying pressure of  $1.5 \text{ kgf/cm}^2$  on the side of the piston open to atmosphere, (*which must be compensated for in the working pressure*), the actual pressure required to move the load will be  $5.35 + 1.5 = 6.85 \text{ kgf/cm}^2$ .

Since we have  $7.3 \text{ kgf/cm}^2$  of air pressure available, it follows that we can tolerate a system pressure drop ( $\Delta p$ ) of  $7.3 - 6.85 = 0.45 \text{ kgf/cm}^2$ .

The system air consumption can be calculated by multiplying the piston area by the distance it has to move in this case:

$$\pi \times 6^2 \text{ cm} \times 20 \text{ cm} / 4$$

$$= 624 \text{ cm}^3$$

or 0.624 litres.

This volume will be occupied by air at  $6.85 \text{ kgf/cm}^2$  which, using Boyles Law ( $P_1V_1 = P_2V_2$ ) gives:

$$(6.85 + 1) \times 0.624 = 1 \times V_2$$

$$V_2 = 7.85 \times 0.624 / 1$$

therefore,

$$\text{air consumption} = 4.9 \text{ l}_N/\text{stroke}$$

This amount of air is consumed each time the system operates (*out strokes of the cylinder*). Since the time taken we know has to be 1 second, the flow rate could be expressed as  $4.9 \text{ l}_N/\text{s}$ .

**Note** →

Pressures used in Boyles Law must be stated as absolute not gauge.

In order that this value can be used in our formula (Q), it must be expressed in  $l_n/\text{min}$ .

$$\begin{aligned} Q &= 4.9 \times 60 \\ &= 294 l_n/\text{min} \end{aligned}$$

We now have the necessary data to calculate the system Cv.

$$Q = 400 \times C_v \times \sqrt{(p_2 + 1.033)} \times \Delta p$$

Transposing this formula gives:

$$C_v = Q / [400 \times \sqrt{(p_2 + 1.033)} \times \Delta p]$$

therefore,

$$\begin{aligned} C_v &= 294 / [400 \times \sqrt{(66.85 + 1.033 \times 0.45)}] \\ &= 0.39 \end{aligned}$$

## Applying System Cv to Component Selection

Individual components within a system each have a Cv value, i.e. valves, tube fittings, and tubing.

The composite Cv when components  $Cv_1$ ,  $Cv_2$ , etc are connected in sequence is calculated by :

$$1/Cv^2 = 1/Cv_1^2 + 1/Cv_2^2 + 1/Cv_3^2 \text{ etc.}$$

In practical terms, it has been found economically sound to allow 50% of system pressure drop to exist in the tube and tube fittings; the other 50% being attributed to the valve system, e.g., if system  $Cv = 1$

$$1/1^2 = 1/Cv_1^2 + 1/Cv_2^2$$

where  $Cv_1$  &  $Cv_2$  have the same value (50:50 split).

$$1 = 2/Cv^2$$

so,  $Cv^2 = 2$

$$\begin{aligned} \text{hence } Cv &= \sqrt{2} \\ &= 1.4 \end{aligned}$$

We can, therefore, assume that for a system Cv of 0.39 (as per our example), a good start point is to assume a valve Cv of  $0.39 \times 1.4 = 0.55$ .

From manufacturer's literature, a valve of suitable function, with a minimum Cv of 0.55 can be selected.

Having selected the valve, its port size will determine the largest tube size that can be used (*dependent on the range of tube fittings available*).

Calculation of the exact Cv for tube and fittings can then be made.

In our example we find that a valve having a port size of 1/8" BSP is suitable.

With this size of port, tube fittings determine that the maximum available tube size is 10 mm O/D.

If our system consists of 2 metres of 10 mm tube, three 10mm O/D x 1/8" BSP straight adaptors and one 10mm O/D x 3/8" BSP elbow adaptor; tube and fittings Cv would be:

10mm O/D tube x 2m: Cv = 1.47\*\*

10mm O/D x 1/8" BSP straight adaptor: S value = 41.5 or Cv = 2.3\*

10mm O/D x 3/8" BSP elbow adaptor: S value = 35.2 or Cv = 1.95\*

\*from manufacturer's literature.

\*\*Cv of nylon tube is calculated by the formula:

$$Cv = [0.1768 \times d^{0.155} \times \sqrt{(d^5/L)}] / 18$$

where d = tube bore in mm

and L = tube length in m.

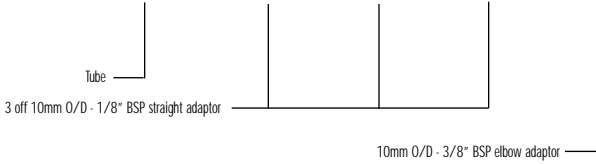
The above formula can be simplified for a selection of popular tube O/D's:

O/D	I/D	Cv =
ø4 mm	ø2.5 mm	$Cv = 0.11/\sqrt{L}$
ø6 mm	ø4 mm	$Cv = 0.39/\sqrt{L}$
ø8 mm	ø6 mm	$Cv = 1.14/\sqrt{L}$
ø10 mm	ø7.5 mm	$Cv = 2.07/\sqrt{L}$
ø12 mm	ø9 mm	$Cv = 3.36/\sqrt{L}$
ø16 mm	ø13 mm	$Cv = 8.91/\sqrt{L}$



Continuing our example:

$$1/Cv^2 = 1/1.47^2 + 1/2.3^2 + 1/2.3^2 + 1/2.3^2 + 1/1.95^2$$



$$1/Cv^2 = 1/1.47^2 + 3/2.3^2 + 1/1.95^2$$

$$1/Cv^2 = 0.46 + 0.57 + 0.26$$

$$= 1.29$$

therefore,

$$Cv = \sqrt{1/1.29}$$

$$= 0.88$$

Since we know that the system Cv has to be 0.39 as per our example:-

$$1/0.39^2 = 1/0.88^2 + 1/Valve Cv^2$$

$$6.575 = 1.29 + 1/Valve Cv^2$$

$$Valve Cv = \sqrt{1/(6.575-1.29)}$$

$$= \underline{0.43}$$

A valve can now be selected having Cv minimum of 0.43 providing it can be used with ø10 mm tube.

# A GUIDE TO TERMINOLOGY

Pneumatics, in common with most advanced technologies, has its own vocabulary which, even to those who have spent years in the industry, can be both confusing and, at times, difficult to remember.

The following is not intended to be a definitive guide; instead, it covers the most commonly used terms and expressions and is designed for use by newcomers and old hands alike.

## Pneumatic Terminology

### Actuator

A device for converting the energy of compressed air into work. The term is generally applied to cylinders.

### Aftercooler

A device for cooling compressed air as it leaves the compressor, to prevent excessive condensation occurring further downstream.

### Air Chuck

Commonly called grippers; pneumatically powered jaws are used to grip a workpiece - typically used for pick and place applications.

### Automatic Drain

Designed to be installed at strategic points throughout the pneumatic system, to allow condensate to be automatically removed.

## Bar

Standard measurement of pressure. One bar is approximately equal to atmospheric pressure.

## Bore Size

The diameter of a piston operating within an actuator.

## Boyles law

At a constant temperature, the volume of a given quantity of any gas is inversely proportional to the pressure upon the gas; i.e.  $V$  is proportional to  $1/P$ , or  $PV = a$  constant. True for a perfect gas. Named after Robert Boyle, (1627-1691).

## Cv

A Cv of one is equal to a flow rate of one US gallon of water per minute, with a pressure drop of one psi.

## Cascade

A type of pneumatic circuit designed to overcome the problems associated with trapped pressure signals.

## CETOP (Comité Européen des Transmissions Oléo Hydrauliques et Pneumatiques)

A European pneumatic standard designed with the aim of component interchangeability.

## Check Valve

A device which allows compressed air to pass through in one direction, but prevents it returning along the same path.  
SEE NON-RETURN VALVE

## Compressor

A machine for compressing atmospheric air so that it can be used to drive pneumatic devices. SEE RECIPROCATING AND ROTARY COMPRESSORS.

## Cushioning

A facility available on actuators to cushion at the end of

stroke to prevent sudden impact.

### **Cylinder**

A linear-actuator.

### **Dew Point**

The temperature at which the water vapour present in air saturates the air and begins to condense, i.e. dew begins to form.

### **Double Acting Cylinder**

A cylinder which is actuated by compressed air in both extending and retracting strokes.

### **F.R.L.**

Air preparation unit consisting of Filter, Regulator, and Lubricator.

### **Filter**

A device for removing contaminants from compressed air, typically moisture, oil and solid particles.

### **Flow**

The flow of air through a pneumatic system. Expressed in normal litres per minute,  $l_n/\text{min.}$ , never as NL/min.

### **kv**

A kv of one is equal to a flow rate of one litre of water per minute, with a pressure drop of one bar.

### **Manifold**

A device which is capable of dividing a single compressed air source into several outlets. The most common application is for supplying air to a number of valves secured to a common mounting base, i.e. a valve manifold.

## **Newton**

The derived SI unit of force. The force required to give a mass of one kilogram an acceleration of one metre per second per second. Symbol N. Named after Sir Isaac Newton (1642-1727).

## **Non Return Valve**

A device which allows compressed air to pass through in one direction, but prevents it returning along the same path. SEE CHECK VALVE

## **Pascal**

The derived SI unit of pressure, equal to 1 newton per square metre. Symbol Pa. ( $100,000 \text{ Pa} = 1 \text{ kgf/m}^2$ ). Named after Blaise Pascal (1623-1662).

## **Poppet Valve**

A type of valve construction whereby sealing is achieved by means of a flat seal against an orifice.

## **Reciprocating Compressor**

A compressor in which air is pressurised by means of piston and cylinder.

## **Regulator**

A device for adjusting the pressure of compressed air, typically used to reduce available pressure to a suitable working pressure.

## **Relative Humidity**

The ratio of the pressure of the water vapour actually present in the atmosphere to the pressure of the vapour which would be present if the vapour were saturated at the same temperature.

## **Ring Main**

A term used to describe a compressed air piping system which is arranged in a complete loop, i.e. a ring.

### **Rodless Cylinder**

A cylinder whose moving element actuates within the length of the cylinder body and does not use a conventional extending piston rod. Space saving is therefore achieved.

### **Rotary Compressor**

A compressor which uses rotating vanes or meshing screws to pressurise air.

### **Single Acting Cylinder**

A cylinder which uses compressed air to actuate the piston in one direction but uses spring force to achieve movement in the opposite direction. Capable of performing work only in the driven direction.

### **Slide Unit**

A precise linear actuator which uses a guide mechanism to improve accuracy of travel and/or provide a facility to limit rotation about its axis of travel.

### **Slide Valve**

Directional control valve where sealing is achieved by sliding a lapped metal seal across the valve's orifices.

### **Solenoid Valve**

A valve which is activated with the use of an electrically operated solenoid.

### **Speed Controller**

A steplessly variable orifice for varying the flow of compressed air thus providing a speed control facility for actuators.

# Electronics Terminology

## **EEPROM or E<sup>2</sup>PROM**

Electrically Erasable Programmable Read Only Memory. A ROM chip (see below) which can be electronically erased.

## **I/O**

Input/Output. A statement of the number of inputs and outputs for a specific device or system.

## **Ladder logic**

Complex programming language used for configuring PLC's (*see below*).

## **PID**

Process Integer Derivative

## **PLC**

Programmable Logic Controller. Sometimes called Programmable Controller. Designed to control the sequencing of electronic equipment.

## **RAM**

Random Access Memory. A memory chip which is used to provide working space for operations in progress at any one time.

## **ROM**

Read Only Memory. A memory chip which, once written to, cannot be erased. Used to store set parameters.

# AIR PREPARATION

High quality compressed air is essential for the efficient, long term operation of all pneumatic devices. Correct air preparation will minimise the risk of component failure, increase their life span and reduce energy consumption.

The subject of air preparation may not be one to capture the imagination, but bear in mind that around 90% of all failures in pneumatics systems are attributable to the poor quality of the air supply.

Before discussing the various devices available for preparing and treating air, it is important to understand where problems can arise.

## Air Contamination

Airborne contamination is the most common problem with compressed air systems. Contaminants include particulate matter, moisture and unwanted oils. These can be drawn in from the surrounding atmosphere or physically injected into the system, either by the compressor or by human error; it is not unknown for lubricating oils to be added to non-lube systems.

Particles suspended in the atmosphere may sound fairly innocuous, yet an average factory contains some 140 million particles of dust, grit and pollen per cubic metre of air, *(50% of these particles are less than  $2\mu\text{m}$  in size)*. Compress this to 7 bar and the density will exceed 1100 million particles per cubic metre.

Dry particulate matter, at low concentrations, may not represent a major problem. Combined with moisture, compressor oil or other lubricants, however, it will congeal

← Note  
Ref. Institute of  
Mechanical Engineers  
paper no. C390/021.



and gradually accumulate on both static and moving surfaces within pneumatic equipment, causing valves to stick, seals and other components to wear and, ultimately, devices to fail.

Water vapour, which naturally occurs in air, condenses as the warm air from the compressor meets the relatively cold surfaces of downstream equipment. Although condensate can be removed via drains fitted to the compressor, or at other points in the distribution system, moisture held in the form of vapour and droplets suspended in the air flow will still remain. Again, these represent a potential threat, as continuous water action will break down lubricating oils, creating corrosion on exposed metal surfaces - which will break away and add to problems elsewhere in the system and increase the friction between moving parts.

In addition to dust and moisture, the air supply has the potential to carry other contaminants. The most common is compressor oil, emitted initially as oil vapour, which gradually condenses to form a film inside valves and cylinders. This film collects dirt and grit, which in turn may score the surface of moving parts. It is never an advantage to have oil from a compressor in the system as this oil is inevitably degraded and oxidised after the heat of compression. Usually it is acidic and can appear as a varnish-like substance possessing properties completely opposed to lubrication. If synthetic oils are being used, these can cause chemical attack on downstream components such as seals and polycarbonate parts.

Valve seals in particular can be prone to attack by compressor oil, which causes the Acrylonitrilebutadiene rubber, used both for O-ring and bonded spool devices, to swell to the point where friction between the seal and the barrel causes the valve to stick in one position.

Further problems can be caused by chemical substances, drawn in through the compressor intake from the

surrounding environment. Left untreated, these will attack rubber and plastic seals and gaskets, corrode air lines and generally contribute to a steady decline in operating efficiency.

## The Solution

Although filters can be fitted to the compressor intake, it is difficult to prevent contaminants under 2-5 microns being drawn in; certainly it is almost impossible to eliminate water vapour and surplus compressor oil being injected into the air supply. Instead, it is necessary to incorporate filtration, drying and pressure regulation equipment downstream of the compressor. Additionally, lubrication units may be required prior to some pneumatic devices.

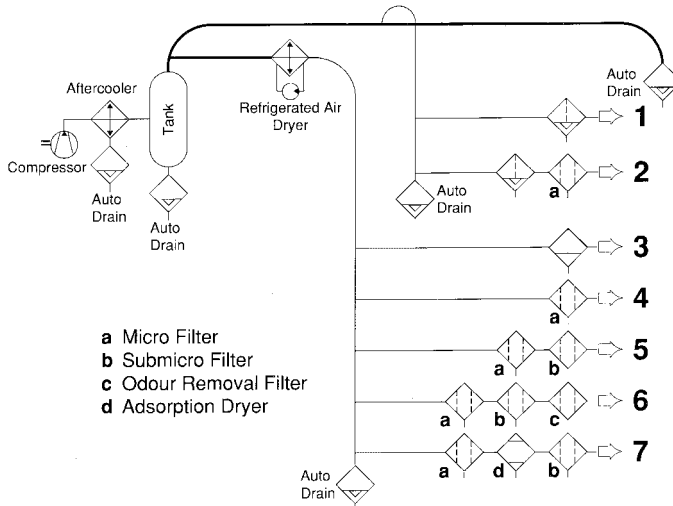
## Filtration

A typical separator unit operates by directing inlet air at high speed over a louvred deflector plate; this creates a vortex where solid particles and moisture droplets are centrifugally spun out of the air stream. Liquid and solid matter in solution then collects at the base of the filter, where it can be drained off.

If large volumes of condensate are likely to form, it is preferable to use automatic drain systems. As these do not require regular maintenance, it is possible to reduce both labour costs and eliminate any problems which may be caused by neglect of manual devices.

This type of unit does not, however, remove particles, such as oil mist, below approximately 0.5 microns. To achieve this, secondary filters, based on air flow through an element, must be incorporated. The elements are manufactured from a fine stainless steel mesh, encompassing multi-layer filter tissues and surrounded by an absorbent gauze. Operation is based on the principle of Brownian movement, where individual particles moving at high

speed through the fibres of the element eventually coalesce, forming a film which adheres to the filter. Depending on the materials used within the element and the number of layers, it is possible to remove particles down to 0.01 micron in size, which typically represents 99.99% of all contaminants.



Number	removal of...	Application	Typical Examples
1	Dust particles >5 $\mu$ . Liquid oil to 99% Saturated humidity to 96%	Where some solid impurities humidity and oil can be accepted.	Workshop air for clamping blowing and simple pneumatic drives
2	Dust particles >0.3 $\mu$ . Oil mist to 99.9% Saturated humidity to 99%	Where removal of dust and oil dominates, but a certain amount of condensation can be risked.	General industrial equipment pneumatic controls and drives, sealless metallic joints, air tools and air motors.
3	Humidity to atmospheric dew point of -17°C. Further as in (1).	Where removal of humidity is imperative but traces of fine dust and oil are acceptable.	Similar to (1) but as the air is dry additional general spray painting.
4	Dust particles >0.3 $\mu$ . Oil mist to 99.9% Humidity up to an atmospheric dew point of -17°C.	Where no humidity, fine dust and oil vapour are acceptable.	Process control, measuring equipment, high quality spray painting, cooling of foundry and injection moulding dies.
5	Dust particles >0.01 $\mu$ . Oil mist to 99.9999% Humidity as (4).	Where pure air, practically free from any impurity is required.	Pneumatic precision measuring devices electrostatic spray painting, cleaning and drying of electronic assemblies.
6	As (5) with additional odour removal.	Where absolutely pure air, as under (5), but odour free.	Pharmacy, food industry for packaging, air transport, brewing and breathing air.
7	All impurities as in (6) but with an atmospheric dew point of greater than -30°C.	Where every risk of condensation during expansion and at low temperatures must be avoided.	Drying electronic components, storage of pharmaceuticals, marine measuring equipment, air transport of powder.

Figure 2A.1

Filter elements should be checked regularly and where possible should be changed to prevent a build-up of material blocking the free flow of air and thus causing a drop in system pressure. Additionally, in chemically hazardous environments special materials are needed, for both the internal and external components; carbon impregnated elements are also available for use in systems where odours must be removed.

## Sizing Separators and Filters

Most manufacturers supply detailed flow/pressure charts to enable filters to be sized correctly. In general terms, however, the size of filters and regulators required depends on the maximum flow of compressed air required to drive downstream equipment, and the maximum acceptable drop in pressure across the air preparation system. With a vortex type filter a pressure drop of approximately 0.2 to 0.3 bar is adequate, to ensure that the velocity of the air stream is increased to the point where contaminants are removed. Extending the pressure drop further, for example, above 0.5 bar, is unnecessary and will simply result in a greater load on the compressor.

Conversely, element type filters operate more efficiently if the pressure drop is minimised, typically around 0.1 bar. As a result, they tend to be relatively large, in order to expose as wide an area of mesh as possible to the air stream. As the mesh gradually becomes saturated, however, so the pressure drop, and hence the energy consumption, will increase, making it important to replace elements when necessary.

## Dehydration

Most compressors are fitted with an aftercooler. This is designed to remove a large proportion of the condensate resulting from the compression process, by reducing the air temperature to within 10-15 °C of the ambient temperature.

To reduce the level of water vapour still further, especially if parts of the pneumatic system are exposed to areas where temperatures fluctuate, such as where pipes are routed along outside walls or through ceiling areas, it is necessary to incorporate drying systems. These are generally absorption (deliquescent), refrigeration or adsorption (desiccant) dryers and function by lowering the dew point (see Chapter 2.B).

Absorption dryers function by forcing the air through a drying agent, typically dehydrated chalk, magnesium chloride, lithium chloride or calcium chloride, which react with the moisture to form a solution which can be drained off.

Refrigeration dryers operate on the principle of heat exchange, using evaporating gas to extract heat from the circulating air and causing moisture to condense.

Absorption dryers use a chemical such as silica gel or activated alumina, to adsorb moisture. Once the drying agent becomes saturated it is regenerated by applied heat or by passing pre-dried air through it.

	<b>Advantage</b>	<b>Disadvantage</b>
<b>Absorption</b>	Pressure Dew Point (PDP) +16°C.  Low capital cost.	Inlet temperature must not exceed 30°C.  Drying agents must be regularly replenished. (additional hidden ongoing costs which can cause down time of air supply.)  Uses highly corrosive chemicals. (Environmentally questionable waste.)
<b>Refrigeration</b>	+3°C PDP best possible dew point.  Input temperatures can be as high as 60°C. (Aftercooler preferred- will remove bulk moisture and suit sites with <b>no</b> low temperatures on outside pipework.)	Output: dew point will vary with approach temperature at the inlet, and cleanliness of heat exchanger.
<b>Adsorption</b>	Achievable pressure dew point of -40°C. (-70°C possible for specialist applications.)	High capital cost High operating cost

Figure 2A.2

An important point to note is that if adsorption or absorption dryers are used, it is essential to incorporate fine micro-filters, to prevent any residue from the chemicals being carried into the pneumatic system as a fine mist.

## Regulation

Pressure regulation is necessary to maintain a consistent operating pressure. If this is too great, energy costs will be unnecessarily high. Too low a pressure and the system will be incapable of supporting the work loads required. Pressure regulators function by means of a piston or diaphragm acting against a spring. Thus, output pressures are controlled. Combined regulator and filter units are also available .

## Lubrication

The majority of modern pneumatic devices are now pre-lubricated and require no additional lubrication. Older equipment, however, does require internal lubrication, by adding a suitable oil to the compressed air. This technique, however, results in increased maintenance and can lead to the presence of vaporised oil in exhaust outlets.

## Points to Consider

The design of air preparation devices should be such that they are easy to install and maintain. Similarly, they should provide an efficient throughput of air, ensuring that contaminants are effectively removed, while pressure losses are reduced to an acceptable level.

Additionally, the system design should take account of the fact that, at any one time, only a certain number of devices will be in operation. This number may change under different conditions, so air consumption figures for peak and average demand must be derived, to ensure that both

air preparation and other equipment, such as valves and actuators, function efficiently.

Incorrect specification of filters is a major contributory factor to the failure of pneumatic devices. Generally, the size of element chosen is too large to remove sufficient quantities of particles, or is left un-serviced for long periods, resulting in erratic or sudden changes in pressure or in a surge of contaminants, as they break away from the element. Alternatively, a build up of debris can create back pressure on the compressor.

Finally, whatever type of system is used, it is important to consider the demands imposed upon it, both by the application and by the surrounding environment, if the performance and long term reliability of pneumatic equipment is to be maintained.

# Dew Point and Relative Humidity

**A**tmospheric air contains a proportion of moisture, which is released when the air is cooled. In a pneumatic system, this occurs when compressed air is delivered from the compressor to downstream equipment.

The terms which are most often applied in this context are dew point and relative humidity.

## Dew Point

The amount of water vapour contained in air is directly proportional to its temperature, not, as is commonly supposed, to its pressure.

As air cools the water vapour within it condenses, reaching the temperature where the air becomes saturated; this is called the dew point. If the temperature drops, additional moisture is liberated in the form of tiny droplets or condensation. Natural examples of atmospheric dew point (*ADP °C*) can be seen where warm air has come into contact with cold surfaces, typically forming condensation on window panes or early morning dew, where warm air at ground level meets a descending cold air mass.

The term atmospheric dew point is most relevant to weather conditions. In compressed air installations and pneumatic systems, pressure dew point is more appropriate.

Pressure dew point (*PDP °C*) is the temperature at which condensation occurs at elevated pressure; typically 7 bar is



used as this is the most common compressed air system pressure in general use.

The actual quantity of water which air is capable of retaining in suspension is dependent on temperature, so one cubic metre of air at 7 bar will hold the same amount of water as one cubic metre at 1 bar.

The table below shows the number of grams of water which one cubic metre of air is capable of supporting at different temperatures; values are given for atmospheric and pressure dew points.

Temperature °C	0	5	10	15	20	25	30	35	40
$g/m^3_n$ (atmospheric)	4.98	6.99	9.86	13.76	18.99	25.94	35.12	47.19	63.3
$g/m^3$ (pressure)	4.98	6.86	9.51	13.04	17.69	23.76	31.64	41.83	54.108

Temperature °C	0	-5	-10	-15	-20	-25	-30	-35	-40
$g/m^3_n$ (atmospheric)	4.98	3.36	2.28	1.52	1.00	0.64	0.40	0.25	0.15
$g/m^3$ (pressure)	4.98	3.42	2.37	1.61	1.08	0.70	0.45	0.29	0.18

Figure 2B.1

# Relative Humidity

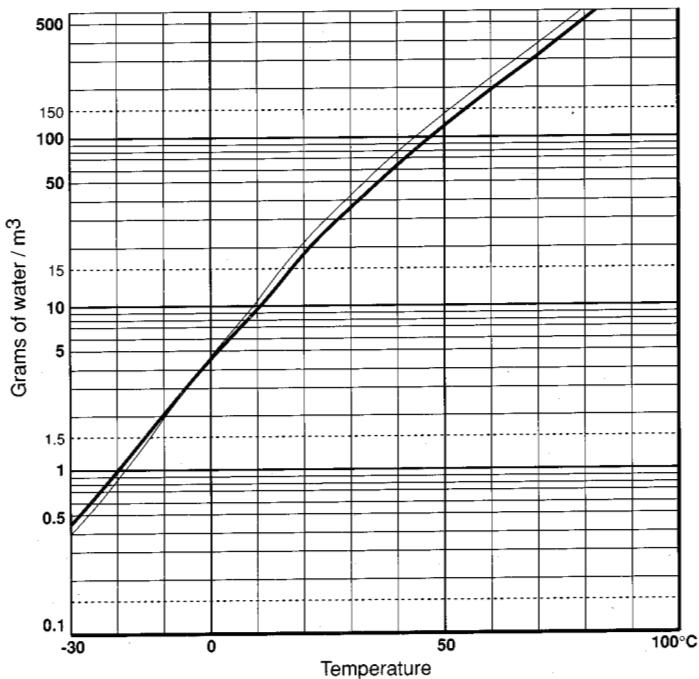
Relative Humidity (*RH*) is the ratio between the actual water vapour content of a volume of air to the maximum water vapour content at a given temperature.

$$RH (\%) = (\text{Actual water content} / \text{Maximum water content}) \times 100$$

RH is usually expressed as a percentage. However care must be taken in using this term as it can be misleading due to temperature variations within any system.

To look at relative humidity, we will follow the progress of 1m<sup>3</sup> of air during compression.

From Fig. 2B.2 below; 1m<sup>3</sup> of atmospheric air can support 17g of water vapour @ 20°C.



**Note**  
This graph is intended as a guide only.

**Note**  
The bold line refers to atmospheric air with the volume at the temperature in question.

The thin line gives the amount of water per standard cubic metre.

Figure 2B.2

For the UK, assuming an average humidity of 65%, the compressor would, therefore, draw in 11g of moisture with each  $1\text{m}^3$  of air. This would equate to the following:

Atmospheric Dew Point ADP  $^{\circ}\text{C} = +20$   
 Pressure Dew Point (1 bar<sub>g</sub>) PDP  $^{\circ}\text{C} = +20$

By compressing the air to 7 bar<sub>g</sub> the temperature would rise dramatically;  $100^{\circ}\text{C}$  would be typical.

$1\text{m}^3$  of air at 7 bar<sub>g</sub> =  $8\text{m}^3$  of atmospheric air.

The actual moisture content of  $1\text{m}^3$  at 7 bar<sub>g</sub> can be calculated as follows:

$17\text{g} \times 65\% \times 8\text{m}^3 = 90\text{g}$   
 Pressure Dew Point at 7 bar<sub>g</sub> =  $+100^{\circ}\text{C}$   
 Relative Humidity = 15%

To reduce the air temperature, an aftercooler is usually fitted to the system. This would result in a temperature decrease to  $+35^{\circ}\text{C}$  (approx).

$1\text{m}^3$  of air at  $35^{\circ}\text{C}$  can only support 40g of water vapour of the 90g drawn in by the compressor. 50g appears as condensed free water needing to be drained from the system. The air condition at this stage would be:

Pressure Dew Point  $+35^{\circ}\text{C}$  (*40g of water*)  
 Relative Humidity 100%

Assuming an ambient temperature of  $+20^{\circ}\text{C}$ ,  $1\text{m}^3$  of air can only support 17g of the 40g left in the system by the aftercooler, a further 23g will be released into downstream receivers, pipework and pneumatic equipment. This would result in an air condition of:

Pressure Dew Point  $+20^{\circ}\text{C}$  (*17g of water*)  
 Relative Humidity 100%

Any further reduction in temperature, such as outside pipe work, will result in further condensation of water vapour and extra free water in the system. Installation of drying equipment will further reduce the water vapour content.

The following are the three main types of compressed air drying equipment:

Deliquescent  
Refrigerant  
Desiccant

Shown below are the dew points, RH values and water vapour contents achieved for each type of dryer:

Deliquescent dryers reduce the moisture content chemically and at an ambient temperature of  $+20^{\circ}\text{C}$ , a pressure dew point of approximately  $+16^{\circ}\text{C}$  can be achieved with a water vapour content of  $13\text{g}/\text{m}^3$ . The relative humidity would be 80%.

A refrigerant type unit would reduce the air temperature to between  $+3^{\circ}\text{C}$  and  $+7^{\circ}\text{C}$  resulting in a maximum water vapour content of  $7\text{g}/\text{m}^3$ .

Pressure Dew Point  $+7^{\circ}\text{C}$   
Relative Humidity 44%

Desiccant dryers reduce the moisture content chemically to the equivalent of  $-40^{\circ}\text{C}$ , giving a maximum moisture vapour content of  $0.12\text{g}/\text{m}^3$ .

Pressure Dew Point  $-40^{\circ}\text{C}$   
Relative Humidity 0.7%

Pressure dew points of as low as  $-70^{\circ}\text{C}$  can be achieved for special applications.

# PNEUMATIC VALVE TECHNOLOGY

Valves are essential components in every pneumatic system, providing a method by which the air flow to or from other devices can be accurately controlled. The following chapter looks at the types of valve that are available and explains the differences between the various techniques employed to improve performance and reliability.

## Basic Requirements

Before considering the different types of valve, it is important to understand the basic operational specification that every valve should meet. In general terms these are as follows:

- i) Long operating life, under a variety of conditions.
- ii) Constant and fast response times.
- iii) High flow characteristics.
- iv) Ease of maintenance.

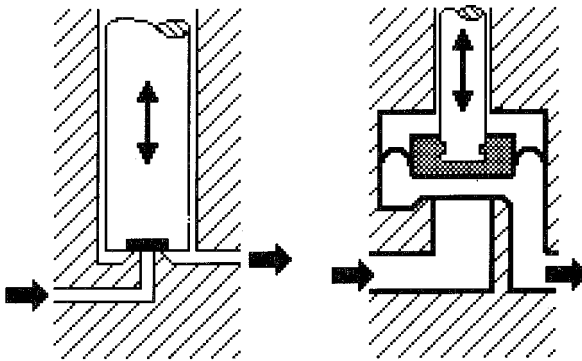
To achieve this combination of features, the valve must provide an efficient method of switching air between inlet and outlet ports, with no internal leaks and using a minimum of energy to carry out each switch movement. In addition, the mechanism which directs the air flow should be constructed so that frictional forces are minimised and a positive location is provided in each operating position. Finally, it is desirable for the valve to have an action such that lubricants are not removed by the sliding action of internal components.

## Valve Types

There are two main types of valve: poppet and spool. These can be further classified by the method of actuation: mechanical or air pilot and solenoid.

### Poppet Valves

Poppet valves incorporate a manual or mechanically operated plunger, which is normally held in the closed position by a spring or by air pressure. Depressing the plunger opens the valve and allows air to flow. A seal is achieved between the plunger and the valve seal by means of flat discs and washers, O-rings or spherical closures.



One of the main advantages of poppet valves is their relative simplicity, with a minimum of moving parts. They are also self-cleaning, using the purging effect of the air flow, and require little maintenance. Although poppet valves have a short stroke before maximum flow is achieved, they can only be operated in an open or closed position, making it difficult to regulate the flow path through the valve.

Poppet valves are not suitable for complex switching operations, where a combination of inputs and outputs are required. They can also be affected by fluctuations in input pressure, which increases or decreases the actuation force needed to open the valve seal.

## Spool Valves

In essence, a spool valve uses a specially profiled rod or spool, sliding longitudinally within the centre of the valve, to switch the air flow between different inlet and outlet ports. The direction of air flow is at right angles to that of the spool. The spool can be moved manually or by means of an air pilot or electrically operated solenoid.

Spool valves offer a considerably higher level of functionality than poppet valves and are unaffected by changes in operating pressure, enabling response times to remain constant.

Spool valves can provide a highly effective method of controlling air flow to and from other pneumatic devices. The level of performance or efficiency which can be achieved, however, is directly related to the design and manufacture of the spool itself. As a result, a number of variations have been developed.

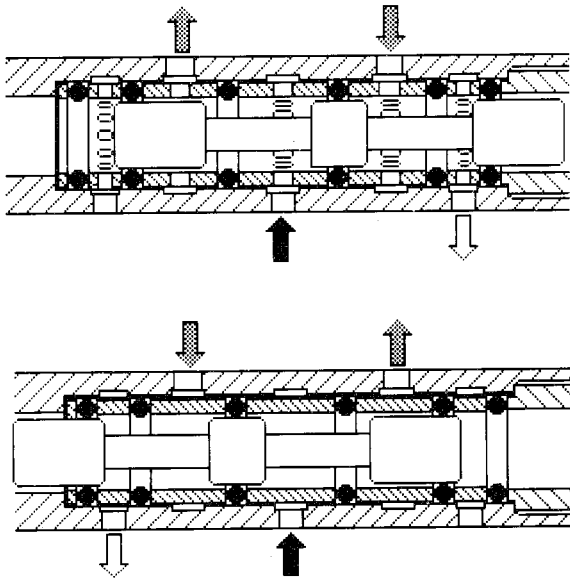
## Spool Design

The spool slides within the barrel of the valve. Cut into the barrel are the various port openings, with the machined profile of the spool providing flow paths across different ports, depending on the position of the spool. The critical factors affecting valve performance are therefore as follows:

- i) Friction between the spool and the barrel.
- ii) The force required to move the spool.
- iii) The leakage of air around the spool. In particular, at the point where the spool seals each port opening.
- iv) The affect of contamination.

## O-ring Spools

Traditionally, spools have been manufactured from crimped stainless steel or turned aluminium, with nitrile rubber O-rings either being fitted into grooves on the spool, with spacers added to keep them in position, or within plastic or metal cages mounted on the inside face of the barrel. In each case, however, the O-rings create a number of problems.



The most common problems relate to the wide tolerance band within which O-rings are often manufactured. At one extreme, this will result in a seal which is too loose, with poor location allowing air to bleed between the O-ring and, depending on the type of valve, the barrel or the spool; conversely, if the O-ring is too large then it will dramatically increase the level of friction and hence the actuation force necessary to move the spool. (The term commonly applied in this context is 'stiction').



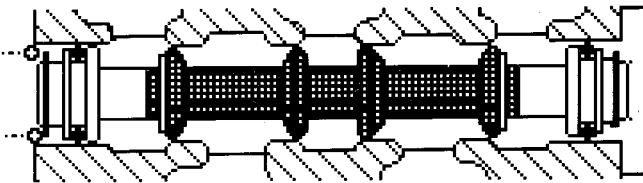
As the O-ring is contained on three sides, by the body of the valve and by spacers, changes in temperature or contamination can also affect its efficiency. The O-ring can either expand, leading to an increase in stiction, or contract, resulting in leakage.

Continuous operation at very low temperatures will also cause the seal to become hard. The physical characteristics of the rubber will similarly deteriorate if there are contaminants, such as compressor oil, within the air system.

The use of O-rings and the various spacers, or other mechanisms designed to hold them in position, account for a significant proportion of the available spool area, thereby limiting the amount of space available for the air flow between ports. The alternative to restricted air flow is to increase the overall size of the valve, which in many applications is an unacceptable solution.

### Elastomer Bonded Spools

To overcome many of these problems elastomer bonded spools were developed. These comprise a metal core, to which a thin coating of elastomer is vulcanised. The coating is then chemically hardened and match ground to a fine tolerance, producing a seal material with superior elasticity and compression properties.



The elastomer bonded seal provides a number of significant advantages over conventional O-ring devices.

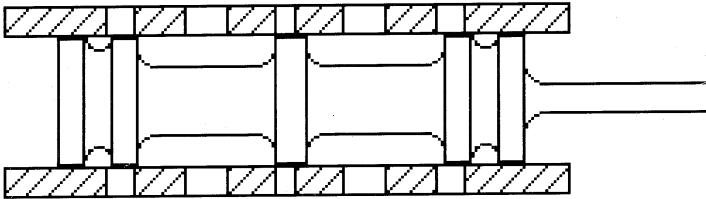
There is only a small number of moving parts, so reliability is considerably improved. In addition, the elastomer is thinly coated, by applying it to the spool and allowing it to set, before it is frozen and ground to match the valve body. Dimensional changes, due to fluctuations in temperature or the ingress of contaminants, therefore have little effect on the efficiency of the valve. And, unlike the O-ring arrangement, the seal material is not constrained in any one dimension, so expansion or contraction occurs vertically as well as laterally. Stictional forces are, therefore, almost eliminated.

As the spool comprises a single component it is possible to make the airways considerably larger, thereby increasing air flow or reducing the overall size of the valve. Additionally, the profile of the spool is such that it is unnecessary for the sealing ridges fully to transverse their respective port opening before optimum air flow is achieved. Consequently, both spool travel and seal wear are reduced. Finally, both spool and barrel are designed so that there are no grooves or holes in which solid contaminants can collect; particles that do enter the valve being removed by the flow of air.

Although elastomer bonded spool valves offer many advantages over conventional O-ring devices, they are still prone to wear, albeit on a much smaller scale, with a typical life of around 20 million cycles.

## Stainless Match Ground Spool and Sleeve Valve

Valves incorporating an all-metal match-ground spool, set within a sleeve, provide an operating life in excess of 100 million cycles. Perhaps as importantly, they have exceptionally short spool travel and require minimal force to move the spool. This allows direct solenoid actuation, with power consumption as low as 1.8 Watts.



The spool and sleeve are separated by a gap of 3.0 microns. Although this allows air to leak from the system it also acts in the same way as a frictionless air bearing, providing a long operating life, fast response times and accounting for the low forces necessary to move the spool. Short spool stroke and high flow rates are enhanced by using different diameter radial holes machined into the sleeve.

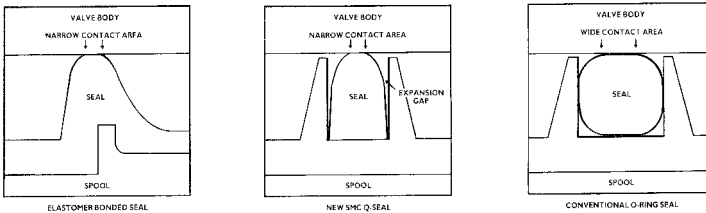
The sleeve is mounted on a series of static O-rings, making the entire assembly immune to vibration, distortion or changes in temperature. Although the system can be affected by a build up of fine dust between the spool and sleeve, the sharp edges of the spool generally prevent particles from becoming trapped. If maintenance is required, the entire assembly is easily removed for cleaning. The only other drawback is, of course, a slow but continuous air loss.

## Q Seals

To reduce the wear characteristics of both O-ring seals and, to a lesser extent, bonded spool devices, a further design of seal is also available.

In common with the bonded seal technology, this was first introduced by SMC and is designed to reduce sliding resistance to a minimum, enhance both reliability and air flow characteristics and provide bi-directional port access.

In essence, the Q seal resembles a flattened O-ring, set within a specially machined pocket on the spool core. Viewed in cross section, the seal is symmetrical and, although free to move within the chamber, is normally held in position by compression between the spool and the barrel of the valve. The overall cross sectional area of the seal is approximately half that of conventional O-ring seals. This makes it possible to expose a considerably larger section of the port and hence increase the air flow for the same length of stroke. In addition, the smaller contact face reduces the sliding resistance of the spool, while maintaining an effective seal.



## Methods of Actuation

Valves can be operated manually, mechanically or by means of a solenoid or an air signal.

Manual operation is achieved by means of a spring return or two-position switch. Mechanical operators include cams or roller levers.

Actuation from an air signal can be carried out using a mono-stable pilot valve, where air pressure moves a piston which, in turn, drives the spool forward; a spring being used for the return stroke. Alternatively, the spool can be returned using air deducted directly from the inlet port, through an internal passage. A further possibility is to use a switchable air supply to move the spool alternately in each direction.

Solenoid valves can act either directly, where the energised coil causes the armature to move the spool or poppet, or indirectly, using the solenoid to actuate a plunger which then opens or closes the pilot valve. Indirect actuation tends to be used on larger capacity valves, to minimise the size of solenoid required.

The design of solenoids can have an affect on system efficiency. Conventional solenoids often exhibit high levels of friction, between the armature and the coil, so it is important to select a device where the coil design reduces frictional losses to a minimum.

## Valve Selection

The changing face of industry in the UK has had a considerable impact on the development of pneumatic systems, especially that of control valves. The current generation of equipment, in particular, is designed to meet the needs of the latest highly automated manufacturing and assembly systems and offers a unique combination of speed, reliability and overall performance, from devices which are compact and lightweight.

Selecting the correct type of valve obviously depends on the specific application. The following table, however, is intended to provide general guidelines. For more detailed information on individual devices please contact SMC Pneumatics (UK).

	O-Ring Seal	Elastomer Bonded Spool	Match Ground Spool	Q Seal
Typical Operating Life	Unspecified	20,000,000 cycles	100,000,000 cycles	20,000,000 cycles
Spool Stroke	Long	Short	Short	Short
Response Times	Good	Excellent	Excellent	Excellent
Reliability	Good	Excellent	Excellent	Excellent
Flow Characteristics	Poor	Good	Good	Good
Stiction	High	Low	Low	Low

# VACUUM TECHNOLOGY

**V**acuum devices play an important role in a wide range of applications. Typically, they are used either in pick and place systems, for moving items ranging from small electronic components to plate glass, or for holding products in position, while other operations are carried out.

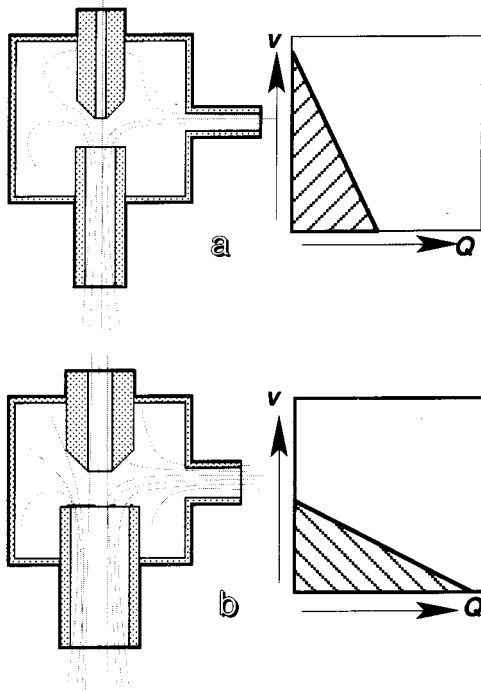
## Pumps and Ejectors

A vacuum is generally defined as a space which is devoid of all matter. In practice, this is difficult to achieve, so that in terms of pneumatic technology a vacuum generally represents a contained area from that of the surrounding atmosphere. The difference in pressure, or the under pressure, as it is sometimes known, is measured either in Torr (named after the Italian physicist, Torricelli) or in standard SI units of bar or Pascal.

There are two methods of applying a vacuum: by means of a special pump, which evacuates a tank and requires dedicated circuits routed to each work station, or by using the normal compressed supply.

Although dedicated pump systems are relatively expensive, they can provide high levels of vacuum over large work surfaces. For most applications, however, a more cost effective method is to use vacuum ejectors, which rely on the kinetic energy of a jet of air to evacuate a vacuum cup or suction pad.

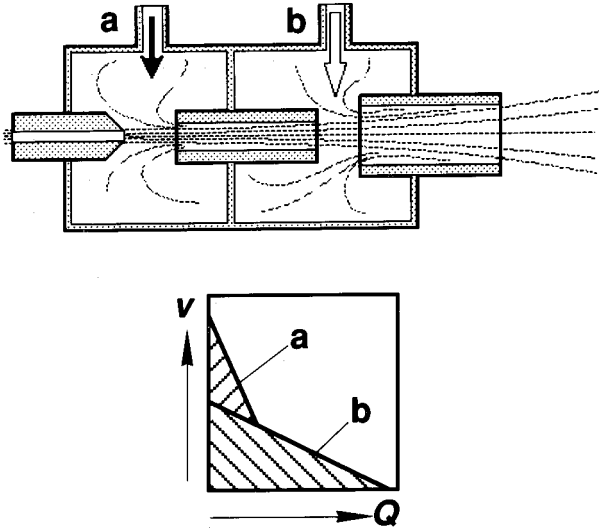
Vacuum ejectors have largely superseded the older venturi-type generators and are constructed as shown in the diagram below.



Compressed air is forced through a nozzle into the mouth of a larger tube or diffuser, causing turbulence within the chamber. This has the effect of drawing air from the vacuum port into the diffuser. As can be seen from the diagram, changes in the relationship between the size of the nozzle and diffuser will affect both the level of vacuum created and the rate of flow through the vacuum port, with larger diameter nozzles and diffusers giving higher flow rates but a reduced vacuum.



This phenomenon can, however, be utilised to produce highly efficient two-stage vacuum ejectors, such as SMC's ZM devices.



The vacuum inlet is split between two chambers, the first of which provides a high level of vacuum, while the second increases the volume of air removed. By installing a check valve between the two chambers it is therefore possible to control the relationship between vacuum and flow, with the valve closing as the vacuum increases or as the flow rate falls. In addition, air consumption is minimised, as the flow rate can be reduced once the vacuum has been applied to the work piece.

Vacuum ejectors such as the ZM incorporate silencers, suction filters, valves and switches within a single compact unit, making them simple to install, even on robotic arms or other moving assemblies, where weight must be minimised to reduce inertia. They also use carefully calculated flow paths and nozzle and diffuser orifices, to provide a level of vacuum which is up to 40% greater than that of conventional devices.

## Vacuum Pads

Having developed a vacuum or, to be more specific, a suction force, it is then necessary to create a seal between the ejector and the workpiece, so that it may be moved or secured. This is generally achieved using vacuum or suction pads, located where possible close to each ejector, to minimise the volume of air which must be evacuated and to improve response times.

Under normal operating conditions each ejector should be connected only to a single pad, to prevent the failure of one pad from affecting the vacuum applied to the remainder.

Vacuum pads are manufactured from a variety of rubber compounds. Typically, these include nitrile (NBR) silicon, urethane and Viton (FPM). For most applications, conventional NBR pads provide a suitable combination of surface compatibility and rigidity; softer silicon pads are useful with items that have deeply contoured surfaces, while viton or other anti-static materials are required in areas, such as the electronics industry, where components are easily damaged.

The size and type of vacuum pad required for a given task depends on a variety of factors, of which the most important are the weight, surface finish and shape of the work piece. In addition, however, the ability of the pad to retain an optimum profile as the vacuum is applied, will also have a direct impact on the performance of the system.

Unsupported vacuum pads can deform as vacuum is applied, with exterior air pressure forcing the outer sections of the pad into contact with the surface of the work piece. This dramatically reduces both the effective pad area and, therefore, the level of vacuum which can be created. Conversely, if the pad material is too hard, air will leak under the rim, so that the supply pressure has to be increased, simply to maintain a static vacuum.

The solution is both to use relatively soft, ribbed pads, capable of retaining the maximum volume of chamber between the pad and workpiece, and to ensure that the devices used to create the vacuum are also capable of generating a high rate of flow. This draws the pad down rapidly onto the work surface before a significant leakage flow is set up. Two stage ejectors are ideal for this purpose.

Ribbed pads should also be used with flexible items, such as plastic sheets, which are likely to deform as vacuum is applied; in this instance, both the size of the pads and the level of vacuum should be reduced, to prevent the work surface from creasing. Flat, rigid work surfaces generally require low profile pads, while curved surfaces can only be moved using pads with a deep, conical profile.

Rough surface finishes will cause air to bleed under the rim of vacuum pads. To overcome this it is necessary to increase the level of vacuum applied and to use pads with smaller diameters, to minimise the air loss. Larger numbers of pads will, therefore, be necessary to retain the same overall pad contact area. With deeply textured surfaces a softer pad material will also reduce air loss, as the pad will mould itself to the contours of the surface; a softer material can, however, affect the level of grip which is achieved, as the pad is likely to deform under pressure.

The time taken to evacuate each pad will affect the sequencing of events which are subsequently carried out. Calculations for response times must take into account a variety of factors. These include the flow rate through the ejectors, and hence the available vacuum pressure, the size of pad, leakage of air from around the pad, the porosity of the work piece and the size and length of air tubes, which will affect the operating pressure.

## Lift Force

Tables showing the lift force available from different sized ejectors are available from vacuum equipment manufacturers. One point which should be remembered, however, is that the figures supplied do not always provide a reasonable safety margin; for example, an allowance is not always made for factors such as the sheer or lateral force acting on each pad as the work piece is moved. Depending on the application, it may therefore be necessary to reduce the lift force quoted by up to 50%, if suction is being applied from above the work piece, or by as much as 75%, if the vacuum pad is applied to the side of the work piece.

## General Points

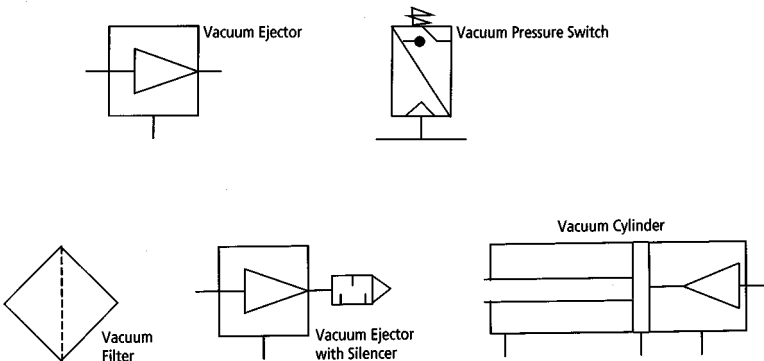
The following is a brief summary of some of the main points which should be considered when designing or specifying vacuum systems.

- a) Use a series of small pads to spread the suction force over as wide an area as possible.
- b) Do not allow pads to protrude beyond the edge of the work piece.
- c) Use multiple pads to prevent the work surface sagging as it is lifted.
- d) Reduce the time taken to reach operating vacuum by mini-mising the amount of tubing used between the ejector and the suction surface.
- e) Use one ejector per pad. Several pads driven by a single ejector will all be affected if one pad fails to function correctly.
- f) Protect multiple ejector and pad systems with a throttle valve, to ensure that a constant flow of air is maintained across the pads, even if one or more suffer from a loss of vacuum.

- g) Always install extra pads, so that in the event of several pads malfunctioning, the work piece continues to be held firmly in position.
- h) Minimise the diameter of air tubes, to reduce flow resistance, leakage and response times.
- i) Use and correctly maintain in-line filters. Efficient filtration will prevent solid debris or air borne particles of oil and other contaminants fouling the vacuum pump or internal orifices in vacuum ejectors. Ejectors should be protected by filters both in the vacuum intake and in the main supply lines.
- j) In certain applications, it is necessary to provide both a suction force and a positive air pressure through the vacuum pad. This can be achieved simply by incorporating a valve into the system, so that when deactivated the valve provides suction. Switching the valve causes air to be blown through the pad, either to dislodge the work piece or to prevent debris entering the vacuum port.

### Vacuum Symbols

The various standard ISO symbols, used to define vacuum devices, are shown below. These can be used in a similar fashion to the symbols for other pneumatic equipment and follow similar conventions.



# PNEUMATIC ACTUATOR TECHNOLOGY

## Pneumatic Actuators

**I**n its basic form, a pneumatic actuator is a device which translates the energy from a compressed air supply into a linear or rotary movement. In essence, actuators generally represent the business end of any pneumatic system, providing the means by which specific tasks such as clamping, picking and placing, filling, ejecting and tool changing - are carried out.

In the early days of pneumatics technology the only actuators commonly available were cylinders that provided a simple linear movement from a conventional and relatively bulky barrel and piston rod assembly. Rapid changes in market requirements and a demand for smaller but more powerful and efficient devices has, however, led to the introduction of a wide range of actuators. Today, the actuator product group includes single and double acting cylinders, single and twin rod slide units, rotary actuators (both vane and rack and pinion), hollow rod cylinders, grippers and compact cylinders, locking head and multi-positional cylinders, capable of providing a combination of rotary and linear motion.

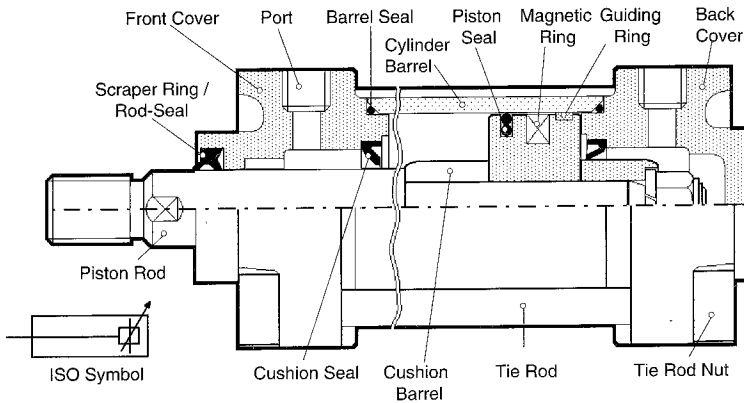
As the range and scope of pneumatic actuators has increased so too has their sophistication and performance, making it harder to specify devices for different tasks. There are, however, a number of criteria that all actuators should meet, over and above those expected of all modern industrial equipment, such as long term reliability and minimal

maintenance. Depending on the application, these include:

- 1) Low break away force (stiction)
- 2) Minimum friction between the piston and barrel
- 3) Fast acceleration and deceleration
- 4) Accurate and repeatable positioning (especially in pick and place systems)
- 5) Maximum efficiency
- 6) Smooth operation

Note: For a detailed explanation on sizing linear acting cylinders refer to chapter 1, "Sizing Pneumatic Valves and Cylinders."

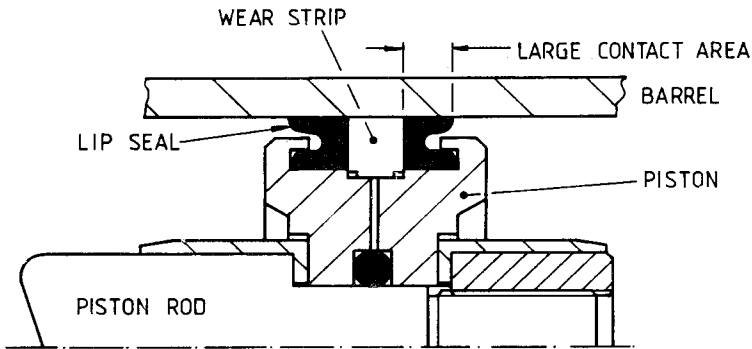
The following diagram shows the various components typically found within a standard double acting linear actuator.



The scraper ring/rod seal is designed to prevent debris on the piston rod from entering the actuator, while the magnetic ring on the piston assembly is used to operate externally mounted auto switches, to show the position of the piston. Perhaps the most important component, however, is the piston seal, as its design can have a considerable impact on the efficiency with which the actuator operates.

## The Importance of the Piston Seal

Conventional linear actuators generally incorporate two lip seals, mounted back to back and separated by a wear strip. Although this arrangement provides an effective seal between the piston rod assembly and the cylinder body it has a number of inherent drawbacks.



The large area of the lip seal, in contact with the cylinder barrel, that is acted upon by the applied air pressure, reduces the effective thrust of the piston and increases the operating pressure necessary to start the piston moving; it also inhibits smooth operation at slow speeds.

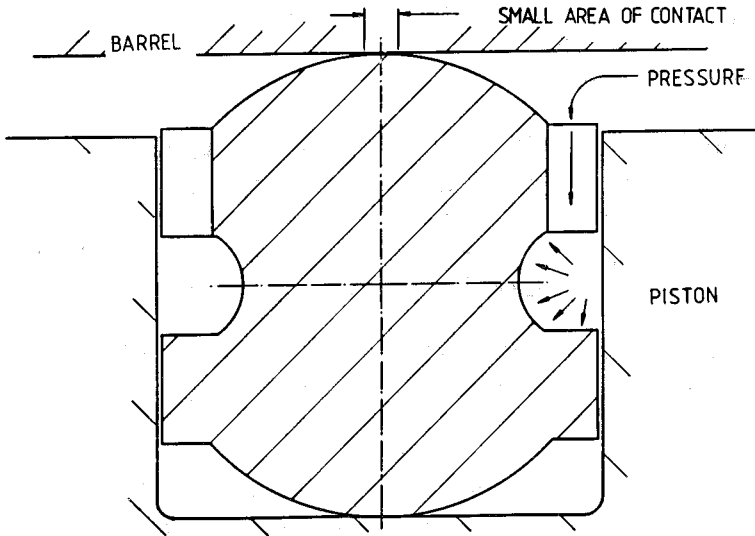
This type of seal design can reduce both cylinder efficiency, by as much as 25%, and the life of the seal itself.

The movement of the lip seals along the barrel also tends to scrape away the vital lubricating materials used to protect the cylinder, so that they collect at either end of the bore. Over time, this can result in the premature failure of the seals, causing air losses and energy consumption to escalate.

To address these problems, SMC has developed a low friction seal, which is now standard on most SMC linear actuators.



In simple terms, the seal fits within a recess in the piston rod and comprises a specially moulded, single piece, waisted oval rubber element. This has a small contact area, to reduce frictional losses to a minimum, and ensures a single point of contact with the cylinder barrel, regardless of the air pressure. As the cylinder reciprocates, the seal flexes about the central waist, causing the actual point of contact to occur across the face of the seal, thereby considerably reducing the amount of wear. The flexing action has the added benefit of gradually redistributing lubricating oils evenly along the inside face of the barrel.



The dramatically reduced level of friction means that the pressure required to overcome the break-away force diminishes from the usual 15 psi to under 5 psi, providing smooth start up and operation, while the problems of 'stick-slip', often encountered with other types of cylinder running at slow speeds, are virtually eliminated.

## The Construction of Linear Actuators

Traditionally, linear actuators have been constructed from a seamless tube or barrel, sealed at either end with end-caps manufactured from alloy or iron castings and held in place by longitudinal tie rods or screwed or crimped to the barrel. Although this method of construction will probably continue for the foreseeable future, it is being supplemented by other production techniques, most notably the use of high pressure extrusion, pioneered by SMC, for the manufacture of a one piece cylinder barrel, extruded from an aluminium slug. This produces a simple, low cost cylinder, with a minimum number of components.

Traditionally manufactured cylinder barrels are generally produced from aluminium, stainless steel, brass or bronze and should be coated and finished so that friction and wear on the internal components is reduced to a minimum. The internal surfaces are lubricated for life, removing the need for the separate lubrication units, previously required in pneumatics systems.

Similarly, the piston rod should either be chromium plated or, for more demanding applications, manufactured from stainless steel, to give a tough, hard wearing component.

Accurate positioning of the piston rod during cylinder operation depends on a number of factors, including the type of cylinder seal that is used and the ability of the piston to withstand side loads. This is primarily achieved by the use of specially strengthened components, including hardened internal faces on cylinder barrels, and by incorporating a series of bushes and/or bearings within the body of the cylinder, to prevent the rod being deflected as it extends. Although piston rod deflection will vary, depending on the size and design of each actuator, it should typically be within  $+0.5^\circ$  at maximum

extension; actuators that fall outside this tolerance band provide poor positional accuracy and are likely to suffer from increased wear of the piston seals.

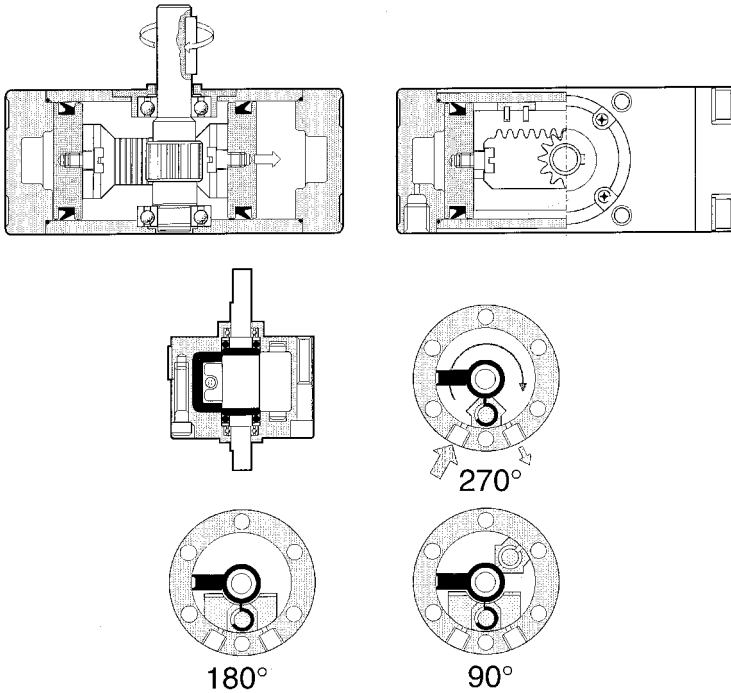
Piston acceleration can be controlled by the use of a flow control valve, enabling control of the exhaust air; while deceleration, especially from high speeds, can be achieved by the use of internal or external rubber bumpers or shock absorbers. An internal air cushion can also be incorporated, which provides an adjustable and highly accurate method of bringing the piston to a halt. The cushion is formed by trapping, and then gradually venting, a pocket of exhaust air between the piston and the end of the cylinder.

## Special Purpose Actuators

In recent years the range and operating performance of pneumatic actuators has expanded considerably, matching the growth in the market for robotics and automation systems. As a result, it is now possible to find an actuator or a combination of actuators, to meet the needs of almost every application. Listed below are just some of the types commonly available; if you would like to discuss a specific requirement please contact your local SMC regional centre.

## Rotary Actuators

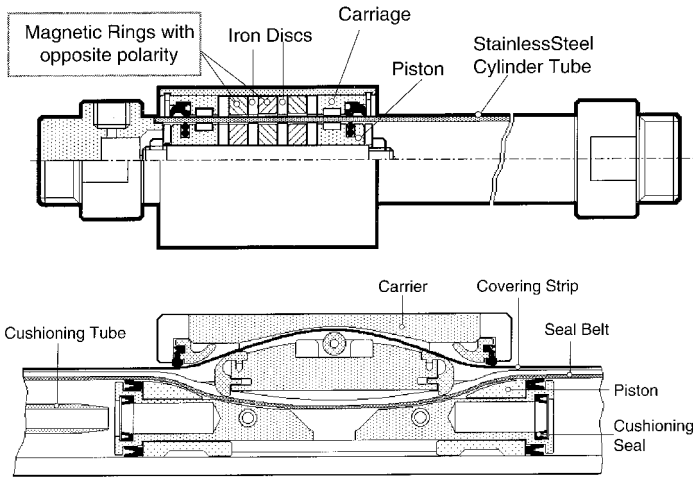
There are two principal types of rotary actuator: rack and pinion or vane. In the first, a linear piston movement is translated into a rotary action by means of a rack and pinion arrangement, giving a maximum rotation of  $190^\circ$ , while the second type uses specially shaped vanes, driven by air pressure, to turn an output shaft.



Typical applications for these actuators are pick and place systems, where a high level of positional accuracy is required.

## Rodless Cylinders

In a number of applications, especially where space is limited or where extreme piston rod extension is required, a conventional linear actuator is impractical because of the combined length of the piston rod and cylinder body at full extension. Rodless cylinders were developed to overcome this problem and feature a carriage mounted directly above the piston rod, enabling maximum use to be made of full piston travel. A conventional cylinder with a stroke of 500mm, for example, will typically require a dimensional length of 1100mm for installation, while a rodless cylinder with a similar stroke requires only 600mm.

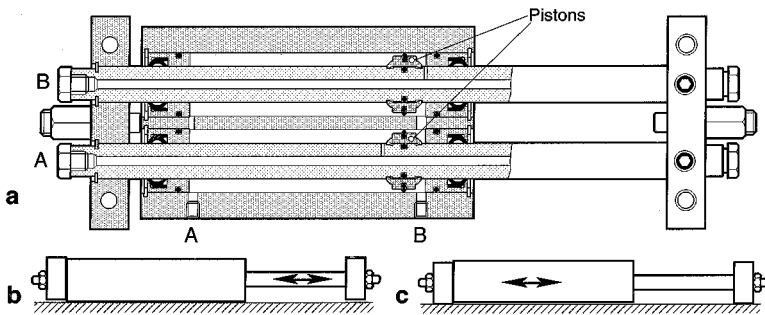


The carriage can be connected to the piston, either magnetically or mechanically. In the first instance a series of powerful neodymium ferrous boron magnets are fitted both to the rod and the carriage; in the second system a mechanical coupling, mounted through the cylinder barrel in a sliding seal is used.

The main advantage of the magnetic rodless cylinder is its ability to provide controlled movement at relatively high speeds. Unlike the mechanical system, there is no opening in the barrel, so air leakage and the risk of dirt entering the cylinder are eliminated. Its one limitation is the restriction of the loads it can carry; heavy duty applications, therefore, require the use of mechanically coupled rodless cylinders.

### Slide Units

In essence, slide units are precision linear actuators, but with a twin piston rod arrangement to eliminate piston rotation and increase the output force. Designed for use on automation systems, especially where components need to be moved or positioned, they can be used to replace traditional multi-component actuator/guide rod assemblies.



## Pin or Needle Cylinders

Pin or needle cylinders are miniaturised devices, capable of providing linear movement in confined spaces in applications such as the electronics industry, where small components need to be moved quickly from process to process, or be clamped, rotated or ejected.

Pin cylinders are compact devices, typically measuring a few centimetres in length, with bore sizes under 15mm.

## Combination Cylinders

Designed primarily for use in pick and place production systems, combination cylinders provide multi-positional movement in a single device; for example linear, rotary and gripping actions.

Typically, a combination cylinder incorporates a rotary action, controlled by a rack and pinion, plus a double action linear movement; these can be carried out sequentially or concurrently, to create an oscillating motion. In each case, piston speed and rotation can be determined accurately by adjustable exhaust valve throttles, while positioning can be indicated using externally mounted auto switches, activated by magnets set within the piston and rack and pinion assemblies. In addition, the piston rod can be drilled longitudinally, to enable a vacuum to be applied to end effects connected to the tip.

# SOLENOID VALVES

## Solenoid Valves

Solenoid valves are used widely throughout the pneumatics industry, as an effective and reliable method of controlling actuators and similar pneumatically operated devices.

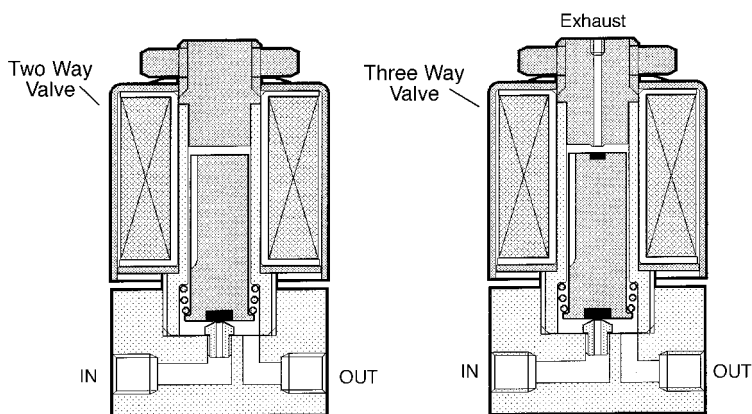
Solenoid valves use electro-magnets to operate valve spools either directly or, more commonly, indirectly, by means of a pilot valve.

Direct operation can only be achieved in valves incorporating almost frictionless, short stroke, steel spools without seals; typically these include directional control valves, which are widely used in America. Although these devices offer relatively fast response times and can be switched at any air pressure, they are relatively large, expensive to manufacture and require additional electronic control equipment before they can function.

In Europe, poppet and elastomer sealed spool valves are far more common. These cannot, however, be operated directly, due to their longer stroke and higher levels of internal friction. Instead a small solenoid pilot valve is used to control the flow of air to a pneumatically driven spool.

## Solenoid Pilot Valves

Early solenoid pilot valves were based on similar design to that used in directly operated valves. This was developed by an American called Skinner and was first used in the 1930s.



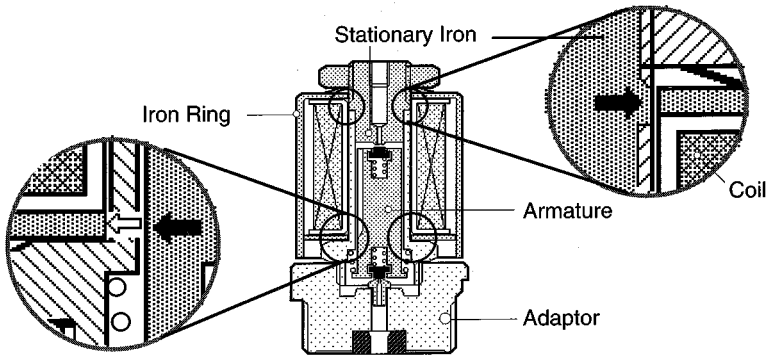
Skinner Coil Principle

The Skinner design incorporates a spring loaded armature, enclosed in a tube of non-magnetic material and held against the air inlet port by the force of the spring, with the port being effectively sealed by a rubber pad inserted into the bottom of the armature. Energising the solenoid lifts the armature against the spring, allowing the supply air through to an outlet port.

Although the Skinner system is relatively simple and is still widely used in solenoid valves, it suffers from a number of inherent problems. Foremost among these is the disruption in the magnetic field, produced by air gaps within the solenoid core, around the iron circuit and the non-magnetic tube. These cause excess heat and noise to be generated as the armature moves, reducing efficiency and increasing the levels of power that need to be generated to operate the solenoid.

The air gap between the armature and the coil also allows the armature to be drawn radially against the inner wall of the tube, again serving to increase friction and the build up of heat and further affecting the operating life of the system. In addition, the armature seals can rapidly degrade through continuous impact with the metal seat around the inlet port.





High Magnetic Resistance

At best, traditional solenoid pilot valves based on the Skinner principle will have an operating life of between twenty and thirty million cycles. Although this may be sufficient in some applications, it can be a problem in modern automation or pick and place systems, where high switching speeds and often limited areas for installation place the various solenoid components under severe stress. In addition, the high power requirement of these devices - often in excess of 2W - often makes them unsuitable for use in systems where direct connection to PLCs or other digital controllers is required.

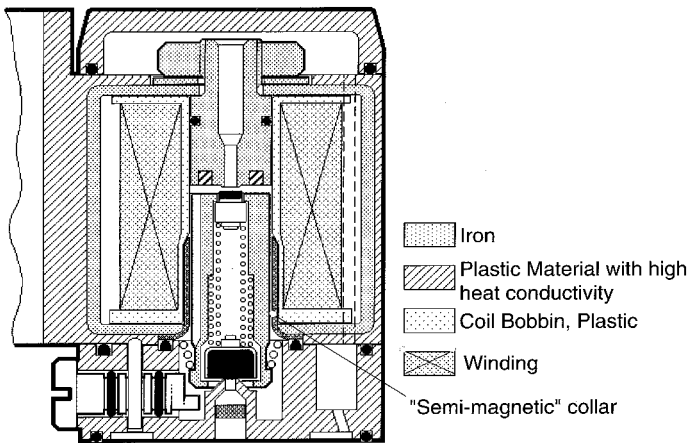
## Recent Developments

SMC pneumatics was one of the first pneumatics manufacturers to address the problems associated with traditional solenoid pilot valves, in an effort to increase reliability, operating life and response times, while decreasing the level of power required.

The main source of these problems was the high levels of internal friction and the existence of air gaps at critical points in the solenoid assembly. The first step was therefore to eliminate the non-magnetic tube around the armature and to construct the iron circuit around the coil

as a single closed ring. This reduces the number of components and, more importantly, removes the primary cause for the disruption of the magnetic field.

The tube has been replaced by a semi-magnetic collar with a low friction coating, mounted between the armature and the iron core. This serves both to guide the armature accurately, preventing radial movement, and effectively closes the final gap in the magnetic circuit, smoothing the field lines, so that frictional losses, heat and noise are reduced to a minimum.



Custom Designed Pilot Valve

In addition, in the latest solenoid pilot valves the armature and seal have been separated into two discrete components, connected by a spring loaded push rod. Energising the coil causes the armature to move away from the valve seat, towards the fixed solenoid core, pulling back the push rod and allowing the valve to open. When the armature subsequently returns to its de-energised or closed position the spring compresses, acting as a cushion over the final few millimetres of travel to prevent the seal from being damaged by what would normally be a relatively heavy impact with the valve inlet port.

To minimise wear still further the air gap between the armature and core has been dramatically reduced, closing to a minimum of 15 microns when the armature is energised. This is sufficient to prevent the two components from making contact, thereby eliminating the problems caused in conventional solenoid valves by continuous collision damage, without impairing overall performance.

Maintaining a minimum air gap also helps to break the magnetic attraction between the core and armature as the latter is de-energised, helping to reduce response times to around 7msec for a valve with a double acting solenoid.

By reducing frictional losses and significantly improving the efficiency with which the latest generation of solenoid valves operate, it has been possible to increase service life to well over one hundred million cycles, while minimising noise and heat levels and improving response times and rates of flow. The power requirement is also far lower, typically under 1.0W, enabling the valve to be driven directly from a PLC or similar device.

Further improvements on this design include a vertical mounting for the pilot valve, on the side of the main valve, enabling overall dimensions to be halved, and the use of standard electrical connectors, located on the valve manifold; individual valves can then be pre-wired for connection directly to the manifold, which can be extended as required.

## Power Requirements

Solenoid valves are available for use with either DC or AC power sources. In simple terms, AC driven solenoid valves are comparatively large devices, consuming higher levels of power to produce a relatively slow action, while DC operated valves use small, solid state components to produce fast actions from compact devices; DC is commonly used with most modern compact solenoid pilot valves.

A detailed explanation of electromagnetic theory and the operating principles of DC and AC solenoids forms part of SMC's training course on electro-pneumatics (contact the Training Department on 01908 563888 for more information). There are, however, a number of general points which should be considered.

## Over Excitation of DC Solenoids

The reaction time of a DC solenoid can be shortened by applying a higher than the nominal voltage for a few milliseconds. This gives a similar effect to the inrush of an AC solenoid. When the armature reaches the end of its stroke, the voltage can be lowered to less than half nominal. This shortens the switch-off time and reduces heat.

## Alternating and Direct Current

### **Inrush/Holding Power**

For AC solenoids there are two other factors to consider:

1. Inductance changes with the position of the armature.
2. The current and with it the magnetic force, drops to zero twice during each period.

The inductance changes drastically with the position of the iron armature. Initially with the air gap at maximum, the force and the inductance are very low. This means that a large current is flowing into the coil to charge it.

This very high initial current causes an AC coil to react violently when compared with a DC coil. When the armature closes the air gap (= the iron circuit), the inductance and the total resistance increases and the current reduces. This is reflected by the catalogue specifications for AC solenoids, inrush and holding.

The difference between DC power and AC inrush and holding power is considerable, as shown by the table opposite.

Power	Inrush Power VA		Holding Power VA		DC Power W
	50Hz	60Hz	50Hz	60Hz	
AC Frequency	50Hz	60Hz	50Hz	60Hz	
Solenoid A	4.5	4.2	3.5	3.0	1.8
Solenoid B	5.6	5.0	3.4	2.3	1.8

In the case of DC ( $W=Watt$ ), the current and voltage remain constant. In the case of AC ( $VA=Volt\ Amperes$ ), both voltage and current change constantly. The difference in the figures between 50Hz and 60Hz is due to the coil resistance.

The solenoid coil is “sized” for the holding current, if the armature sticks, the reduction of current does not take place and the coil heats up until its insulation melts. More and more windings are then short circuited and the current rises enormously by a snow ball effect which results in “a burned out coil.”

## Shading Ring

Each time the alternative current goes through zero, the spring starts to return the armature. It will, in effect, only just get free from the fixed force, and then is attracted again when the current increases, with the opposite polarity.

This creates a sound called “hum”. Not only is this irritating, but the constant banging of the armature against the fixed force (a hundred times a second) causes deterioration in a short time.

To remedy this, a second magnetic feed is created, as close to  $90^\circ$  as possible, to bridge the gaps. This second field is called the Shading Ring.

## Spring Characteristics

A crucial factor for the efficient operation of any solenoid valve is the rapid and consistent return of the spring loaded armature to the rest position as the coil is de-energised.

The pressure of the return spring must be sufficient to overcome any residual magnetic attraction holding the armature in the energised position. In devices where a relatively weak spring force is used, to reduce the energy of the coil, the magnetic field has to drop to a low level before the armature is released; over time, however, the spring will inevitably weaken while the residual magnetic attraction will increase, causing the armature to stick.

The correct choice of spring characteristics by the solenoid manufacturer is therefore crucial to ensure that the opposing force on the armature is as low as possible, while maintaining sufficient pressure to close the valve seat after de-energisation.

**(Please note:** for information on valve technology please refer to chapter 3 of the SMC Pneu Book)

## RODLESS CYLINDERS

Rodless cylinders were originally developed to overcome the space limitations of conventional actuators, providing relatively compact, space saving devices, capable of moving or positioning components or tools in assembly and automation systems.

To understand the advantages of a rodless cylinder, it is worth firstly considering a conventional cylinder with, for example, a stroke length of 500mm.

In the retracted position the length of the cylinder is 500mm, plus the length of the end caps, piston, nose bearing and piston rod, giving a total length of around 600mm; when the cylinder is fully outstroked, this length will increase to 1100mm. In many applications, however, such as compact automation assembly machines, it is impractical to incorporate a device with such a large footprint.

By comparison, a rodless cylinder of similar stroke has a length of only 600mm, enabling it to perform the same function as a conventional cylinder but without compromising on the space available.

As the name implies a rodless cylinder has no piston rod, being constructed with a slide table assembly mounted directly above the piston. The table and piston are connected either directly, using a slot cut along the top of the cylinder body, or indirectly, through magnets located on both the piston and table.

## Directly Coupled Rodless Cylinders

The latest generation of directly connected rodless cylinders, such as SMC's Series MY, make extensive use of aluminium and special resins and plastics to ensure that the inertial effects of the moving table assemblies are as low as possible and to improve overall performance.

Unlike earlier rodless cylinders, where connection between the table and piston was through a simple slot, with a rubber seal closing the area behind and ahead of the table as it moved, the latest rodless cylinders use a sophisticated seal belt, which reduces both air loss through the slot and maintains frictional losses to a minimum as the table slides.

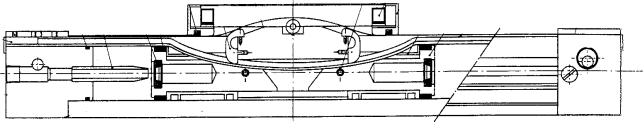
The slot and rubber seal arrangement used in earlier rodless cylinders often meant that air losses could be as high as thirty per cent of the pressure applied, while dirt and moisture inevitably penetrated the piston barrel, resulting in reduced performance and product life.

To overcome these major problems SMC developed the mechanically coupled Series MY of rodless cylinders, where the extruded aluminium cylinder barrel has an open slot running along its length. The piston and slide table assembly are directly coupled by a yoke that extends from the piston through the slot to the base of the table and a stainless steel support ring, between the top of the yoke and the table. The cylinder barrel incorporates table guidance mechanisms within the extrusion, to reduce the overall dimension of the cylinder, plus slide bearing surfaces to ensure smooth operation with a minimum of friction.

A belt is then used to seal the slot as the table assembly moves. Unlike previous rubber seals, however, this is manufactured from a high performance resin and is carefully moulded to fit the exact profile of the slot in the cylinder barrel. Perhaps as importantly, the belt seal is automatically



guided through a shaped groove in the top of the piston; this effectively breaks and re-closes the seal as close to the table assembly as possible, thereby reducing air losses to an insignificant level. (See diagram below).



Dust and other contaminants are prevented from entering the cylinder barrel by an NBR coated stainless steel dust band that passes over the top of the piston at the point where it locates in the base of the table. In addition, scraper seals are used to keep the slide area free of debris, to ensure that lubricants remain evenly distributed and to help guide the belt seal and dust band.

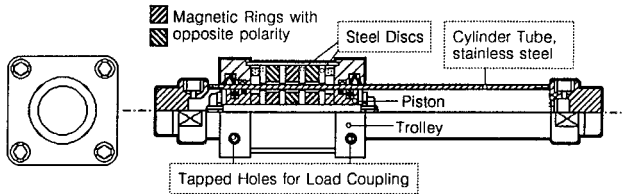
Directly coupled rodless cylinders can be mounted in a wide range of positions: vertical, horizontal, inverted and at an angle. They are capable of handling heavier loads and withstanding greater side forces than magnetically coupled devices (see below) and eliminate the possibility of the table becoming disconnected from the piston by a sudden shock or abrupt halt.

### **Indirectly Coupled Rodless Cylinders**

In applications where air losses must be eliminated or where lighter loads are to be moved, magnetically coupled rodless cylinders can be used.

In these types of device, the piston and table assembly both incorporate powerful magnets, manufactured from Neodymium Ferrous Boron, a material with magnetic properties ten times greater than traditional permanent

magnets. As a result, the direct connection, slot and seal arrangement in directly coupled rodless cylinders can be dispensed with completely. (See diagram below).



The cylinder barrel and table assembly retain the same integral guide mechanisms and slide and bearing surfaces as directly coupled devices, to produce a smooth, low friction movement. Internal air cushions can also be used to decelerate the table gently at the end of each stroke.

Magnetically coupled rodless cylinders are ideal for applications where relatively light loads need to be moved at low or medium velocities. They can, however, only be used in a horizontal or close to a horizontal plane, and are limited in operating speed by the strength of the magnets used to hold the table in position. In addition, for loads that project significantly beyond the edge of the table, it may be necessary to incorporate extra guides outside the envelope of the cylinder.

### Typical Applications

Rodless cylinders were originally developed for use in all areas where space is restricted; they have, however, since become used in a wide range of applications, as they provide a simple, compact and reliable method of transferring, moving or positioning components or workpieces.

Typical applications include: Assembly automation, Packaging, Electronics, etc

## Basic Rules For Drawing Pneumatic Circuits & Symbols

Pneumatic circuits are represented by common symbols and should be drawn following several basic guidelines. By following these guidelines engineers can quickly and simply construct circuits that can be easily and safely interpreted by all those involved in system design, specification, manufacturing and maintenance.

The symbols used for constructing fluid power systems and for defining individual components are detailed in the standard ISO 1219, which covers both pneumatic and hydraulic devices.

This states that: 'A symbol consists of the lines, letters and abbreviations which identify the purpose and method of operation of the component represented. The symbols show connections, flowpaths and the functions of the components represented. The symbols do not indicate the physical location of ports or the position of control elements on actual components. With certain obvious exceptions symbols may be reversed and/or rotated without altering their meaning'.

Standard ISO symbol conventions are therefore intended to represent graphically the function, not the construction or appearance, of each device.

It should be noted, however, that the ISO standards do not always keep abreast of developments in pneumatics technology, so that new products often fail to be clearly defined until some time after their introduction. As a result, product manufacturers often use proprietary symbols until such time as a standard unit is defined.

The situation can be further confused by the fact that the Japanese Industry Standard (JIS) and the American Standards Authority (ASA) also use differing sets of symbols.

All three standards authorities use common symbols for air preparation equipment and, with a few exceptions, valves; the JIS, however, reflecting the greater diversity of equipment originating in Japan, often uses different symbols for special purpose or newly developed actuators.

For most pneumatic circuits, however, the standard ISO nomenclature is adequate, with the majority of air preparation, air treatment, actuators, valves and ancillary components being defined by common symbols.

A complete list of symbols and guidance on their construction is available from SMC.

When constructing a circuit diagram, there are always basic rules that should be followed.

- The flow of working energy in a circuit diagram is drawn from the bottom to the top of the diagram.
- The sequence of the working cycle is from left to right of the circuit diagram; the air supply is therefore shown at the lower left, with the cylinder that performs the first stroke of the cycle being situated in the upper left.
- Power valves are drawn directly below the cylinders they operate.
- All circuit components are shown in their rest position, with the supply under pressure.
- Electrical connections are not generally shown.
- Mechanically operated valves, controlling the rest position of cylinder driven parts, are operated in the rest position and must be drawn accordingly; external connections are drawn to the valve symbol square on the operator side.

# INTELLIGENT ACTUATORS

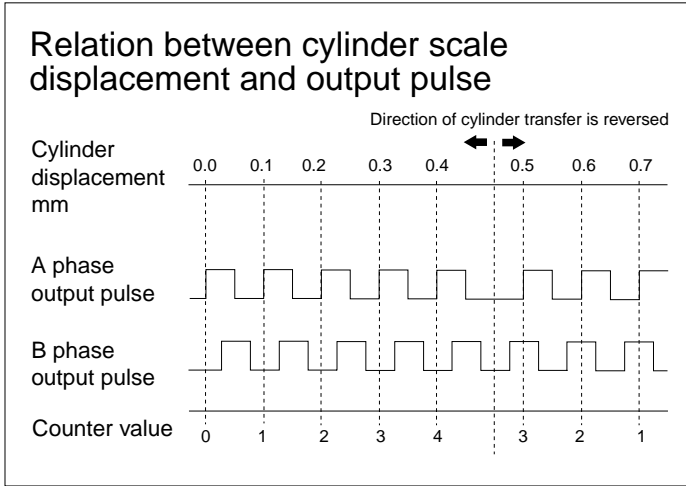
## What they are and how they work

Intelligent actuators have been developed for use in a wide range of applications, in particular repetitive, multi-position tasks, such as single axis robotic automation, for drilling, packaging and materials handling. They typically combine long term, high accuracy stopping of a piston in mid-stroke, even from high speeds, with programmable flexibility.

Although there are various methods of building intelligence into pneumatic actuators, those developed by SMC represent two of the most cost effective and reliable and are therefore worth describing in greater detail. It is important to note, however, that each technology will not necessarily be appropriate in every application and SMC's technical department should be consulted at an early stage of system design or construction.

One of the simplest methods of introducing intelligence is demonstrated by the Series CE1 cylinder. This uses a special cylinder rod, manufactured from stainless steel, solution heat treated to 1100°C and then drawn to reduce the original sectional area by thirty per cent; this has the effect of magnetising the rod. This is subsequently heat treated locally using a laser, to create a series of narrow bands of regular width along the length of the rod; these are alternately magnetised and non-magnetised. The rod also incorporates opposing flats, to prevent it rotating

In operation, the 0.1mm wide bands are read by a sensor as the rod extends and retracts, enabling its exact position, with reference to a datum point, to be established. The sensor has two pick-up points, mounted one behind the other, both of which detect the presence or absence of the magnetic field and give two outputs A and B.



The use of twin outputs, when analysed by a suitable counter, enable a finer resolution than the 0.1mm pitch of the bands to be achieved while, by examining the sequence of waveforms, the counter can determine the direction in which the piston rod is moving.

Taking these developments a stage further, SMC has more recently introduced the Series CE2, which has a carbon steel piston rod, etched with grooves of regular pitch. The grooves are plated with nickel and then hard chromed to again produce alternate magnetic and non-magnetic rings which, in this instance, run completely around the rod, eliminating the need for flats to maintain suitable alignment.

The Series CE2 cylinder is then paired with an application specific controller, the Series CEU2, to give accurate local control of the cylinder and interact with a system PLC to give multi-position sequences.

The Series CEU2 controller ensures excellent repeatability, even over long periods with extended cycles. Stop positions are automatically corrected by a 'try again' (repeat) function,

while a continuous learning function compensates for changing loads and other conditions.

Series CE2 cylinders are available in bore sizes from 40mm to 100mm in diameter and can operate at piston speeds of up to 500mm/sec, with positional accuracy being 0.5mm, independent of load and speed.

The controller can store up to 16 programs of 32 position sequences and is programmed via a simple keypad. This ability to store programs can help to significantly reduce set-up or change over times where the cylinder is being used, for example, on a flexible automation system handling more than one product.