SI units, symbols and dimensioning

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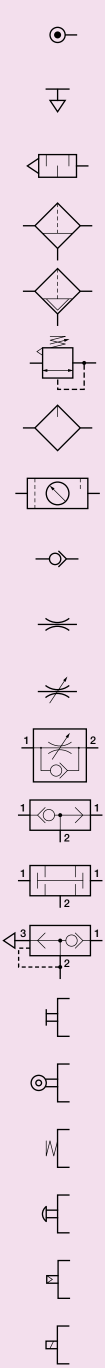
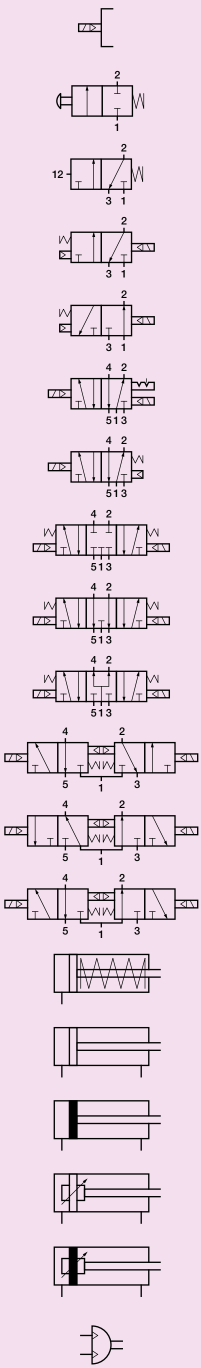
Contents

Common pneumatic symbols



- Supply of compressed air (1 or P)
- Exhaust (3, 5 or E, R)
- Silencer
- Filter with manual water drain
- Filter with automatic water drain
- Pressure regulator with secondary exhaust
- Lubricator
- FRL – filter/regulator/lubricator-assembly
- Check valve
- Flow controller
- Adjustable flow controller
- Adjustable speed controller
- OR valve
- AND valve
- Quick exhaust valve
- Valve control, general symbol
- Valve control, roll
- Valve control, spring
- Valve control, push button
- Valve control, pilot valve
- Valve control, direct acting solenoid



- Valve control, solenoid pilot valve
- 2/2 valve, normally closed, monostable, push button-controlled with spring return
- 3/2 valve, normally closed, monostable, pressure-controlled with spring return
- 3/2 valve, normally closed
- 3/2 valve, normally open
- 5/2 valve, bistable
- 5/2 valve, monostable
- 5/3 valve, closed center
- 5/3 valve, open center
- 5/3 valve, pressurized center
- Double 3/2 valve, normally closed/normally closed
- Double 3/2 valve, normally open/normally open
- Double 3/2 valve, normally closed/normally open
- Single acting cylinder with spring return
- Double acting cylinder
- Double acting cylinder with magnetic piston for sensors
- Double acting cylinder with adjustable cushioning at both end positions
- Double acting cylinder with magnetic piston for sensors and adjustable cushioning at both end positions
- Rotary actuator

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Numbering of connections

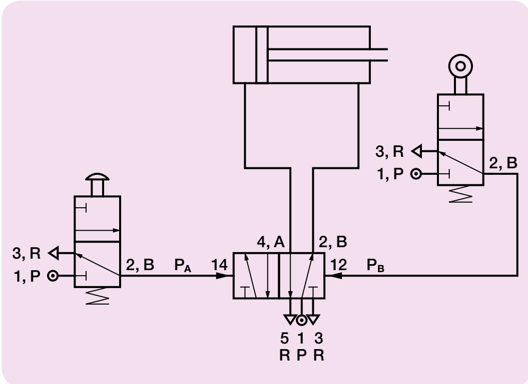
Explanation of how the different connections on the pneumatic components are named.

Port number:

1 (P) Inlet, usually related to mains air supply.
2 (B) Outlet to consumers.
3 (R, E) Drain exhaust.
4 (A) Outlet to consumers.
5 (R, E) Drain exhaust.

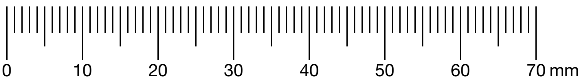
10 Connection for impulse that closes the valve. Only 3/2 N.O.
12 Connection for impulse that combines inlet 1 with outlet 2.
14 Connection for impulse that combines inlet 1 with outlet 4.

- Single digit even numbers indicates the outlet.
- Single digit odd numbers (except 1) indicate exhaust.
- Double digits indicating controlling connections.



Other definitions exist depending on the brand.

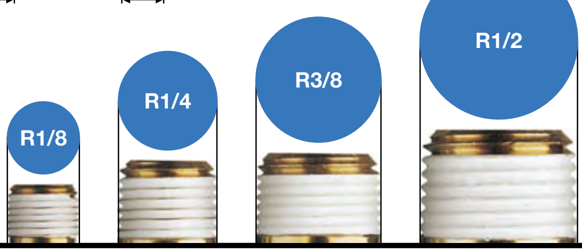
Thread sizes



Thread designation			Outside diameter	Inside diameter
M3			3 mm	2.5 mm
M5			5 mm	4.2 mm
1/8"	01	R6	9.7 mm	8.6 mm
1/4"	02	R8	13.2 mm	11.4 mm
3/8"	03	R10	16.7 mm	15 mm
1/2"	04	R15	21 mm	18.6 mm
3/4"	06	R20	26.4 mm	24.1 mm
1"	10	R25	33.2 mm	30.3 mm
1 1/4"	12	R32	41.9 mm	39.8 mm
1 1/2"	14	R40	47.8 mm	44.8 mm
2"	20	R50	59.6 mm	56.7 mm

SMC's part number provides information on the thread. In chapter 10 you will find KQ2 fittings. The last positions in the order number indicate the type of thread. Here you can see what they stand for:

U01 UNI-thread. Fits tapered, NPT, straight threads. Disc for sealing.
01S Taper thread. Also fits straight thread. Sprayed PTFE on the threads to seal.
G01 Straight thread. Disc for sealing.
M3/M5 Metric thread. Disc for sealing.



Subject to change

Expressions and definitions

A short glossary of common terms and definitions in pneumatics.

Cylinders

Double acting cylinder where the piston movement in both directions occurs through the influence of pressurized medium.

Single acting cylinder where the piston movement in one direction is done by the influence of pressurized medium and in the other direction by some other force (spring).

Cylinder end cover the end caps that limit the piston movement in the cylinder.

Piston rod the part that is firmly connected to the piston and passes through one end or both ends.

Extension when the piston rod moves out of the cylinder.

Retraction when the piston rod moves into the cylinder.

Extended when the piston rod is in its outer end position.

Retracted when the piston rod is in its inner end position.

Plus chamber the cylinder chamber, which when pressurized generates extension.

Minus chamber the cylinder chamber, which when pressurized generates retraction.

Valves

2/2 valve valve with an inlet and an outlet, can assume two different positions.

3/2 valve valve with an inlet, an outlet and an exhaust, can assume two different positions.

5/2 valve valve with one inlet, two outlets and two exhausts, can assume two different positions.

5/3 valve valve with one inlet, two outlets and two exhausts, can assume three different positions.

Normally closed valve (N.C.) If the valve is not activated, the connection between inlet and outlet is closed.

Normally closed valve (N.O.) If the valve is not activated, the connection between inlet and outlet is open.

Bistable valve Missing spring and remains in position until it is activated. Has two stable positions and “memory”.

Monostable valve Has a spring and returns to its home position when it is not activated.

Directional control valve Valve that can control the flow of alternate routes, or open and close the flow path.

Flow control valve Valve that can regulate the flow volume.

Pressure control valve Valve that can regulate the pressure.

Direct operated The valve is direct activated by hand, foot, or by mechanical means.

Pilot operated The valve is indirect activated by compressed air through amplifying a manual, mechanical or electrical signal to the valve stem or spool. A small and easily adjustable valve controls the major valve.

SI units and designations

The SI system is based on seven basic units that can be combined to derived units. Here are the units that are common in pneumatics.

In Europe, the SI system is used since a long time, and it is introduced in more than one hundred countries worldwide. The abbreviation “SI” is French and is read *Système International d’Unités* – that is “The International System of Units”.

Prefix

In the SI system, the units are made larger or smaller by using a prefix to indicate orders of magnitude.

Common prefixes are found in the table on the right.

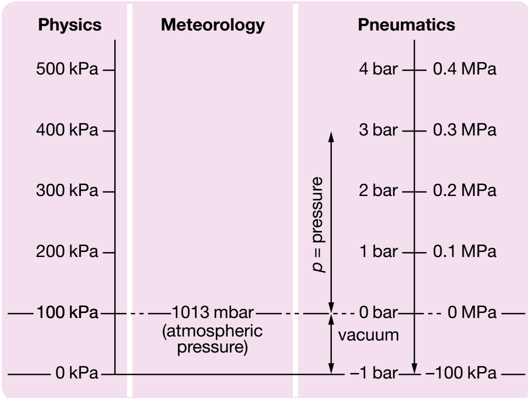
Exponent	Multiplier	Prefix	Symbol
10^{-6}	0.000 001	micro-	µ
10^{-3}	0.001	milli-	m
10^{-2}	0.01	centi-	c
10^{-1}	0.1	deci-	d
10^{1}	10	deca-	da
10^{2}	100	hecto-	h
10^{3}	1 000	kilo-	k
10^{6}	1 000 000	mega-	M

Units for pressure

Pressure in pascal (bar is an older term used less and less). 1 bar = 100 000 Pa (pascal) = 100 kPa (kilopascal) = 0.1 MPa (megapascal).

Pressure in physics

In physics, used absolute pressure (*p abs*), which means that the scale begins with zero point at absolute vacuum.



Pressure in pneumatics

In pneumatics a scale is used where zero is at atmospheric pressure and –100 kPa at absolute vacuum. This is how we define air pressure in this product overview.

Air in the normal state is usually denoted by an n after the device (for example ln for normal liters). Normal air has an atmospheric pressure, is 20 °C and has a relative humidity of 65%. Popularly known as “air in the room environment”.

Quantity	Symbol	Unit symbol	Unit name	Comments
			Basic units	
Mass	m	kg	kilogram	
Length	s	m	meter	
Time	t	s	second	
			Derived units	
Area	A	m^2	square meter	
Volume	V	m^3	cubic meter	
Velocity	v	m/s	meter per second	
Acceleration	a	m/s^2	meter per second squared	
Inertia	J	kgm^2	kilogram square meter	
Force	F	N	newton	$= kg \cdot m/s^2$
Weight	G	N	newton	$= kg \cdot 9.82$
Energy (work)	W	J	joule (= newtonmeter)	$= kg \cdot m^2/s^2$
Moment	M	Nm	newtonmeter	
Effect	P	W	watt	= J/s = Nm/s
			Derived units related to compressed air	
Pressure	p	Pa	pascal	$= N/m^2$
Standard volume	V_n	$m^3{}_n$	normal cubic meter	
Volume flow	Q_n	$m^3{}_n/s$	normal cubic meter per second	

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Subject to change

Units for flow

Comparison and conversion between different international flow units.

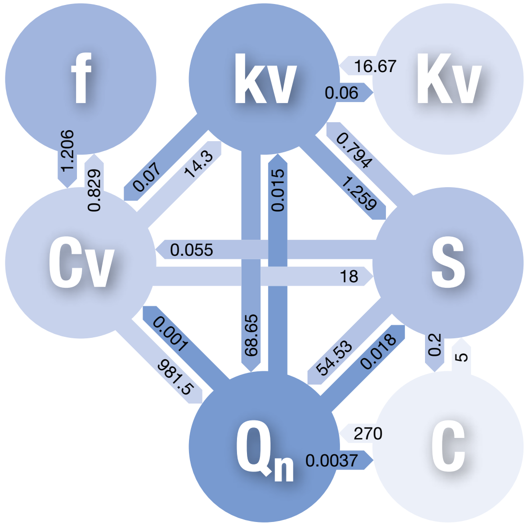
In order to determine if a valve has sufficient output for a given application, requires more than knowing the maximum flow. You must also know how a value is measured in order to use it in the actual case.

A valve flow performance depends not only on the dimensions and geometry of the valve body. The following variables are significant:

- The pressure at the output port
- The pressure drop across the valve
- The relationship between this pressure and the primary pressure
- The temperature

In all cases, based on a data flow performance on the so-called normal volume. It is the volume of air occupied at atmospheric pressure, 20 °C and relative humidity of 65% (normal air). This volume is frequently given in l_n resp Nm^3. Since newton (N) has been introduced as a unit of force, this writing is no longer correct. Since liter is not an SI unit, volume should be given in $dm^3{}_n$, and since that unit is unnecessarily complicated, we have chosen l_n for simplicity.

In the adjacent chart is shown the international use of the units and their interrelationships. The arrows pointing to another unit states the conversion factor.



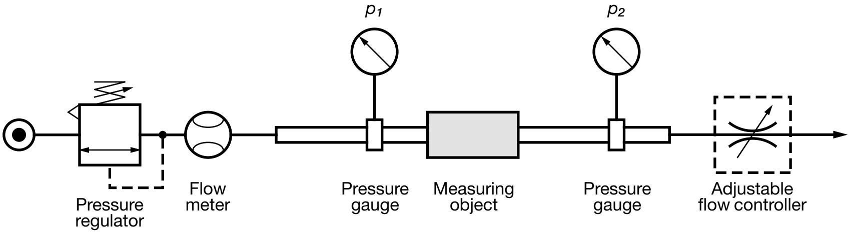
	S mm²	kv dm³/min	Kv m³/h	Cv USG/min	f gal/min	Q_n l_n/min
S	1	0.794	0.048	0.055	0.046	54.53
kv	1.259	1	0.06	0.07	0.058	68.65
Kv	20.979	16.667	1	1.166	1.035	1 144
Cv	18	14.3	0.858	1	0.829	981.5
f	21.7	17.243	0.967	1.206	1	1 184

Q_n – normal flow rate

To roughly indicate flow, volume is currently used, i.e. the flow that the valve is performing at a primary pressure of 6 bar and 1 bar pressure drop across the valve. It is only a rough indication, because the measurement methods and conditions may vary from make to make.

S – equivalent flow area

The value of S in mm^2 is the flow area (holes) in a measuring instrument that provides the same pressure drop as a valve or a system of components at the same output. SMC specifies this value for each component. It is measured with air as a medium and can be converted to other units, such as kv or Cv factor.



C value

C value (conductance) is the unit that ISO and the current standard uses to indicate flow. One way to find out a product's C value is dividing the product's maximum flow rate (Q_n) with the absolute inlet pressure (P1a). The unit is liter/second/bar. $Q_n \approx C \cdot 270$. The factor 270 will vary depending on the product's b value.

b value

A product's b value is obtained by dividing the absolute outlet pressure (P2a) with the absolute inlet pressure (P1a), at the crossing between the upper and lower critical flow. The value is a number less than 1 and is without a unit as it indicates a relationship. The larger the number, the greater the flow. Two products can have the same C value but different b value. This means that the products have the same maximum flow rate (Q_n), but different pressure drops in, for example, half the flow.

kv value

Metric measurements in "normal liters per minute". This measurement is based on measurements of water. When a liter of water each minute passes with a pressure drop of 1 bar is defined q value to 1. There is thus a pure and dimensionless correlation factor.

Kv value

As the kv value above, however, expressed in m^3/h, a measure that meets the SI standard.

Cv factor

As the above value but based on the Anglo-Saxon system of measurement. It is related to US gallons (USG) per minute at a pressure drop of 1 psi (0.07 bar) and a temperature of 60 °F (15.6 °C).

f factor

As Cv factor but in Imperial gallons (gal) per minute.

Dimensioning

Get help to calculate the cylinder size that is best suited for each task.

Cylinder force can be determed by using the table or the following formulas below to calculate the theoretical cylinder power:

$$F = P \cdot A \qquad A = \frac{\pi \cdot d^2}{4}$$

F = force (N)
P = pressure (MPa)
d = cylinder bore (mm)
A = area (mm^2)

At retraction, the force is lower because the rod reduces the available piston area.

Load rating should be around 70% for ordinary cylinder movements and around 50% for slow moving. Check available pressure (as a basic rule, SMC uses the column for 0.5 MPa).

Example: For cylinder force 1 000 N, choose cylinder bore 63 mm: 1 000 (force) ÷ 0.7 (maximum load rate 70%) ≈ 1 428, the next higher cylinder force in the column for 0.5 MPa is 1 559 N corresponding bore 63.

Calculation of theoretical cylinder force

Nominal cylinder bore	Piston rod diameter	Operation	Effective piston area (cm^2)	Pressure (MPa), cylinder force in newton (N)								
				0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
6 mm	3 mm	Extens.	0.28	6	8	11	14	17	20	–	–	–
		Retract.	0.21	4	6	8	11	13	15	–	–	–
10 mm	4 mm	Extens.	0.79	16	24	31	39	47	55	–	–	–
		Retract.	0.66	13	20	26	33	40	46	–	–	–
12 mm	6 mm	Extens.	1.13	23	34	45	57	68	79	90	102	113
		Retract.	0.85	17	25	34	42	51	59	68	76	85
16 mm	6 mm	Extens.	2.01	40	60	80	101	121	141	161	181	201
		Retract.	1.73	35	52	69	86	104	121	138	155	173
20 mm	8 mm	Extens.	3.14	63	94	126	157	188	220	251	283	314
		Retract.	2.64	53	79	106	132	158	185	211	238	264
25 mm	10 mm	Extens.	4.91	98	147	196	245	295	344	393	442	491
		Retract.	4.12	82	124	165	206	247	289	330	371	412
32 mm	12 mm	Extens.	8.04	161	241	322	402	483	563	643	724	804
		Retract.	6.91	138	207	276	346	415	484	553	622	691
40 mm	16 mm	Extens.	12.57	251	377	503	628	754	880	1 005	1 131	1 257
		Retract.	10.56	211	317	422	528	633	739	844	950	1 056
50 mm	20 mm	Extens.	19.63	393	589	785	982	1 178	1 374	1 571	1 767	1 963
		Retract.	16.49	330	495	660	825	990	1 155	1 319	1 484	1 649
63 mm	20 mm	Extens.	31.17	623	935	1 247	1 559	1 870	2 182	2 494	2 806	3 117
		Retract.	28.03	561	841	1 121	1 402	1 682	1 962	2 242	2 523	2 803
80 mm	25 mm	Extens.	50.27	1 005	1 508	2 011	2 514	3 016	3 519	4 022	4 522	5 027
		Retract.	45.36	907	1 361	1 814	2 268	2 722	3 175	3 629	4 082	4 536
100 mm	30 mm	Extens.	78.53	1 571	2 356	3 141	3 927	4 712	5 497	6 282	7 068	7 853
		Retract.	71.47	1 429	2 144	2 859	3 574	4 288	5 003	5 718	6 432	7 147
125 mm	32 mm	Extens.	123	2 450	3 680	4 910	6 150	7 360	8 590	9 820	11 040	12 270
		Retract.	115	2 294	3 441	4 588	5 735	6 882	8 029	9 176	10 323	11 470
140 mm	36 mm	Extens.	154	3 080	4 620	6 160	7 700	9 240	10 800	12 300	13 900	15 400
		Retract.	144	2 880	4 320	5 760	7 200	8 640	10 100	11 500	13 000	14 400
160 mm	40 mm	Extens.	201	4 020	6 030	8 040	10 050	12 060	14 070	16 080	18 100	20 110
		Retract.	189	3 770	5 650	7 540	9 420	11 310	13 190	15 080	16 960	18 850
180 mm	45 mm	Extens.	254	5 080	7 620	10 200	12 700	15 200	17 800	20 300	22 900	25 400
		Retract.	239	4 780	7 170	9 560	12 000	14 300	16 700	19 100	21 500	23 900
200 mm	50 mm	Extens.	314	6 280	9 420	12 600	15 700	18 800	22 000	25 100	28 300	31 400
		Retract.	295	5 900	8 850	11 800	14 800	17 700	20 700	23 600	26 600	29 500
250 mm	60 mm	Extens.	491	9 820	14 700	19 600	24 600	29 500	34 400	39 300	44 200	49 100
		Retract.	463	9 260	13 900	18 500	23 200	27 800	32 400	37 000	41 700	46 300
300 mm	70 mm	Extens.	707	14 100	21 200	28 300	35 400	42 400	49 500	56 600	63 600	70 700
		Retract.	668	13 400	20 000	26 700	33 400	40 100	46 800	53 400	60 100	66 800

Flow in tubing and fittings

A simple quick reference sheet to calculate the air flow in tubes of varying lengths and dimensions.

The table below shows the air flow in the different tube sizes and lengths. The upper value is only the tubing and lower is the tubing with a straight KQ2H fitting at one end and a KQ2L elbow fitting at the other end.

The flow (Q_n) is given in l_n/min. i.e.: IN = 0,6 MPa and OUT = 0,5 MPa.

Tubing (outer/inner diam.)	0.5 m	1 m	3 m	5 m
3.2 mm/2 mm	76	54	35	27
with fittings	61	48	33	26
4 mm/2.5 mm	134	101	61	48
with fittings	98	82	56	45
6 mm/4 mm	424	333	209	165
with fittings	314	272	191	156
8 mm/5 mm	722	581	374	297
with fittings	473	426	321	268
8 mm/6 mm	1 105	906	596	476
with fittings	700	641	498	422
10 mm/8 mm	2 156	1 826	1 251	1 012
with fittings	1 083	1 056	958	879
12 mm/9 mm	2 780	2 387	1 666	1 355
with fittings	1 662	1 565	1 419	1 276

Note! If you choose tubing with the *same* flow as the selected valve, flow is reduced to 71% of valve capacity.

Example: A VZ3000-valve (196 l_n/min) with 3 meters of tube, diameter 6 mm/4 mm (191 l_n/min with fittings), provides a flow of about 140 l_n/min.

Serial connection w. same flow rates	Serial connection w. diff. flow rates	Parallel connection
1 + 1 ⇨ 71%	2 + 1 ⇨ 89%	1 + 1 ⇨ 2
1 + 1 + 1 ⇨ 58%	3 + 1 ⇨ 95%	1 + 2 ⇨ 3
1 + 1 + 1 + 1 ⇨ 50%	4 + 1 ⇨ 97%	1 + 3 ⇨ 4

Example: If two components with the same flow (1) are serially connected, the flow is reduced to 71% of what a component normal has.

Serial connection

$$\frac{1}{S^2} = \frac{1}{S_1^2} + \frac{1}{S_2^2} + \frac{1}{S_n^2}$$

Parallel connection

$$S = S_1 + S_2 + S_n$$

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Subject to change

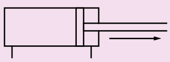
Average air consumption

How to calculate the average air consumption of cylinders and air lines.

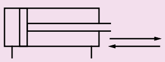
You need to know the average air consumption to determine the compressor size and running cost.

Here we show how to use the charts on this page to calculate the average air consumption of cylinders and air lines.

Single stroke (extension or retraction)



Double stroke = cycle (extension and retraction)



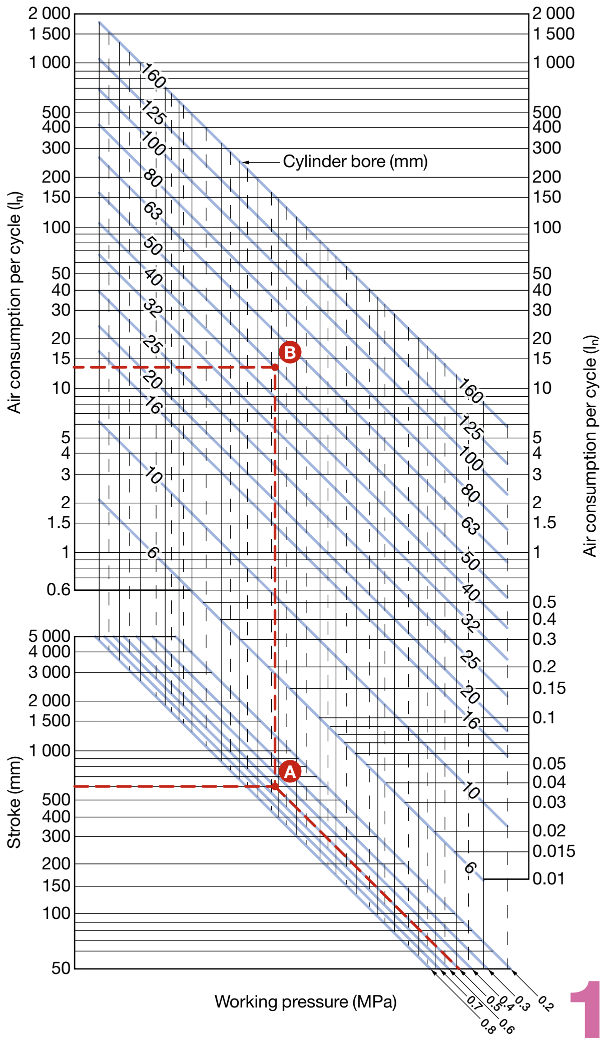
Example:
Cylinder bore: 50 mm
Stroke: 600 mm
Working pressure: 0.5 MPa
Work cycles: 5 cycles per minute
Air tubing inner diameter: 6 mm
Air tubing length: 2 m

Air consumption of cylinder

1. Use chart 1 and find the point where the working pressure line (0.5 MPa) crosses the stroke line (600 mm). See point A.
2. From point A, go straight up until you cross the bore line (50 mm). See point B.
3. From there, go horizontally to the right or the left and find air consumption per cycle (Q_t) = 13 l_n.
4. Since there are five working cycles per minute, multiply the air consumption per cycle (Q_t) with 5 to get the actual average air consumption (Q_v).

$Q_v = Q_t \cdot$ number of cycles per minute
$Q_v = 13\ l_n/min \cdot 5$
$Q_v = 65\ l_n/min$

Chart 1 – cylinder air consumption per cycle



Air consumption for air tubing

5. Use chart 2 and find the point where the working pressure line (0.5 MPa) crosses the line for air tubing length (2 m). See point C.
6. From point C, go straight up until you cross the line for air tubing inner diameter (6 mm). See point D.
7. From there, go horizontally to the right or the left and find air consumption per cycle (Q_t) = 0.56 l_n.
8. Since there are five working cycles per minute, multiply the air consumption per cycle (Q_t) with 5 to get the actual average air consumption (Q_v).

$Q_v = Q_t \cdot$ number of cycles per minute
$Q_v = 0.56\ l_n/\text{min} \cdot 5$
$Q_v = 2.8\ l_n/\text{min}$

Total air consumption

The total average air consumption (Q) for the cylinder and air line is obtained by adding the two Q_v values.

$Q = Q_v$ cylinder + Q_v air tubing
$Q = 65\ l_n/\text{min} + 2.8$ ln/min
$Q = 67.8\ l_n/\text{min}$

Formulas

The average air consumption can also be calculated by the following formulas:

Average air consumption for cylinder

$$Q = \frac{D^2 \cdot \frac{\pi}{4} \cdot H \cdot (p + 0.1) \cdot n}{10^5}$$

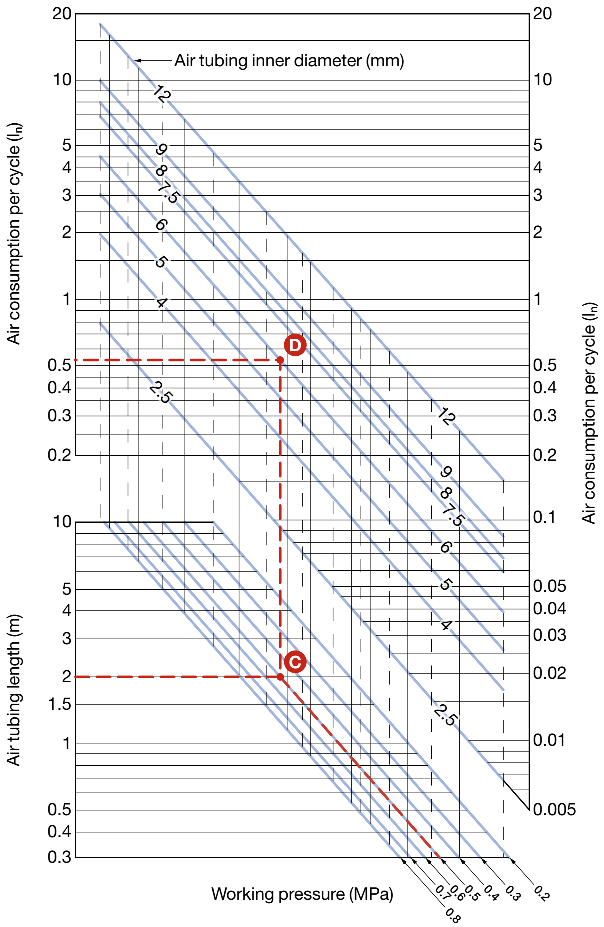
Average air consumption for air tubing

$$Q = \frac{ID^2 \cdot \frac{\pi}{4} \cdot L \cdot p \cdot n}{10^5}$$

Q = Air consumption (l_n/min)
D = Cylinder bore (mm)
H = Stroke (mm)
ID = Air tubing inner diameter (mm)
L = Air tubing length (mm)
p = Working pressure (MPa)
n = Number of single strokes per minute

Air consumption – or flow – indicated in normal liters per minute (l_n/min). 1 normal liter is 1 dm^3 air at "room environment" (normal atmospheric pressure, temperature 20 °C and a relative humidity of 65%).

Chart 2 – air tubing air consumption per cycle



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Maximum air flow

How to calculate the maximum air flow in cylinders and air tubing.

It is necessary to know the maximum air flow in order to determine the size of the FRL, valves, tubings, and more. If the components are too small, the maximum/required cylinder speed is not achieved.

Here we show how to use the chart on this page to calculate the maximum air flow for a cylinder.

Example:
Cylinder bore: 63 mm
Average piston speed: 355 mm/s
Working pressure: 0.6 MPa

Maximum air flow for cylinder

1. Determine the maximum piston speed by multiplying the average speed of 1.41.

   v max = v average· 1.41
   v max = 355 mm/s · 1.41 = 500 mm/s

2. Use chart 3 and find the point where the working pressure line (0.6 MPa) crosses the line for maximum piston speed (500 mm/s). See point E.
3. From point E, go straight up until you cross the cylinder bore line (63 mm). See point F.
4. From point F, go horizontally left or right and find the maximum air flow (Q) = 620 l_n/min.

Formulas

The maximum air flow can also be calculated using the following formulas:

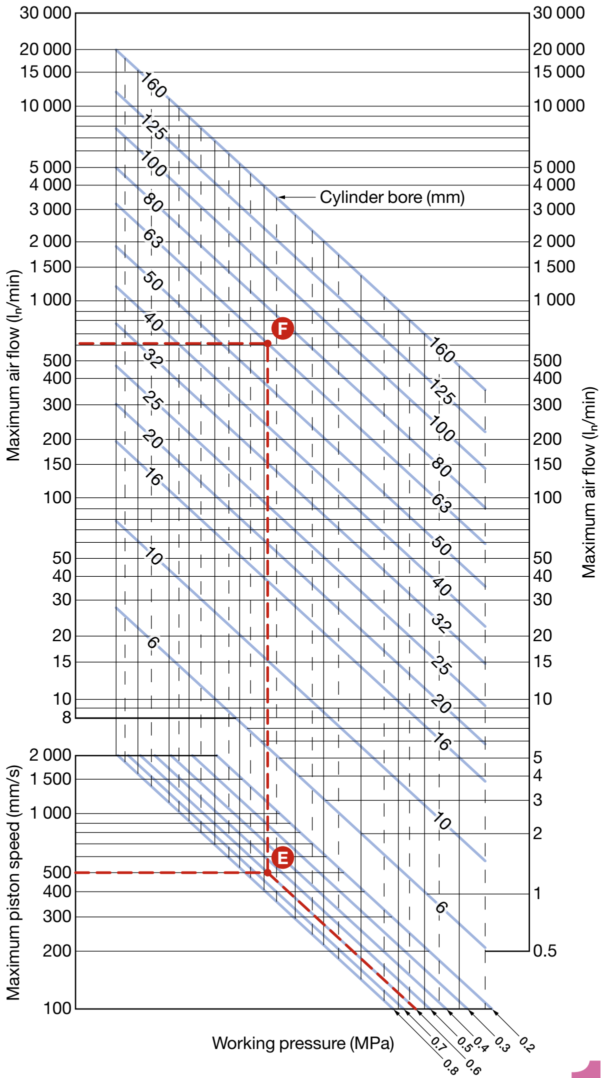
Maximum air flow for cylinder

$$Q = \frac{D^2 \cdot \frac{\pi}{4} \cdot v \cdot (p + 0.1) \cdot 60}{10^5}$$

Maximum air flow for air tubing

$$Q = \frac{ID^2 \cdot \frac{\pi}{4} \cdot v_l \cdot p \cdot 60}{10^5}$$

Chart 3 – cylinder maximum air flow



Q = Air flow (l_n/min)
D = Cylinder bore (mm)
ID = Air tubing inner diameter (mm)
p = Working pressure (MPa)
v = Max. speed = average speed · 1.41 (mm/s)
v_l = Max. speed of air movement in tubing

Subject to change

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Quick selection for choosing right flow

If you do not make an estimate of cylinder air consumption by the methods shown on previous pages, the following speed selection table provide benchmarks for dimensioning.

NThe table below shows the maximum air flow (in normal liters per minute [l_n/min]) a cylinder needs. This value depends on the cylinder piston diameter and operating speed.

The table is applicable at a pressure of 0.5 MPa and the rate used is the maximum speed/end speed.

If you know the average speed and want to know the maximum speed you get a proxy if you multiply the average speed of 1.4.

v max ≈ v average · 1.4

Example:
A cylinder with a bore of 32 mm is moving at max. 300 mm/s. According to the table, the cylinder needs a flow of 90 normal liters per minute.

Should you choose a suitable filter, regulator, valve and tubing you can not select these components with a flow rate of about 90 normal liters per minute. If you do, the pressure drop is too large, and the flow into the cylinder is halved. Any components before the cylinder is like a long chain, producing constrictions and losses.

As a general rule you can say that the pressure drop is max. 0.03 MPa of each component. To get the right flow to the cylinder, each component must handle much more in flow. A rough guideline is that each component shall have four times greater flow than the cylinder needs.

Since 4 · 90 is 360, the filter, the regulator and all the other components should have a flow of about 400 normal liters per minute.

The beginning of chapter 4 contains tables that can also be useful when dimensioning.

Air flow requirement for cylinder – l_n/min, at a pressure of 0.5 MPa

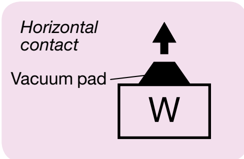
Bore (mm)	Maximum cylinder speed (mm/s)									
	100	200	300	400	500	600	700	800	900	1000
20	10	30	40	50	60	70	80	90	100	120
25	20	40	60	70	90	110	130	140	160	180
32	30	60	90	120	150	180	210	230	260	290
40	50	90	140	180	230	270	320	370	410	460
50	70	140	210	280	360	430	500	570	640	710
63	110	230	340	450	560	680	790	900	1 010	1 130
80	180	360	550	730	910	1 090	1 270	1 450	1 630	1 810
100	290	570	850	1 130	1 420	1 700	1 980	2 260	2 550	2 830
125	440	880	1 320	1 770	2 210	2 650	3 090	3 530	3 970	4 420
140	550	1 110	1 660	2 220	2 770	3 320	3 880	4 430	4 990	5 540
160	720	1 450	2 170	2 890	3 620	4 340	5 060	5 790	6 510	7 230
180	920	1 830	2 750	3 660	4 580	5 490	6 410	7 320	8 240	9 160
200	1 130	2 260	3 390	4 520	5 650	6 780	7 910	9 040	10 170	11 300
250	1 770	3 530	5 300	7 070	8 830	10 600	12 360	14 130	15 900	17 660
300	2 540	5 090	7 630	10 170	12 720	15 260	17 800	20 350	22 890	25 430

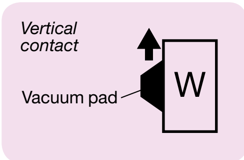
Lifting force of vacuum pads

How to calculate the theoretical lifting force of vacuum pads at different vacuum.

To be able to choose the correct dimensions on the vacuum pads, you should know the different vacuum pads theoretical lifting force at different vacuum levels.

Here we present formulas and a table that you can use as a basis for your calculations.





Formulas

Vacuum in kPa

$$F = P \cdot A \cdot \frac{1}{t} \div 10$$

P = Vacuum (kPa)

Vacuum in mmHg

$$F = P \div 760 \cdot A \cdot \frac{1}{t} \cdot 10.13$$

P = Vacuum (mmHg)

F = Lifting force with safety factor (N)
A = Pad area (cm^2)
t = Safety factor (horizontal contact surface: 2–4; vertical contact surface: 4–8)

As a complement to these formulas, you can find the lifting force at different vacuum in the table below.

Note! The values you get from the table should be multiplied by $\frac{1}{t}$ as in the above formulas.

Calculation of theoretical lifting force

Vacuum pad diameter			2 mm	4 mm	6 mm	10 mm	16 mm	20 mm	25 mm	32 mm	40 mm	50 mm
Vacuum pad area (cm^2)			0.031	0.126	0.238	0.785	2.01	3.14	4.91	8.04	12.6	19.6
Vacuum	–86 kPa	–650 mmHg	0.27 N	1.09 N	2.45 N	6.8 N	17.4 N	27.2 N	42.5 N	69.7 N	109.2 N	169.8 N
	–80 kPa	–600 mmHg	0.25 N	0.98 N	2.26 N	6.3 N	16.1 N	25.1 N	39.3 N	64.3 N	100.8 N	156.7 N
	–73 kPa	–550 mmHg	0.23 N	0.92 N	2.07 N	5.8 N	14.7 N	23 N	36 N	58.9 N	92.4 N	143.7 N
	–66 kPa	–500 mmHg	0.21 N	0.84 N	1.89 N	5.2 N	13.4 N	20.9 N	32.7 N	53.6 N	84 N	130.6 N
	–60 kPa	–450 mmHg	0.19 N	0.76 N	1.7 N	4.7 N	12.1 N	18.8 N	29.5 N	48.2 N	75.6 N	117.6 N
	–53 kPa	–400 mmHg	0.17 N	0.67 N	1.51 N	4.2 N	10.7 N	16.7 N	26.2 N	42.9 N	67.2 N	104.5 N
	–46 kPa	–350 mmHg	0.14 N	0.59 N	1.32 N	3.7 N	9.4 N	14.6 N	22.9 N	37.5 N	58.8 N	91.5 N
	–40 kPa	–300 mmHg	0.12 N	0.5 N	1.13 N	3.14 N	8 N	12.6 N	16.9 N	32.1 N	50.4 N	78.4 N

100 kPa = 0.1 MPa = 1 bar = 1 000 mbar

Evacuation time of vacuum pads

How to calculate evacuation time for vacuum pads, and choosing ejector and tubing.

Here we show, using formulas and charts, how to calculate how long it takes for a vacuum pad to achieve the desired vacuum level.

Calculation of evacuation time

Average suction flow in ejector

$$Q_1 = 0.4 \cdot Q_{max}$$

Tubing maximum flow

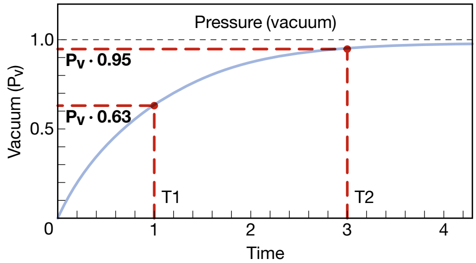
$$Q_2 = S \cdot 11.1$$

Tubing volume between ejector and vacuum pad

$$V = 1 \div 1\,000 \cdot \pi \div 4 \cdot D^2 \cdot L$$

Evacuation time

$$T1 = V \cdot 60 \div Q$$
$$T2 = 3 \cdot T1$$



Q_{max} = Ejector's maximum suction flow (l/min), see the technical data

S = Tubing equivalent cross-sectional area (mm²), see chart 4

V = Tubing volume (l) between ejector and vacuum pad

T1 = Time (s) to reach 63% of maximum vacuum level (P_V)

T2 = Time (s) to reach 95% of maximum vacuum level (P_V)

Q = The lowest of Q_1 and Q_2

Example:
Ejector: ZH10BS-06-06
Max. vacuum (P_V): –88 kPa
Max. suction flow (Q_{max}): 24 l/min
Tubing length (L): 1 m
Tubing inner diameter (D): 6 mm
Vacuum pad diameter: 10 mm
Necessary vacuum: 63% of P_V, no leakage

1. Calculate ejector's average suction flow (Q_1) by multiplying the maximum suction flow by 0.4.

   $Q_1 = 0.4 \cdot 24$ l/min $= 9.6$ l/min

2. Calculate maximum tubing flow (Q_2) by finding the tubing's equivalent cross-sectional area (S) in chart 4 and multiplying this by 11.1.

   $Q_2 = 18 \cdot 11.1 = 198$ l/min

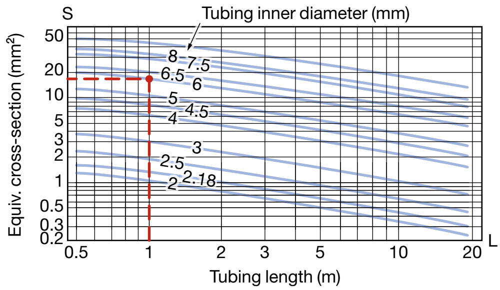
3. Calculate tubing volume between ejector and pad.

   $V = 1 \div 1\,000 \cdot \pi \div 4 \cdot 6^2 \cdot 1 = 0.028$ l

4. Calculate evacuation time. Since Q_1 is lower than Q_2 this means $Q = Q_1$ i.e. 9.6 l/min. The time to reach 63 % of max. vacuum equals:

   $T1 = 0.028 \cdot 60 \div 9.6 = 0.18$ s

Chart 4 – tubing equivalent cross-sectional area



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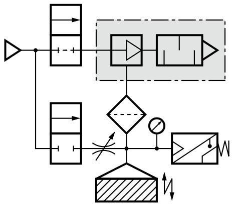
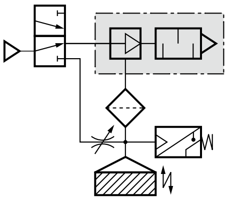
Subject to change

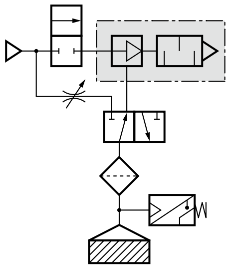
Connection examples



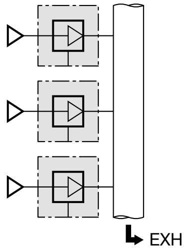
Individual control of ejector and release



Switching between vacuum and release



Switching between vacuum and release – on suction side



Common exhaust

Instructions

Supply connection (supply): Dimension supply line, valves and connections considering the ejector's air consumption (see technical data).

Vacuum ejector (vac): the tubing between ejector and vacuum pad should be as short as possible. Filters should be installed for use in dusty environment (dust).

Ejector exhaust connection (exh): *Type B* – do not block the silencer. *Type D* – do not connect longer tubing that 0.5 meter (= pressure < 5 kPa).

Number of vacuum pads: One vacuum pad per ejector for maximum safety.

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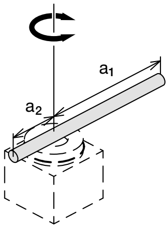
Mass moment of inertia

When dimensioning a rotary actuator you must, in addition to necessary torque, also consider the load's mass moment of inertia. For your aid, please find the formulas below (dimensions in meters).

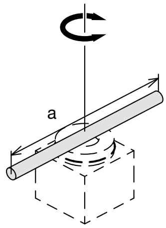
1. Thin axle, excentrically suspended

$$J = m_1 \cdot \frac{a_1^2}{3} + m_2 \cdot \frac{a_2^2}{3}$$



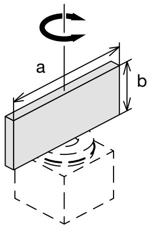
2. Thin axle, centered suspension

$$J = m \cdot \frac{a^2}{12}$$



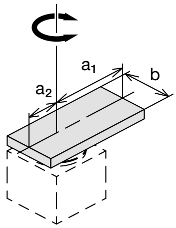
3. Thin rectangular plate, on edge and centered

$$J = m \cdot \frac{a^2}{12}$$



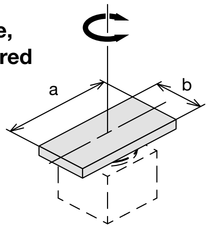
4. Thin rectangular plate, lying down and excentrically suspended

$$J = m_1 \cdot \frac{4a_1^2 + b^2}{12} + m_2 \cdot \frac{4a_2^2 + b^2}{12}$$



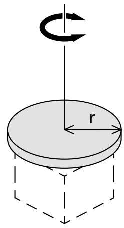
5. Thin rectangular plate, lying down and centered

$$J = m \cdot \frac{a^2 + b^2}{12}$$



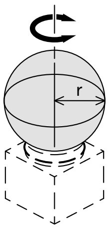
6. Thin disc, lying down and centered

$$J = m \cdot \frac{r^2}{2}$$



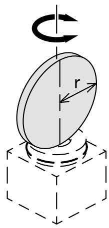
7. Sphere (ball), centered

$$J = m \cdot \frac{2r^2}{5}$$



8. Thin disc, on edge and centered

$$J = m \cdot \frac{r^2}{4}$$



9. Thin axle with mass

$$J = m_1 \cdot \frac{a_1^2}{3} + m_2 \cdot a_2^2 + K$$

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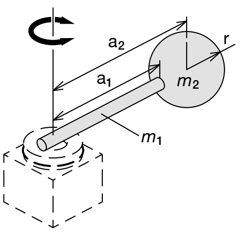
When m_2 is spherical, K equals, as in case 7:

$$K = m \cdot \frac{2r^2}{5}$$

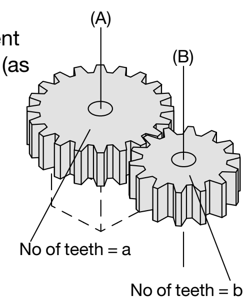


If the axle is carrying a disc, calculate K as in case 6 or 8.

10. Transmission

First calculate mass moment of inertia for gears A and B (as in case 6) and then:

$$J = (\frac{a}{b})^2 J_B + J_B$$



Subject to change