SI units, symbols and dimensioning
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Subject to change

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
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

<table>
<thead>
<tr>
<th>Thread designation</th>
<th>Outside diameter</th>
<th>Inside diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>M3</td>
<td>3 mm</td>
<td>2.3 mm</td>
</tr>
<tr>
<td>M5</td>
<td>5 mm</td>
<td>4.2 mm</td>
</tr>
<tr>
<td>1/8&quot; 01</td>
<td>R6</td>
<td>9.7 mm</td>
</tr>
<tr>
<td>1/4&quot; 02</td>
<td>R8</td>
<td>13.2 mm</td>
</tr>
<tr>
<td>3/8&quot; 03</td>
<td>R10</td>
<td>16.7 mm</td>
</tr>
<tr>
<td>1/2&quot; 04</td>
<td>R15</td>
<td>21 mm</td>
</tr>
<tr>
<td>3/4&quot; 06</td>
<td>R20</td>
<td>26.4 mm</td>
</tr>
<tr>
<td>1&quot; 10</td>
<td>R25</td>
<td>33.2 mm</td>
</tr>
<tr>
<td>1 1/4&quot; 12</td>
<td>R32</td>
<td>41.9 mm</td>
</tr>
<tr>
<td>1 1/2&quot; 14</td>
<td>R40</td>
<td>47.8 mm</td>
</tr>
<tr>
<td>2&quot; 20</td>
<td>R50</td>
<td>59.6 mm</td>
</tr>
</tbody>
</table>

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.
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.

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”.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit symbol</th>
<th>Unit name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>m</td>
<td>kg</td>
<td>kilogram</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>s</td>
<td>m</td>
<td>meter</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>t</td>
<td>s</td>
<td>second</td>
<td></td>
</tr>
<tr>
<td>Derived units</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>A</td>
<td>m²</td>
<td>square meter</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>V</td>
<td>m³</td>
<td>cubic meter</td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>v</td>
<td>m/s</td>
<td>meter per second</td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td>a</td>
<td>m/s²</td>
<td>meter per second squared</td>
<td></td>
</tr>
<tr>
<td>Inertia</td>
<td>J</td>
<td>kgm²</td>
<td>kilogram square meter</td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td>F</td>
<td>N</td>
<td>newton</td>
<td>= kg · m/s²</td>
</tr>
<tr>
<td>Weight</td>
<td>G</td>
<td>N</td>
<td>newton</td>
<td>= kg · 9.82</td>
</tr>
<tr>
<td>Energy (work)</td>
<td>W</td>
<td>J</td>
<td>joule (= newtonmeter)</td>
<td>= kg · m²/s²</td>
</tr>
<tr>
<td>Moment</td>
<td>M</td>
<td>Nm</td>
<td>newtonmeter</td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>P</td>
<td>W</td>
<td>watt</td>
<td>= J/s = Nm/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit symbol</th>
<th>Unit name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>p</td>
<td>Pa</td>
<td>pascal</td>
<td>= N/m²</td>
</tr>
<tr>
<td>Standard volume</td>
<td>V₀</td>
<td>m³</td>
<td>normal cubic meter</td>
<td></td>
</tr>
<tr>
<td>Volume flow</td>
<td>Q₀</td>
<td>m³/s</td>
<td>normal cubic meter per second</td>
<td></td>
</tr>
</tbody>
</table>
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\(^3\), 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.

### 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 \(P_{1a}\). The unit is liter/second/bar. \(Q_n = C \cdot 270\). 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 \(P_{2a}\) with the absolute inlet pressure \(P_{1a}\), 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 \(\text{m}^3/\text{h}\), 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.
<table>
<thead>
<tr>
<th>Diameter</th>
<th>Pressure (MPa)</th>
<th>Cylinder Bore (mm)</th>
<th>Effective Piston Area (cm²)</th>
<th>Cylindrical Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mm</td>
<td>0.2</td>
<td>6.2</td>
<td>11.9</td>
<td>1,000 (force) ÷ 0.7 (max load rate) ≈ 1,428, next higher column for 0.5 MPa is 1,559 corresponding bore 63.</td>
</tr>
<tr>
<td>32 mm</td>
<td>0.2</td>
<td>6.6</td>
<td>12.5</td>
<td>1,000 (force) ÷ 0.7 (max load rate) ≈ 1,428, next higher column for 0.5 MPa is 1,559 corresponding bore 63.</td>
</tr>
<tr>
<td>35 mm</td>
<td>0.2</td>
<td>7.0</td>
<td>13.1</td>
<td>1,000 (force) ÷ 0.7 (max load rate) ≈ 1,428, next higher column for 0.5 MPa is 1,559 corresponding bore 63.</td>
</tr>
<tr>
<td>38 mm</td>
<td>0.2</td>
<td>7.4</td>
<td>13.7</td>
<td>1,000 (force) ÷ 0.7 (max load rate) ≈ 1,428, next higher column for 0.5 MPa is 1,559 corresponding bore 63.</td>
</tr>
<tr>
<td>40 mm</td>
<td>0.2</td>
<td>7.8</td>
<td>14.2</td>
<td>1,000 (force) ÷ 0.7 (max load rate) ≈ 1,428, next higher column for 0.5 MPa is 1,559 corresponding bore 63.</td>
</tr>
</tbody>
</table>

Cylinder force can be determined using the following formulas below to calculate the theoretical cylinder power:

\[ F = P \cdot \frac{A}{\pi \cdot d^2} \]

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.

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

<table>
<thead>
<tr>
<th>Tubing (outer/inner diam.)</th>
<th>0.5 m</th>
<th>1 m</th>
<th>3 m</th>
<th>5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 mm/2 mm</td>
<td>76</td>
<td>54</td>
<td>35</td>
<td>27</td>
</tr>
<tr>
<td>with fittings</td>
<td>61</td>
<td>48</td>
<td>33</td>
<td>26</td>
</tr>
<tr>
<td>4 mm/2.5 mm</td>
<td>134</td>
<td>101</td>
<td>61</td>
<td>48</td>
</tr>
<tr>
<td>with fittings</td>
<td>98</td>
<td>82</td>
<td>56</td>
<td>45</td>
</tr>
<tr>
<td>6 mm/4 mm</td>
<td>424</td>
<td>333</td>
<td>209</td>
<td>165</td>
</tr>
<tr>
<td>with fittings</td>
<td>314</td>
<td>272</td>
<td>191</td>
<td>156</td>
</tr>
<tr>
<td>8 mm/5 mm</td>
<td>722</td>
<td>581</td>
<td>374</td>
<td>297</td>
</tr>
<tr>
<td>with fittings</td>
<td>473</td>
<td>426</td>
<td>321</td>
<td>268</td>
</tr>
<tr>
<td>8 mm/6 mm</td>
<td>1105</td>
<td>906</td>
<td>596</td>
<td>476</td>
</tr>
<tr>
<td>with fittings</td>
<td>700</td>
<td>641</td>
<td>498</td>
<td>422</td>
</tr>
<tr>
<td>10 mm/8 mm</td>
<td>2156</td>
<td>1826</td>
<td>1251</td>
<td>1012</td>
</tr>
<tr>
<td>with fittings</td>
<td>1083</td>
<td>1056</td>
<td>958</td>
<td>879</td>
</tr>
<tr>
<td>12 mm/9 mm</td>
<td>2780</td>
<td>2387</td>
<td>1666</td>
<td>1355</td>
</tr>
<tr>
<td>with fittings</td>
<td>1662</td>
<td>1565</td>
<td>1419</td>
<td>1276</td>
</tr>
</tbody>
</table>

**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

$$\frac{1}{S_T} = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_n}$$

Parallel connection

$$S = S_1 + S_2 + S_n$$
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.

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 \(Q_t = 13 \text{ l/h}\).
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 \(Q_v\).

\[Q_v = Q_t \cdot \text{number of cycles per minute}\]
\[Q_v = 13 \text{ l/h} \cdot 5\]
\[Q_v = 65 \text{ l/h}\]
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 \(Q_t\) with 5 to get the actual average air consumption \(Q_v\).

\[
Q_v = Q_t \cdot \text{number of cycles per minute} \\
Q_v = 0.56 \text{ l/min} \cdot 5 \\
Q_v = 2.8 \text{ l/min}
\]

Total air consumption

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

\[
Q = Q_v \text{ cylinder} + Q_v \text{ air tubing} \\
Q = 65 \text{ l/min} + 2.8 \text{ l/min} \\
Q = 67.8 \text{ l/min}
\]

Formulas

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

**Average air consumption for cylinder**

\[
Q = \frac{\pi D^2 \cdot 4 \cdot H \cdot (p + 0.1) \cdot n}{10^6}
\]

**Average air consumption for air tubing**

\[
Q = \frac{\pi ID^2 \cdot 4 \cdot L \cdot p \cdot n}{10^6}
\]

\(Q\) = Air consumption (l/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/min).

1 normal liter is 1 dm³ air at “room environment” (normal atmospheric pressure, temperature 20 °C and a relative humidity of 65%).
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.

\[ v_{\text{max}} = v_{\text{average}} \cdot 1.41 \]
\[ v_{\text{max}} = 355 \text{ mm/s} \cdot 1.41 = 500 \text{ mm/s} \]

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/min.

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

**Maximum air flow for cylinder**
\[ Q = \frac{\pi D^2 \cdot 4 \cdot v_{\text{max}} \cdot (p + 0.1) \cdot 60}{10^6} \]

**Maximum air flow for air tubing**
\[ Q = \frac{\pi ID^2 \cdot 4 \cdot v_l \cdot p \cdot 60}{10^6} \]

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

The 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.

\[ v_{\text{max}} = v_{\text{average}} \cdot 1.4 \]

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.

<table>
<thead>
<tr>
<th>Bore (mm)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
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<td>360</td>
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<td>22890</td>
<td>25430</td>
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</tbody>
</table>

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

\[ F = P \cdot A \cdot \frac{1}{t} ÷ 10 \]

\[ F = P ÷ 760 \cdot A \cdot \frac{1}{t} \cdot 10.13 \]

\( P = \) Vacuum (kPa)

\( P = \) 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

<table>
<thead>
<tr>
<th>Vacuum pad diameter (cm)</th>
<th>2 mm</th>
<th>4 mm</th>
<th>6 mm</th>
<th>8 mm</th>
<th>10 mm</th>
<th>12 mm</th>
<th>16 mm</th>
<th>20 mm</th>
<th>25 mm</th>
<th>32 mm</th>
<th>40 mm</th>
<th>50 mm</th>
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</thead>
<tbody>
<tr>
<td>–86 kPa –650 mmHg</td>
<td>0.27 N</td>
<td>1.09 N</td>
<td>2.45 N</td>
<td>6.8 N</td>
<td>17.4 N</td>
<td>27.2 N</td>
<td>42.5 N</td>
<td>69.7 N</td>
<td>109.2 N</td>
<td>169.8 N</td>
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<td></td>
</tr>
<tr>
<td>–80 kPa –600 mmHg</td>
<td>0.25 N</td>
<td>0.98 N</td>
<td>2.26 N</td>
<td>6.3 N</td>
<td>16.1 N</td>
<td>25.1 N</td>
<td>39.3 N</td>
<td>64.3 N</td>
<td>100.8 N</td>
<td>156.7 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>–73 kPa –550 mmHg</td>
<td>0.23 N</td>
<td>0.92 N</td>
<td>2.07 N</td>
<td>5.8 N</td>
<td>14.7 N</td>
<td>23 N</td>
<td>36 N</td>
<td>58.9 N</td>
<td>92.4 N</td>
<td>143.7 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>–66 kPa –500 mmHg</td>
<td>0.21 N</td>
<td>0.84 N</td>
<td>1.89 N</td>
<td>5.2 N</td>
<td>13.4 N</td>
<td>20.9 N</td>
<td>32.7 N</td>
<td>53.6 N</td>
<td>84 N</td>
<td>130.6 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>–60 kPa –450 mmHg</td>
<td>0.19 N</td>
<td>0.76 N</td>
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<td>117.6 N</td>
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<tr>
<td>–53 kPa –400 mmHg</td>
<td>0.17 N</td>
<td>0.67 N</td>
<td>1.51 N</td>
<td>4.2 N</td>
<td>10.7 N</td>
<td>16.7 N</td>
<td>26.2 N</td>
<td>42.9 N</td>
<td>67.2 N</td>
<td>104.5 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>–46 kPa –350 mmHg</td>
<td>0.14 N</td>
<td>0.59 N</td>
<td>1.32 N</td>
<td>3.7 N</td>
<td>9.4 N</td>
<td>14.6 N</td>
<td>22.9 N</td>
<td>37.5 N</td>
<td>58.8 N</td>
<td>91.5 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>–40 kPa –300 mmHg</td>
<td>0.12 N</td>
<td>0.5 N</td>
<td>1.13 N</td>
<td>3.14 N</td>
<td>8 N</td>
<td>12.6 N</td>
<td>16.9 N</td>
<td>32.1 N</td>
<td>50.4 N</td>
<td>78.4 N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

100 kPa = 0.1 MPa = 1 bar = 1000 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**

\[ Q_1 = 0.4 \cdot Q_{\text{max}} \]

**Tubing maximum flow**

\[ Q_2 = S \cdot 11.1 \]

**Tubing volume between ejector and vacuum pad**

\[ V = \frac{1}{1000} \cdot \pi \cdot \frac{4 \cdot D^2}{4} \cdot L \]

**Evacuation time**

\[ T_1 = \frac{V}{Q_1} \cdot 60 \]
\[ T_2 = 3 \cdot T_1 \]

**Example:**

Ejector: ZH10BS-06-06

Max. vacuum (P_V): –88 kPa

Max. suction flow (Q_{\text{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.

\[ Q_1 = 0.4 \cdot 24 \text{ l/min} = 9.6 \text{ l/min} \]

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.

\[ Q_2 = 18 \cdot 11.1 = 198 \text{ l/min} \]

3. Calculate tubing volume between ejector and pad.

\[ V = \frac{1}{1000} \cdot \pi \cdot \frac{4 \cdot 6^2}{4} \cdot 1 = 0.028 \text{ l} \]

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:

\[ T_1 = 0.028 \cdot 60 \div 9.6 = 0.18 \text{ s} \]

**Chart 4** – tubing equivalent cross-sectional area

<table>
<thead>
<tr>
<th>Tubing inner diameter (mm)</th>
<th>Equiv. cross-section (mm²)</th>
<th>Tubing length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>3.5</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
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<td>5.5</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
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<td>7</td>
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<td>7.5</td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

Subject to change
Connection examples

![Diagram of connection examples](image)

### 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.
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
   \[ J = m_1 \cdot \frac{a_1^2}{3} + m_2 \cdot a_2^2 + K \]
   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:
    \[ J = \left( \frac{a}{b} \right)^2 J_B + J_B \]