Pneumatics and Hydraulics

Pneumatic actuators part 2

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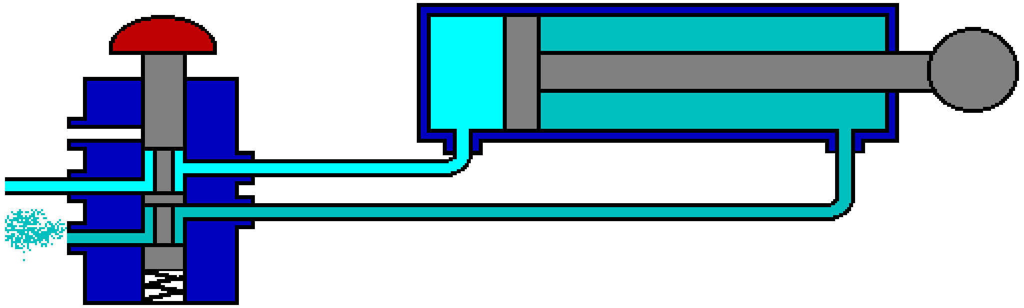
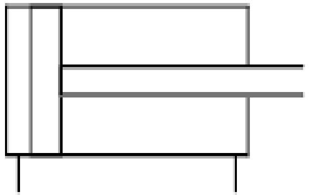
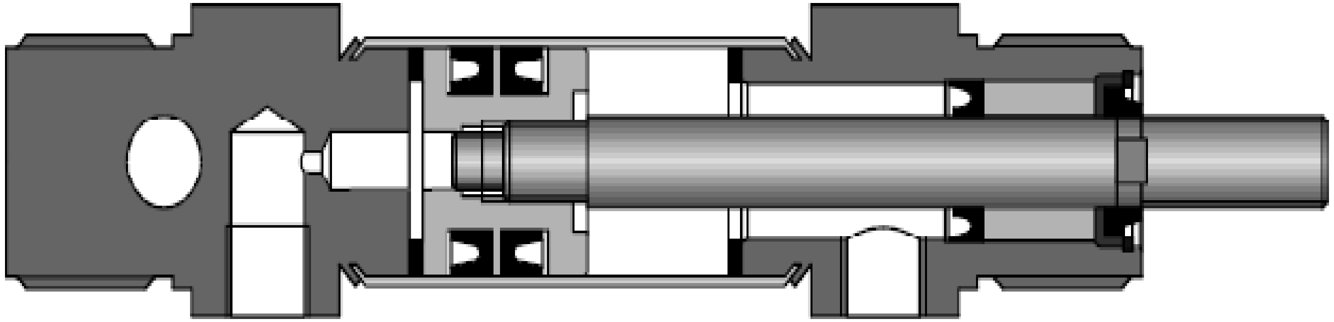
Double-acting cylinders

- The construction principle of a double-acting cylinder is similar to that of the single-acting cylinder. However, there is no return spring, and the two ports are used alternatively as supply and exhaust ports.
- The double-acting cylinder has the advantage that the cylinder is able to carry out work in both directions of motion. Thus, installation possibilities are universal.
- The force transferred by the piston rod is somewhat greater for the forward stroke than for the return stroke as the effective piston surface is reduced on the piston rod side by the cross-sectional area of the piston rod.

Double-acting cylinder







Design development

Pneumatic cylinders have developed in the following directions:

- Contactless sensing requirements, hence the use of magnets on pistons for reed switch operation.
- Stopping heavy loads
- Rodless cylinders where space is limited
- Alternative manufacturing materials such as plastic
- Protective coatings against harsh environments, i.e. acid-resistant
- Increased load carrying capacity
- Robotic applications with special features such as non-rotating piston rods, hollow piston rods for vacuum suction cups

Cylinder with end position cushioning

- If large masses are moved by a cylinder, cushioning is used in the end positions to prevent sudden damaging impacts.

- Before reaching the end position, a cushioning piston interrupts the direct flow path of the air to the outside. Instead a very small and often adjustable exhaust aperture is open.

- For the last part of the stroke the cylinder speed is progressively reduced. If the passage adjustment is too small, the cylinder may not reach the end position due to the blockage of air.

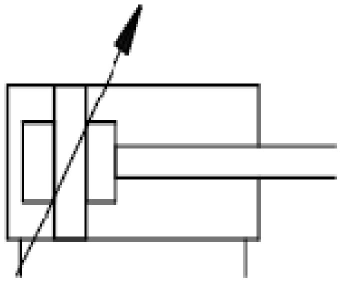
Cylinder with end position cushioning

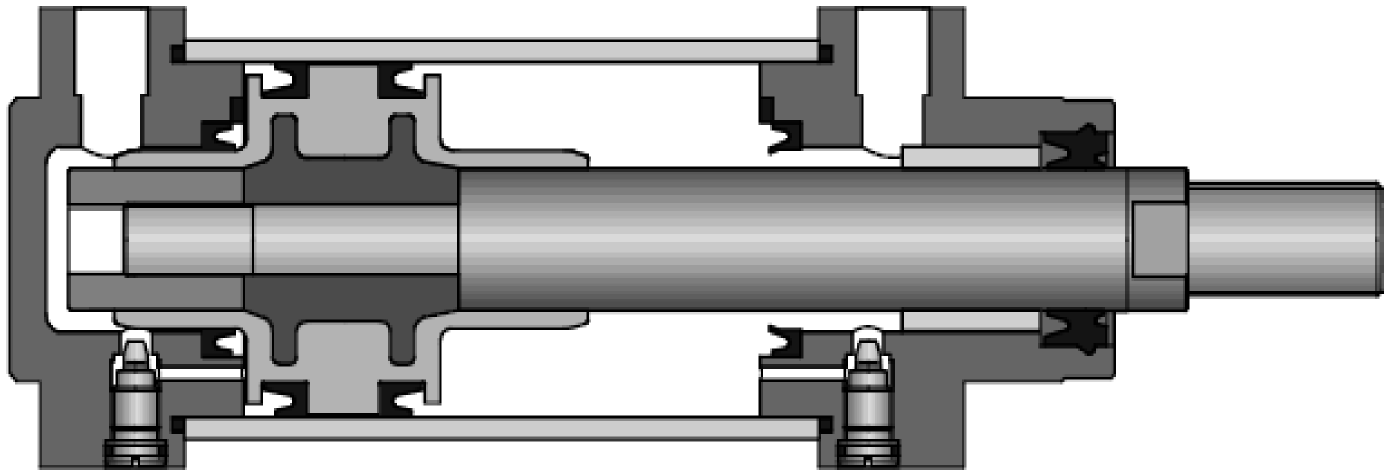
- With very large forces and high accelerations extra measures must be taken such as external shock absorbers to assist the load deceleration.

To achieve correct deceleration:

- the regulating screw should first be screwed in fully and backed off in order to allow the adjustment to be increased slowly to the optimum value.

Double-acting cylinder with end position cushioning





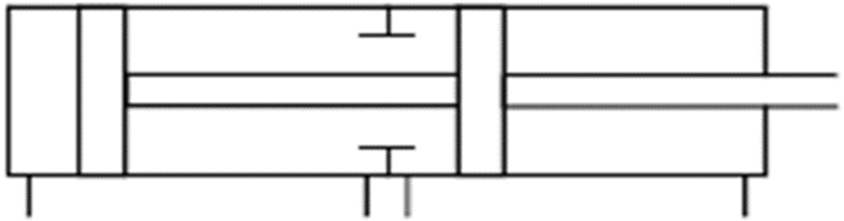
Tandem double-acting cylinder

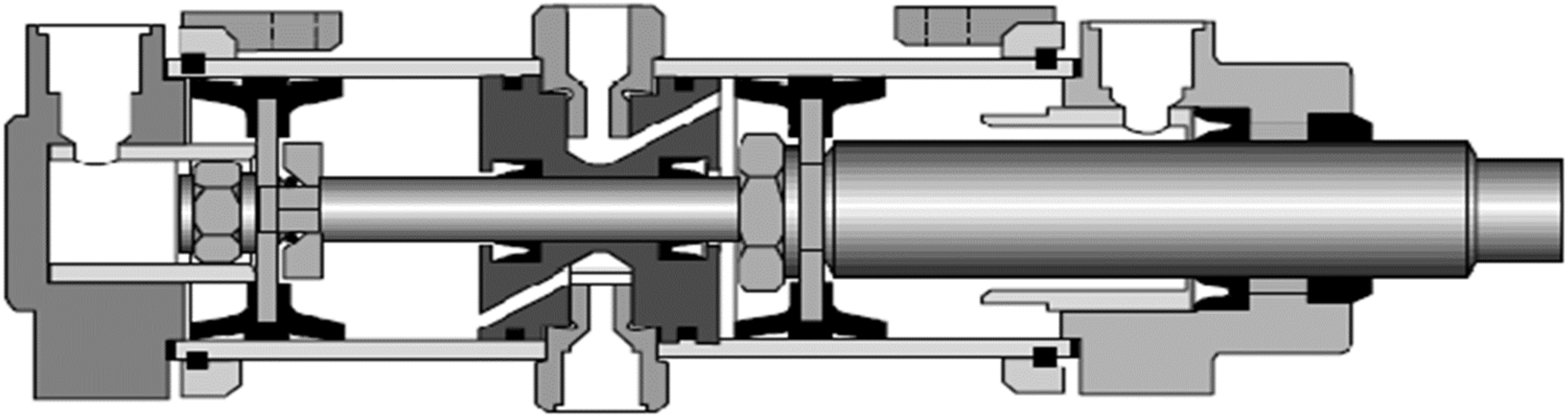
- The tandem cylinder incorporates the features of two double-acting cylinders which have been joined to form a single unit.

- By this arrangement and with the simultaneous loading of both pistons, the force on the piston rod is almost doubled.

- This design is suitable for such applications where a large force is required but the cylinder diameter is restricted.

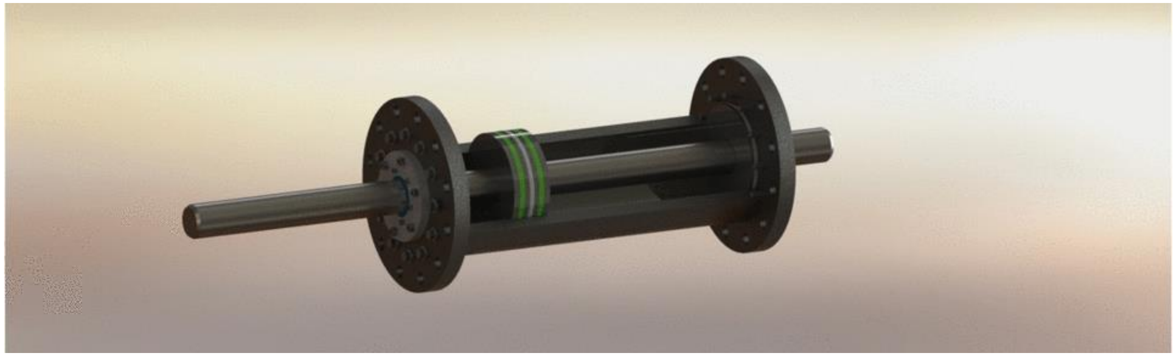
Tandem double-acting cylinder



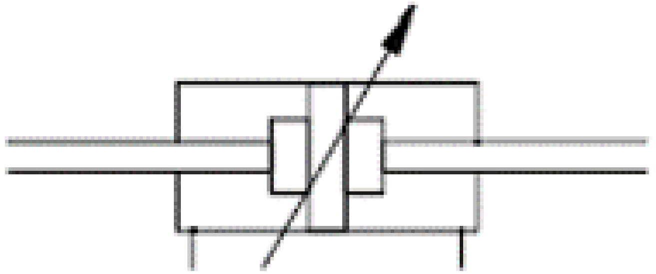


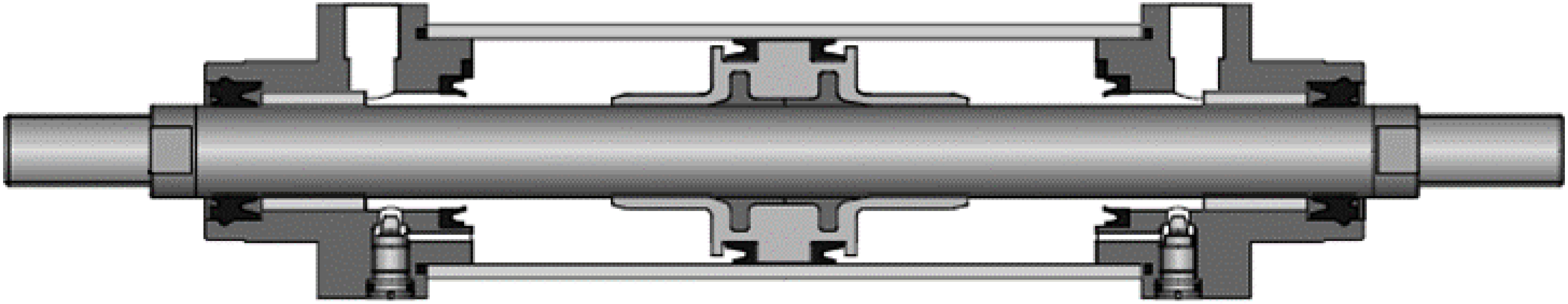
Cylinders with through piston rod

- This cylinder has a piston rod on both sides, which is a through piston rod.
- The guide of the piston rod is better, as there are two bearing points.
- The force is identical in both directions of movement.
- The through piston rod can be hollow, in which case it can be used to conduct various media, such as compressed air.
- A vacuum connection is also possible.



Cylinders with through piston rod





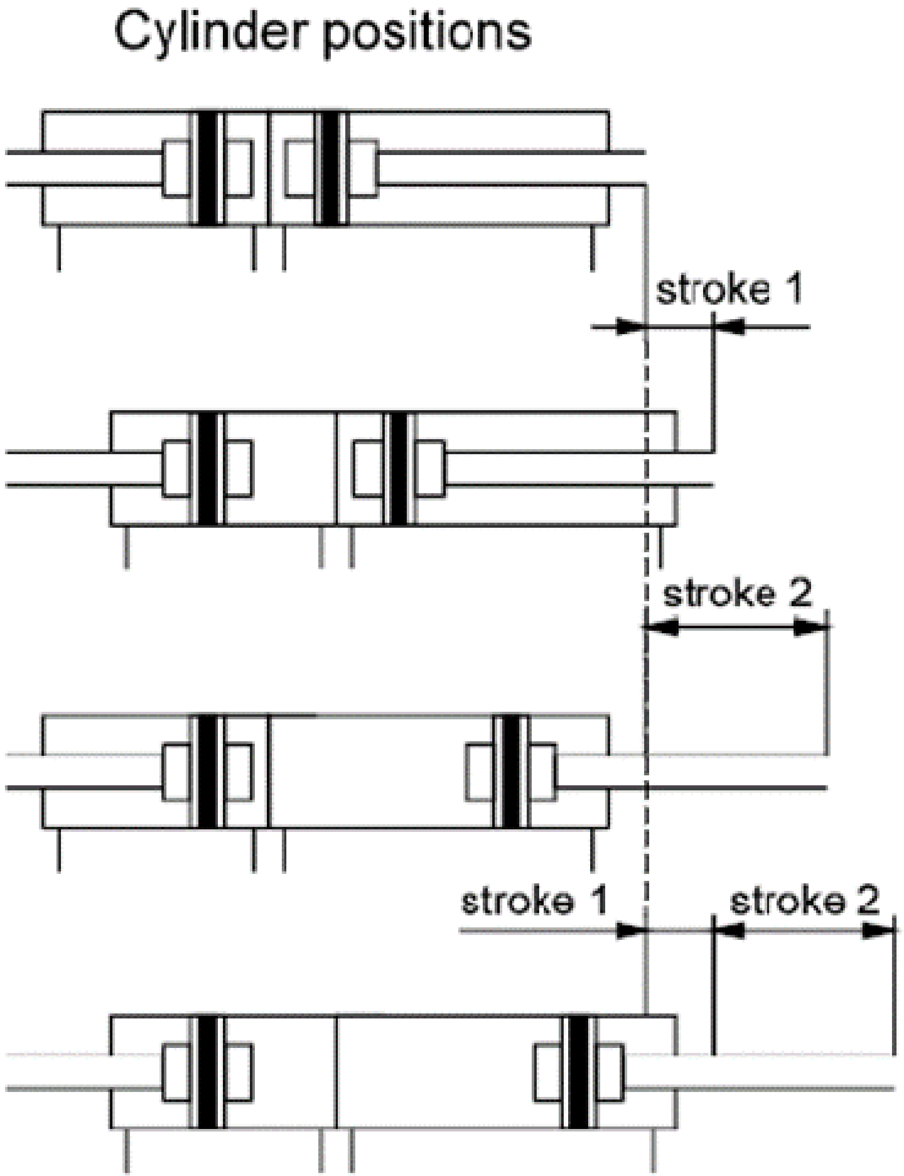
Multi-position cylinders

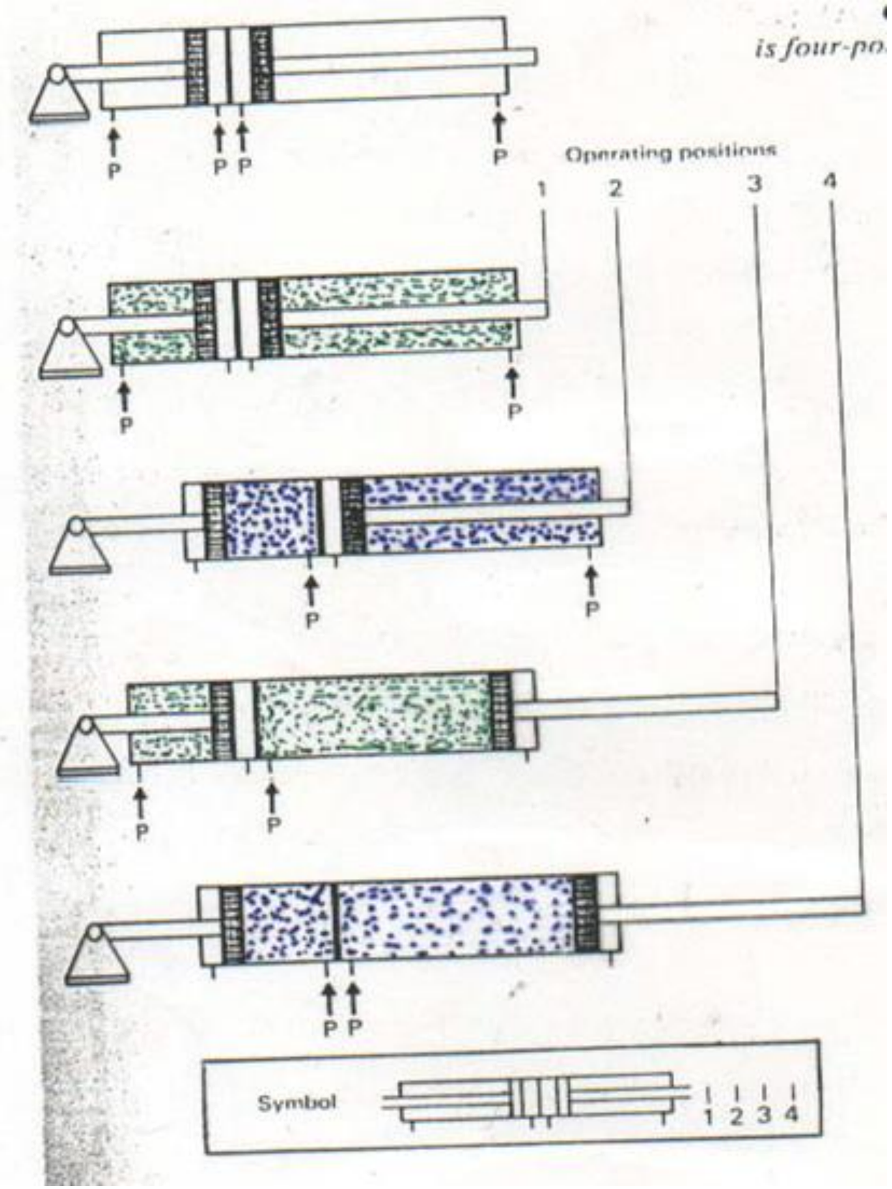
- The Multi-position cylinder consists of two or several double-acting cylinders, which are interconnected.

- The individual cylinders advance when pressure is applied.

- In the case of two cylinders with different stroke lengths, four positions are obtained.

Multi-position cylinders



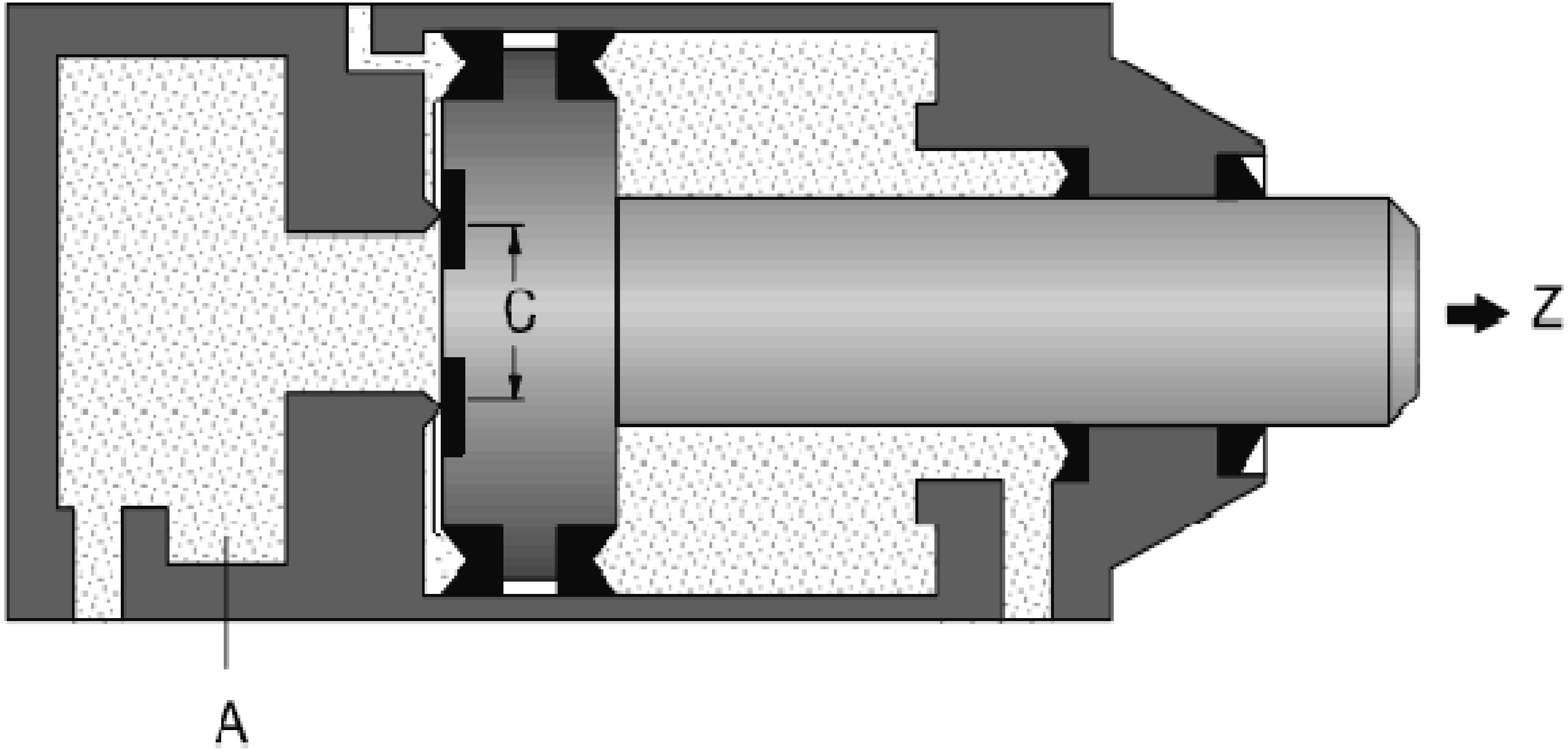


Impact cylinders

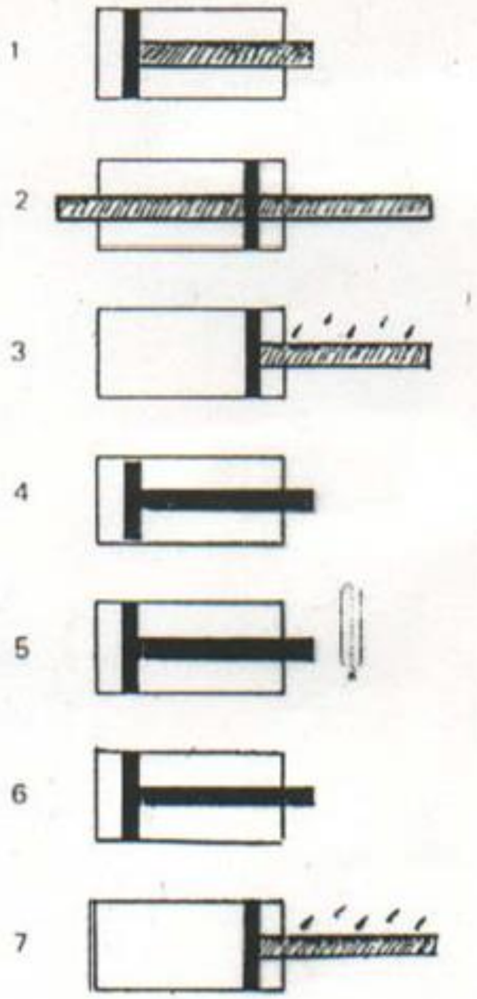
$e_k = \frac{1}{2} m v^2$

- The pressure forces of pneumatic cylinders are limited. One cylinder for high kinetic energy is the impact cylinder.
- The high kinetic energy is achieved by means of increasing the piston speed. The piston speed of the impact cylinder is between 7.5 m/s and 10 m/s.
- However, in the case of large forming distances, the speed is rapidly reduced. The impact cylinder is therefore not suitable for large forming distances.
- Actuation of a valve causes pressure to build up in chamber A. If the cylinder moves in direction Z, the full piston surface is exposed. The air from chamber A is able to flow quickly via the large cross section C. The piston is greatly accelerated.

Impact cylinders



Special Design Cylinders



Special designs of double-acting cylinder

1 *Reinforced piston rod*

2 *Push-pull piston rod*

3 *Acid-resisting piston rod*

4 *Hard chromium cylinder lining*

5 *Heat-resisting seals (e.g., to 200 °C)*

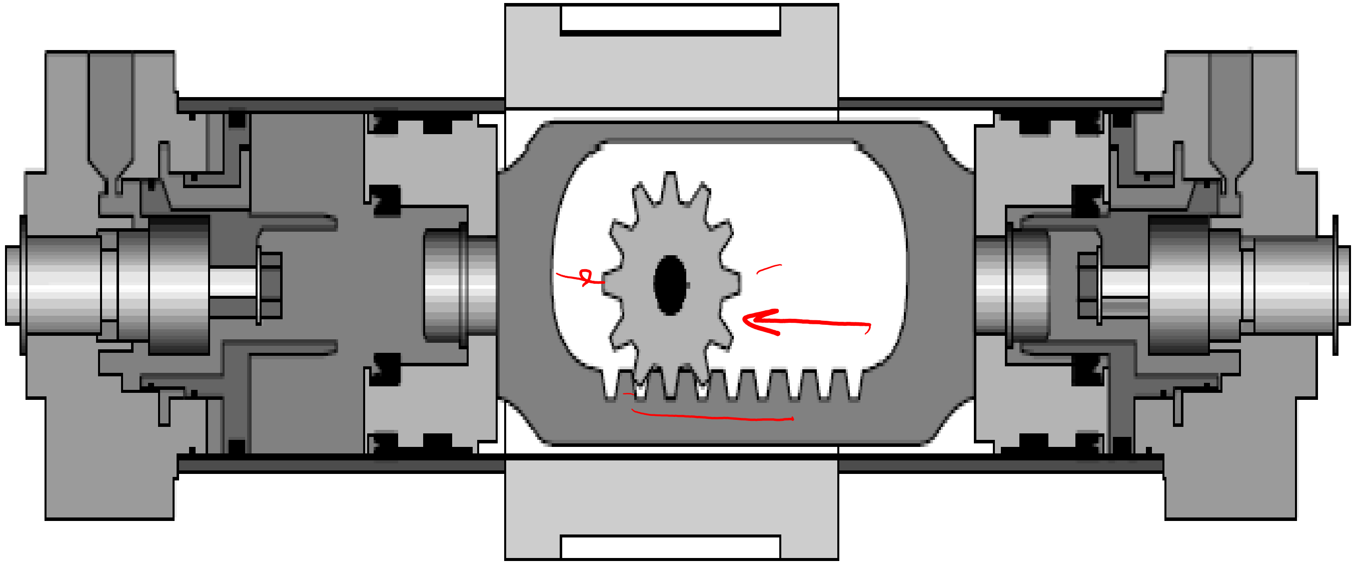
6 *Brass cylinder housing*

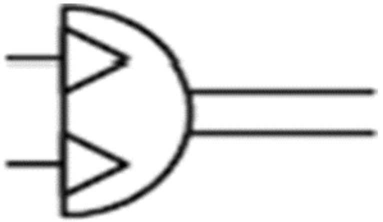
7 *Plastic cylinder coating and acid-resisting piston rod*

Several special-design features can be incorporated into one cylinder

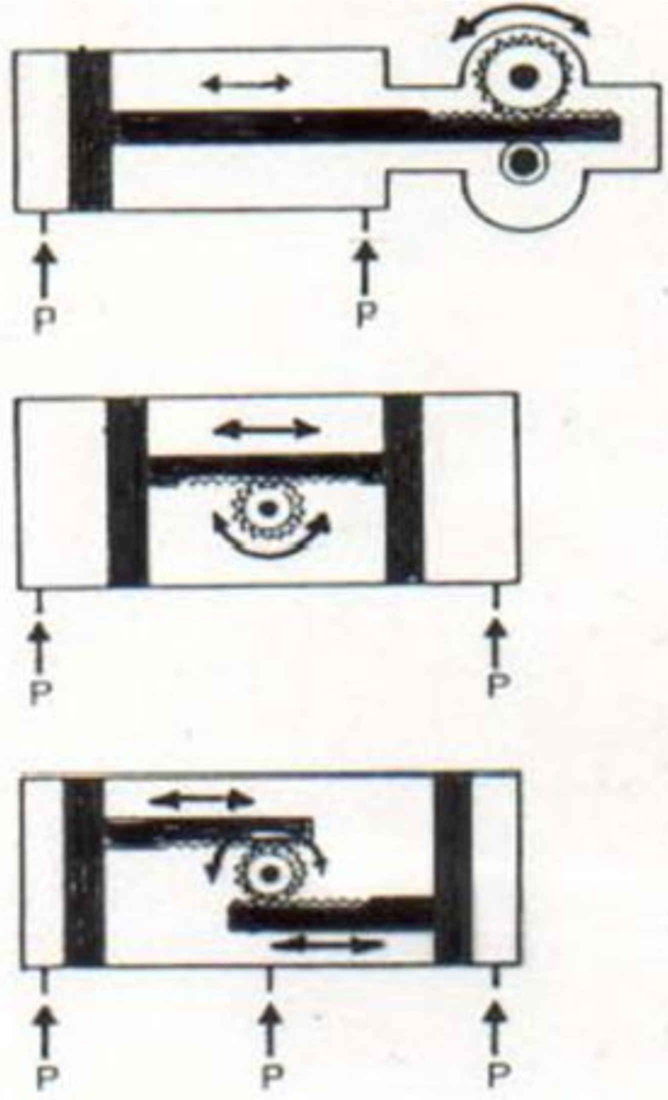
Rotary cylinders

- With this design of double-acting cylinder, the piston rod has a gear tooth profile. The piston rod drives a gear wheel, and a rotary movement results from a linear movement.
- The range of rotation varies from 450, 900, 1800, 2700 to 3600. The torque is dependent on pressure, piston surface and gear ratio; values of roughly up to 150 Nm are possible.





Rotary cylinders



Rotary cylinder; linear motion of piston converted to angular motion by toothed rod and pinion

Rodless cylinder

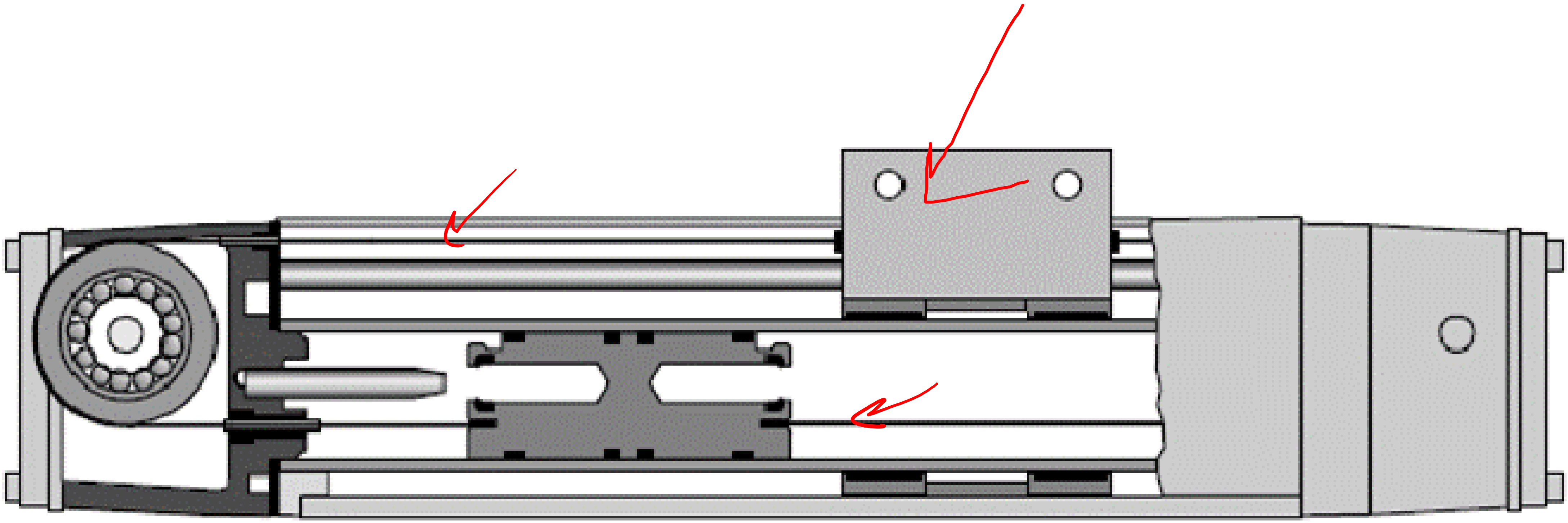
Three different operational principles are used for the construction of rodless cylinders:

- Band or cable cylinder
- Sealing band cylinder with slotted cylinder barrel
- Cylinder with magnetically coupled slide
- Compared with conventional double-acting cylinders, rodless cylinders are shorter in length. This eliminates the risk of a buckling piston rod and movement can take place over the entire stroke length.
- The cylinder design can be used for extremely large cylinder lengths of up to 10 m.
- Devices, loads etc, can be attached directly to the mounting surface provided for this on a carriage or outer slide. The force is identical in both directions of movement.

Band cylinder

- In the case of band cylinders, the piston force is transferred to a slide via a circulating band.
- When leaving the piston chamber, the band passes through a seal.
- In the cylinder caps, the band is reversed via guide rollers.
- Wipers ensure that no contamination reaches the guide rollers via the band.

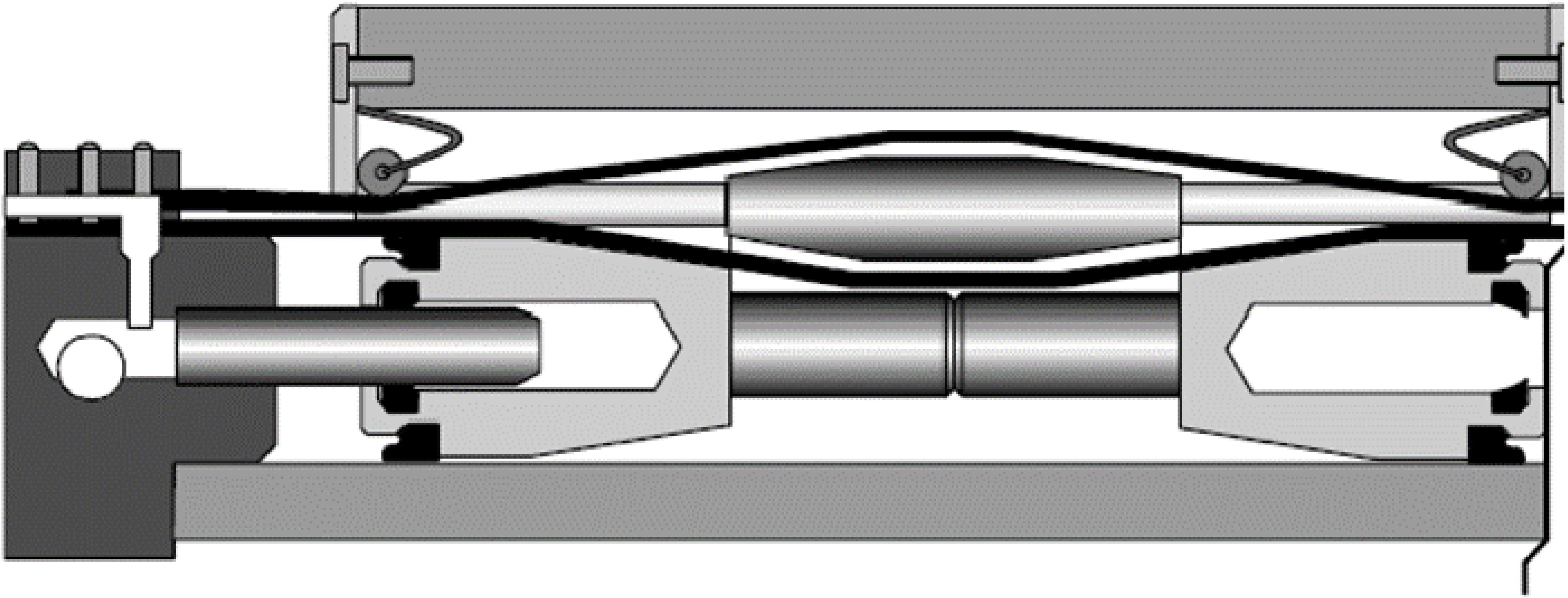
Band cylinder



Sealing band cylinder

- With this type, the cylinder barrel is provided with a slot across the entire length.
- The force is transmitted via a slide permanently connected to the piston.
- The connection from piston to slide is directed outwards via the slotted cylinder barrel.
- The slot is sealed by means of a sealing band, which seals the inside of the slot.
- The sealing band is guided between the piston seals and passed under the slide.
- A second cover strip covers the slot from the outside in order to prevent the ingress of dirt.

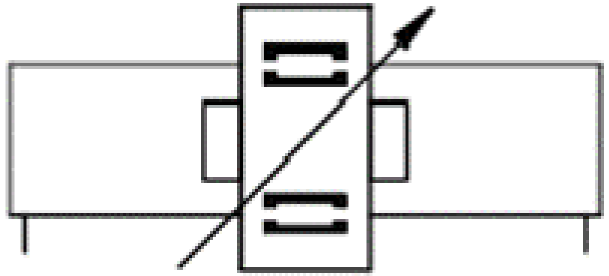
Sealing band cylinder

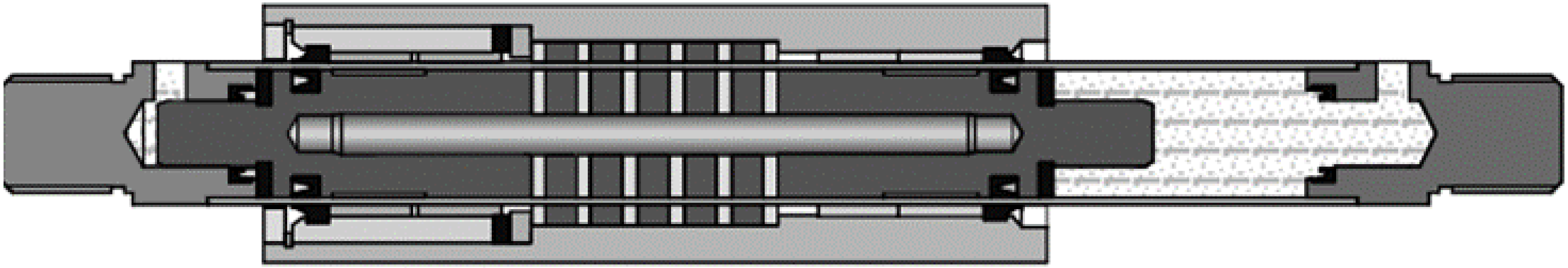


Cylinder with magnetic coupling

- This double-acting pneumatic linear actuator (rodless cylinder) consists of a cylindrical barrel, a piston and 2 slide.
- The piston in the cylinder is freely movable according to pneumatic actuation, but there is no positive external connection.
- The piston and the slide are fitted with a set of annular permanent magnets. Thus, a magnetic coupling is produced between slide and piston. As soon as the piston is moved by compressed air the slide moves synchronously with it.
- The cylinder barrel is hermetically sealed from the outer slide since there is no mechanical connection. There are no leakage losses.

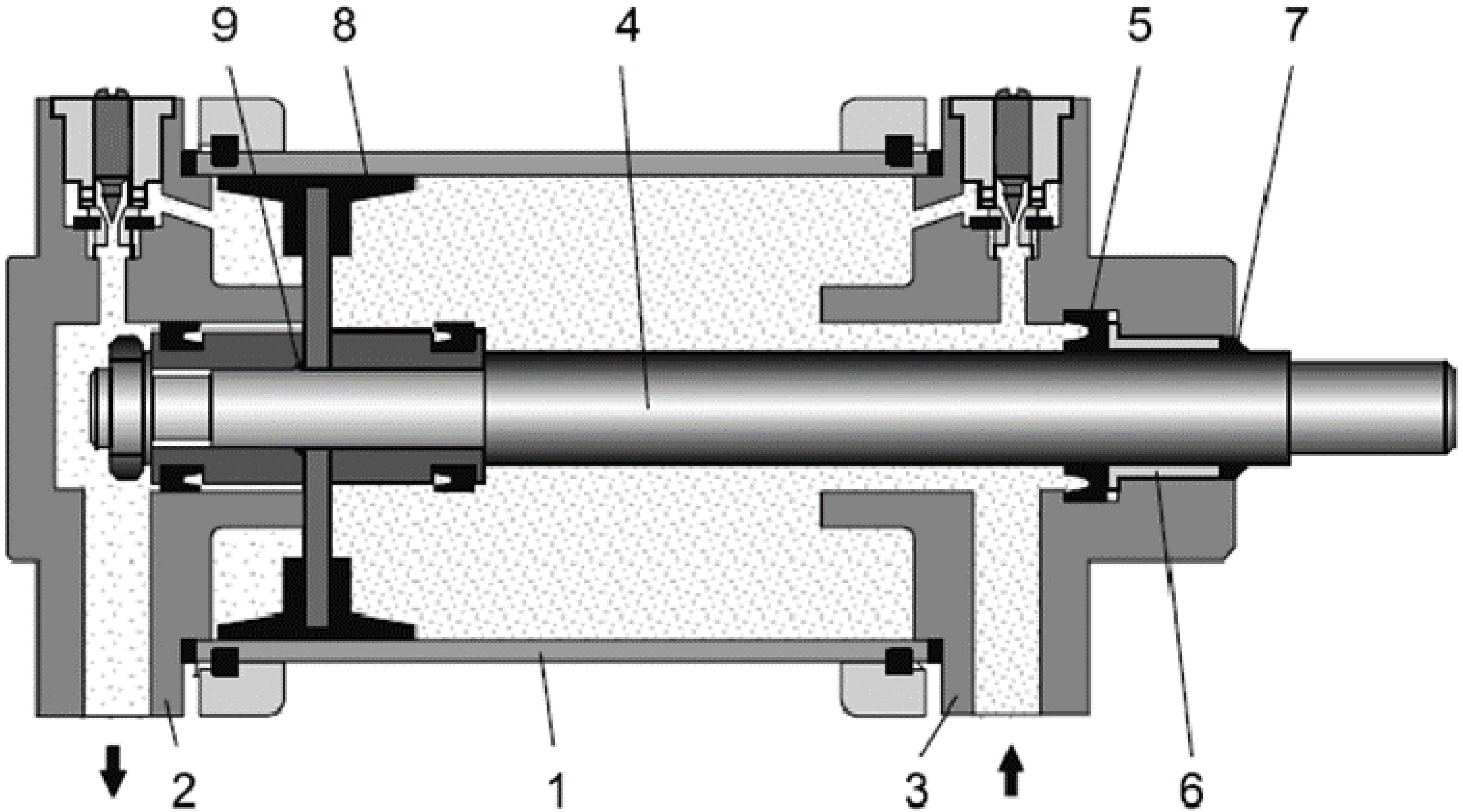
Cylinder with magnetic coupling





Cylinder construction

- The cylinder consists of a cylinder barrel, bearing and end cap, piston with seal (double-cup packing), piston rod, bearing bush, scraper ring, connecting parts and seals.



Cylinder construction

- The cylinder barrel (1) is usually made of seamless drawn steel tube.
- To increase the life of the sealing components, the bearing surfaces of the cylinder barrel are precision-machined.
- For special applications, the cylinder barrel can be made of aluminum, brass or steel tube with hard chromed bearing surface. These special designs are used where operation is infrequent or where there are corrosive influences.
- The end cap (2) and the bearing cap (3) are, for the most part, made of cast material (aluminum or malleable cast iron).
- The two caps can be fastened to the cylinder barrel by tie rods, threads or flanges.

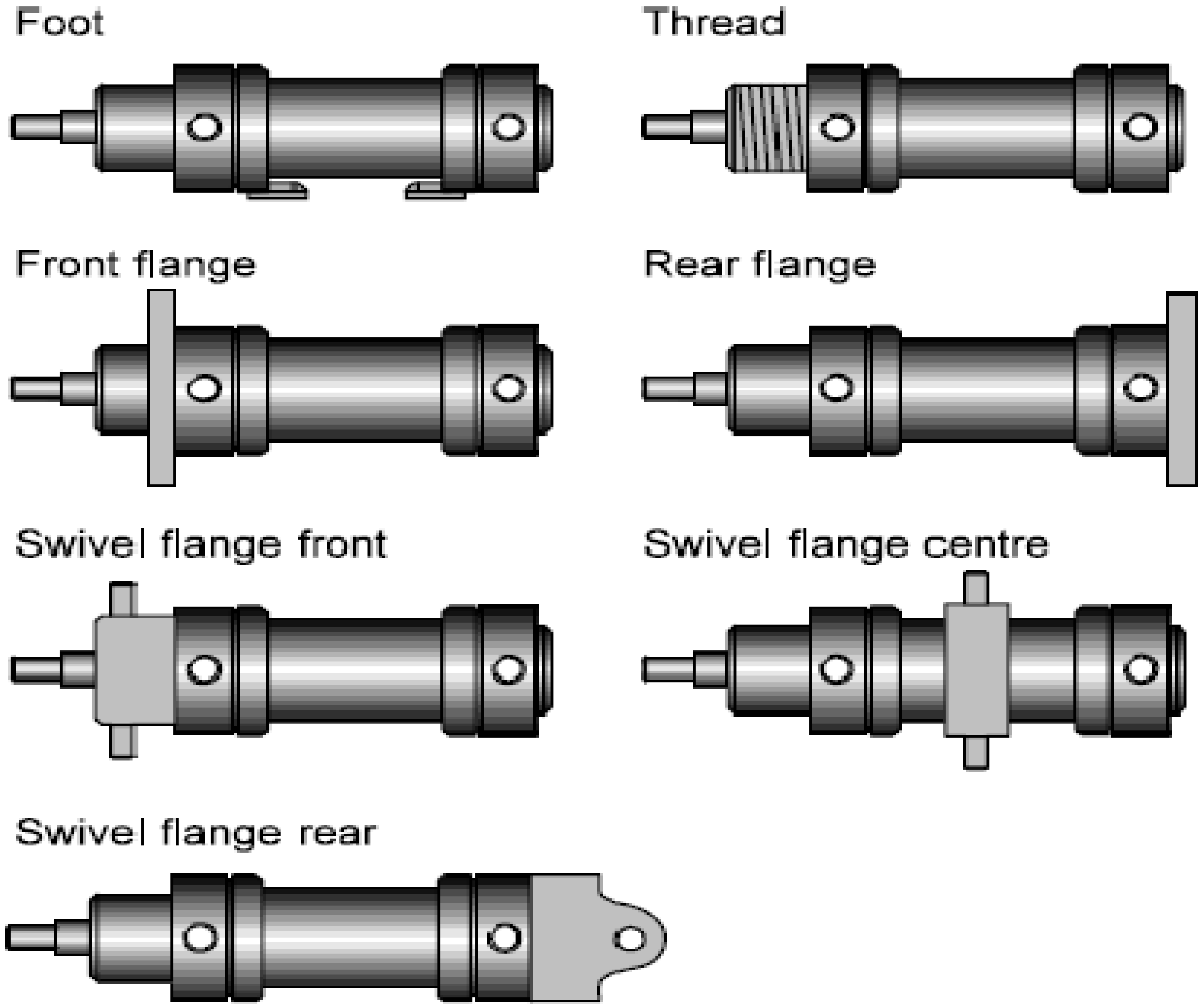
Cylinder construction

- The piston rod (4) is preferably made from heat-treated steel. A certain percentage of chrome in the steel protects against rusting.
- A sealing ring (5) is fitted in the bearing cap to seal the piston rod.
- The bearing bush (6) guides the piston rod and may be made of sintered bronze or plastic-coated metal.
- In front of this bearing bush is a scraper ring (7). It prevents dust and dirt particles from entering the cylinder space. Bellows are therefore not normally required.

The materials for the double-cup packing seals (8) are:

- Perbunan for – 20 °C to + 80 °C
- Viton for – 20 °C to + 150 °C
- Teflon for – 80 °C to + 200 °C

Actuators mounting

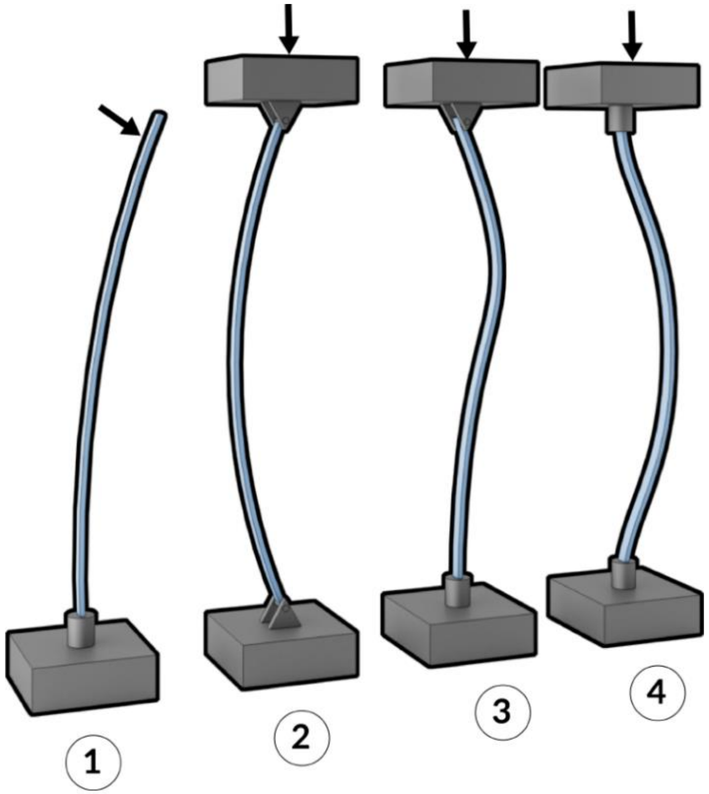


Actuators mounting

- As soon as force is transmitted to a machine, stresses occur at the cylinder.
- If shaft mismatching and misalignments are present, bearing stresses at the cylinder barrel and piston rod can also be expected.

The consequences are :

1. High edge pressures on the cylinder bearing bushes leading to increased wear.
2. High edge pressures on the piston rod guide bearings.
3. Increased and uneven stresses on piston rod seals and piston seals.
4. With large cylinder strokes, the buckling load of the piston rod should be observed.



Cylinder performance characteristics

- Cylinder performance characteristics can be determined theoretically or by the use of manufacturer’s data.

- Both methods are acceptable, but in general the manufacturer's data is more relevant to a particular design and application.

Piston force

The piston force exerted by the cylinder is dependent upon:

1. The air pressure,
2. The cylinder diameter
3. The frictional resistance of the sealing components.

The theoretical piston force is calculated by the formula:

$$F_{th} = PA$$

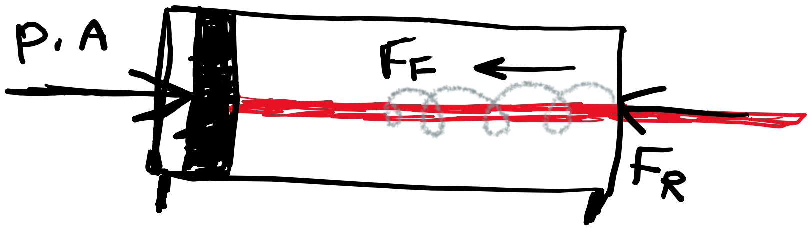
Where F_{th} in N, P is the operating pressure (Pa)

A is the useful piston area (m^2) (the area where the pressurised air is applied)

Piston force

- In practice, the effective piston force is significant.
- When calculating this, frictional resistance should be taken into consideration.
- Under normal operating conditions (pressure range of 400 to 800 kPa / 4 to 8 bar) frictional force of approx. 10% of the theoretical piston force can be assumed.

Piston force



Single-acting cylinder

$F_{eff} = (A \bullet p) - (F_R + F_F)$

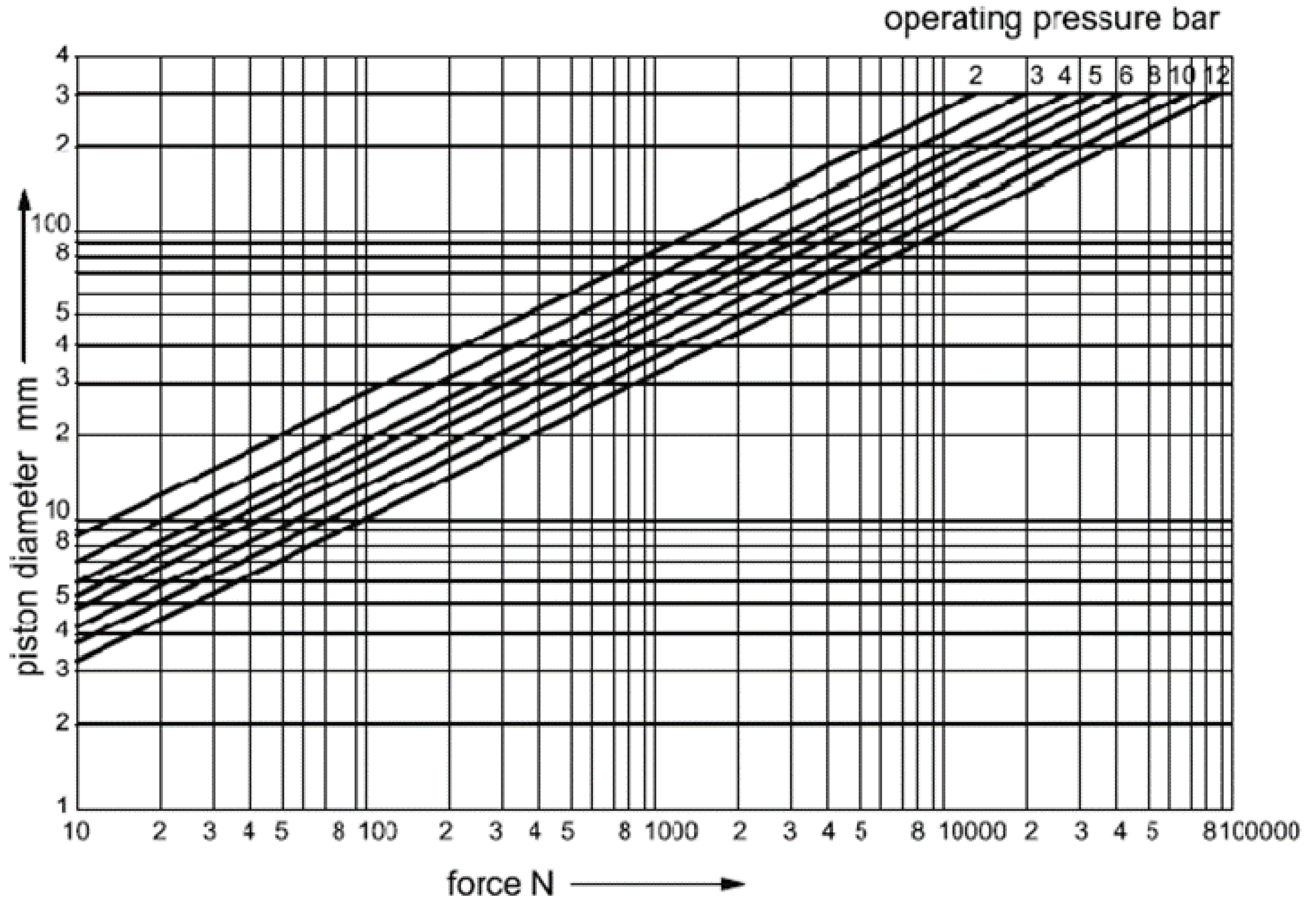
Double-acting cylinders

Forward stroke	F_{eff}	=	$(A \bullet p) - F_R$
Return stroke	F_{eff}	=	$(A' \bullet p) - F_R$
	F_{eff}	=	effective piston force (N)
	A	=	useful piston surface (m^2)
		=	$(\frac{D^2 \bullet \pi}{4})$
	A'	=	useful annular surface (m^2)
		=	$(D^2 - d^2)\frac{\pi}{4}$
	p	=	Working pressure (Pa)
	F_R	=	Frictional force (approx. 10 % of F_{th}) (N)
	F_F	=	Return spring force (N)
	D	=	Cylinder diameter (m)
	d	=	Piston rod diameter (m).

Piston force

- Note: Under normal operating pressure (6 bar) the spring force in single acting cylinders is approximately selected about 10%-15% of the theoretical piston force in order to ensure the adequate speed return.

Pressure vs force diagram



Pressure for pneumatic cylinders

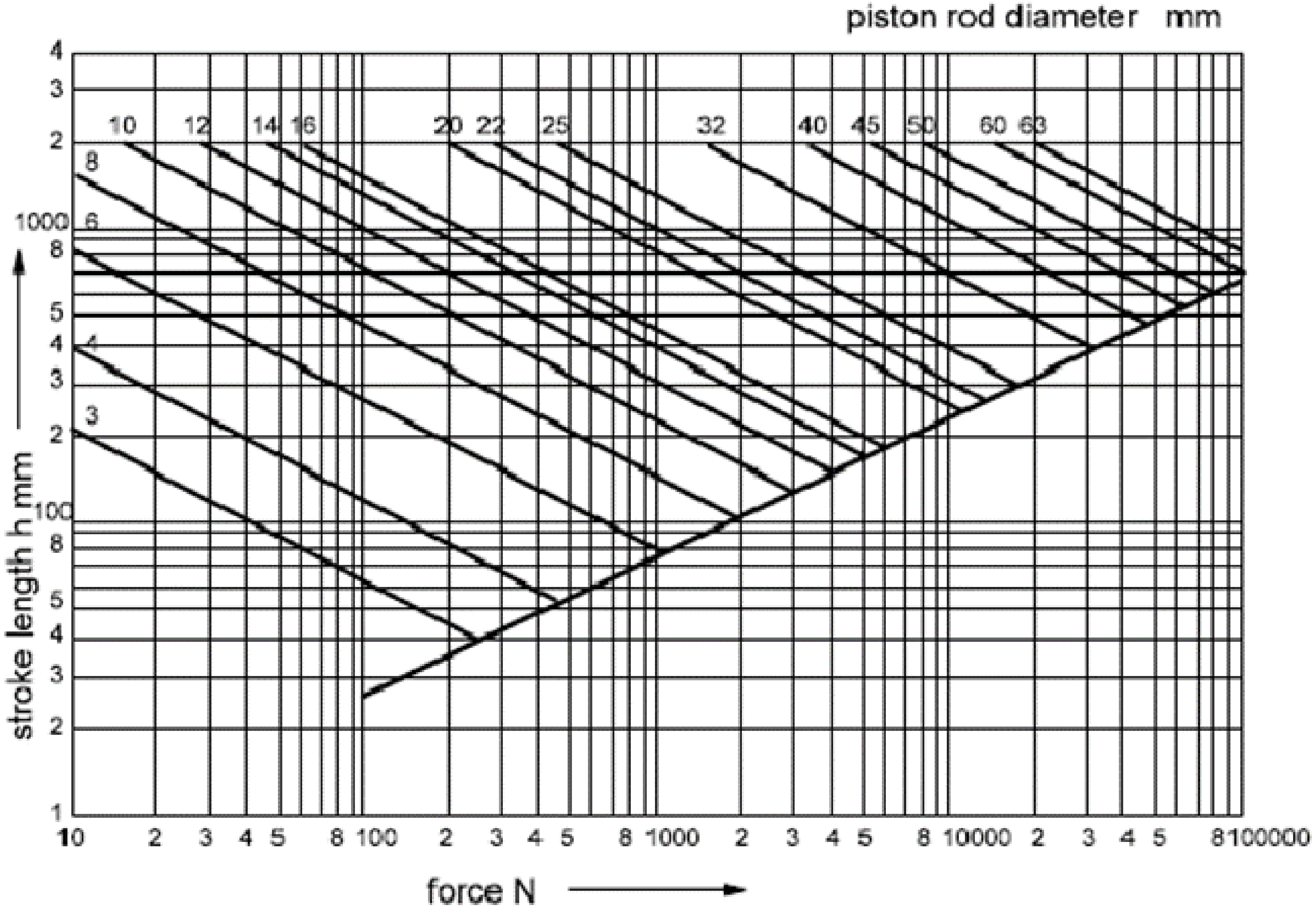
Pressure force table for Pneumatic cylinders

Operating pressure bar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Piston-dia. mm							Piston force [N]								
8	4.5	9.0	13.6	18.1	22.6	27.1	31.7	36.2	40.7	45.2	49.8	54.3	58.8	63.3	67.9
10	7.1	14.1	21.2	28.3	35.3	42.4	49.5	56.5	63.6	70.7	77.8	84.8	91.9	99.0	106
12	10.2	20.4	30.5	40.7	50.9	61.0	71.3	81.4	91.6	101	112	122	132	143	153
16	18.1	36.2	54.3	72.4	90.5	109	127	145	163	181	199	217	235	253	271
20	28.3	56.5	84.8	113	141	170	198	226	254	283	311	339	368	396	424
25	44.2	88.4	133	177	221	265	309	353	398	442	486	530	574	619	663
32	72.4	145	217	290	362	434	507	579	651	724	796	869	941	1010	1090
40	113	226	339	452	565	679	792	905	1020	1130	1240	1360	1470	1580	1700
50	177	353	530	707	884	1060	1240	1410	1590	1770	1940	2120	2300	2470	2650
63	281	561	842	1120	1400	1680	1960	2240	2520	2810	3090	3370	3650	3930	4210
80	452	905	1360	1810	2260	2710	3170	3620	4070	4520	4980	5430	5880	6330	6790
100	707	1410	2120	2830	3530	4240	4950	5650	6360	7070	7780	8480	9190	9900	10600
125	1100	2210	3310	4420	5520	6630	7730	8840	9940	11000	12100	13300	14400	15500	16600
160	1810	3620	5430	7240	9050	10900	12700	14500	16300	18100	19900	21700	23500	25300	27100
200	2830	5650	8480	11300	14100	17000	19800	22600	25400	28300	31100	33900	36800	39600	42400
250	4420	8840	13300	17700	22100	26500	30900	35300	39800	44200	48600	53000	57400	61900	66300
320	7240	14500	21700	29000	36200	43400	50700	57900	65100	72400	79600	86900	94100	101000	109000

Stroke length

- The stroke lengths of pneumatic cylinders should not be greater than 2 m and for rodless cylinders 10 m.
- With excessive stroke lengths the mechanical stress on the piston rod and on the guide bearings would be too great.
- To avoid the danger of buckling, the buckling diagram should be observed with large stroke lengths.

Buckling diagram



Buckling diagram

Standardized cylinder sizes and stroke lengths, stock range from minimum to maximum strokes

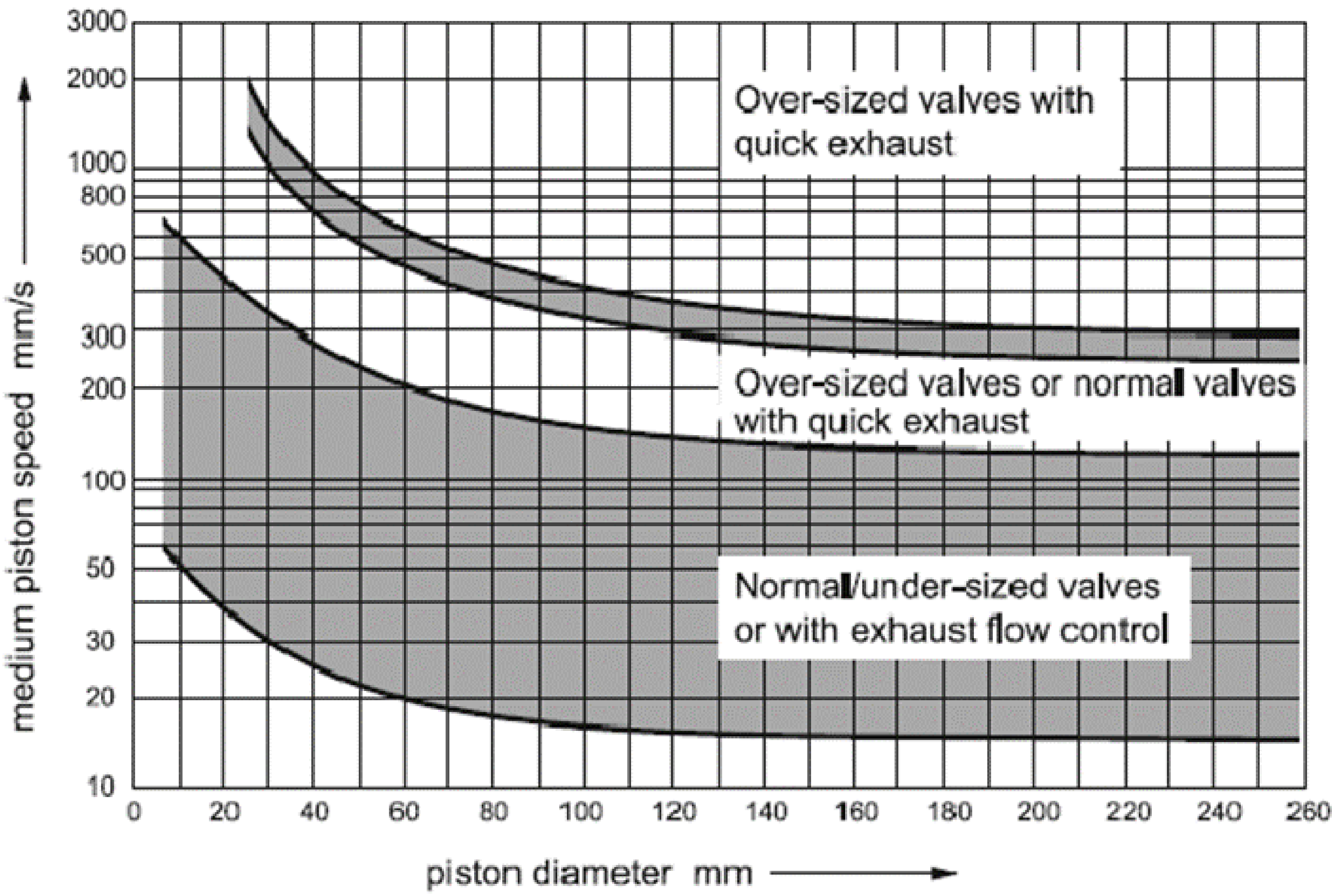
Piston diameter (mm)	Thrust at 6 bars air (kgf)	Standardized strokes (mm)	Minimum-maximum stroke range (mm)
6	1.2	10, 25, 40, 80	10–80
12	6	10, 25, 40, 80, 140, 200	10–200
16	12	10, 25, 40, 80, 140, 200, 300	10–400
25	24	25, 40, 80, 140, 200, 300	10–500
35	52	70, 140, 200, 300	10–2000
40	72	40, 80, 140, 200, 300	10–2000
50	106	70, 140, 200, 300	10–2000
70	208	70, 140, 200, 300	10–2000
100	424	70, 140, 200, 300	10–2000
140	832	70, 140, 200, 300	10–2000
200	1700	70, 140, 200, 300	10–1100
250	2600	70, 140, 200, 300	10–1100

Piston speed

The piston speed of pneumatic cylinders is dependent on:

- The load,
- The prevailing air pressure,
- The length of pipe,
- The cross-sectional area of the line between the control element and the working element the flow rate through the control element.
- In addition, the speed is influenced by the end position cushioning.
- The average piston speed of standard cylinders is about **0.1-1.5 m/sec.**
- With special cylinders (impact cylinders), speeds of **up to 10 m/sec** are attained.
- The piston speed can be regulated by one way flow control valves and speed increased by the use of quick exhaust valves.

Piston speed



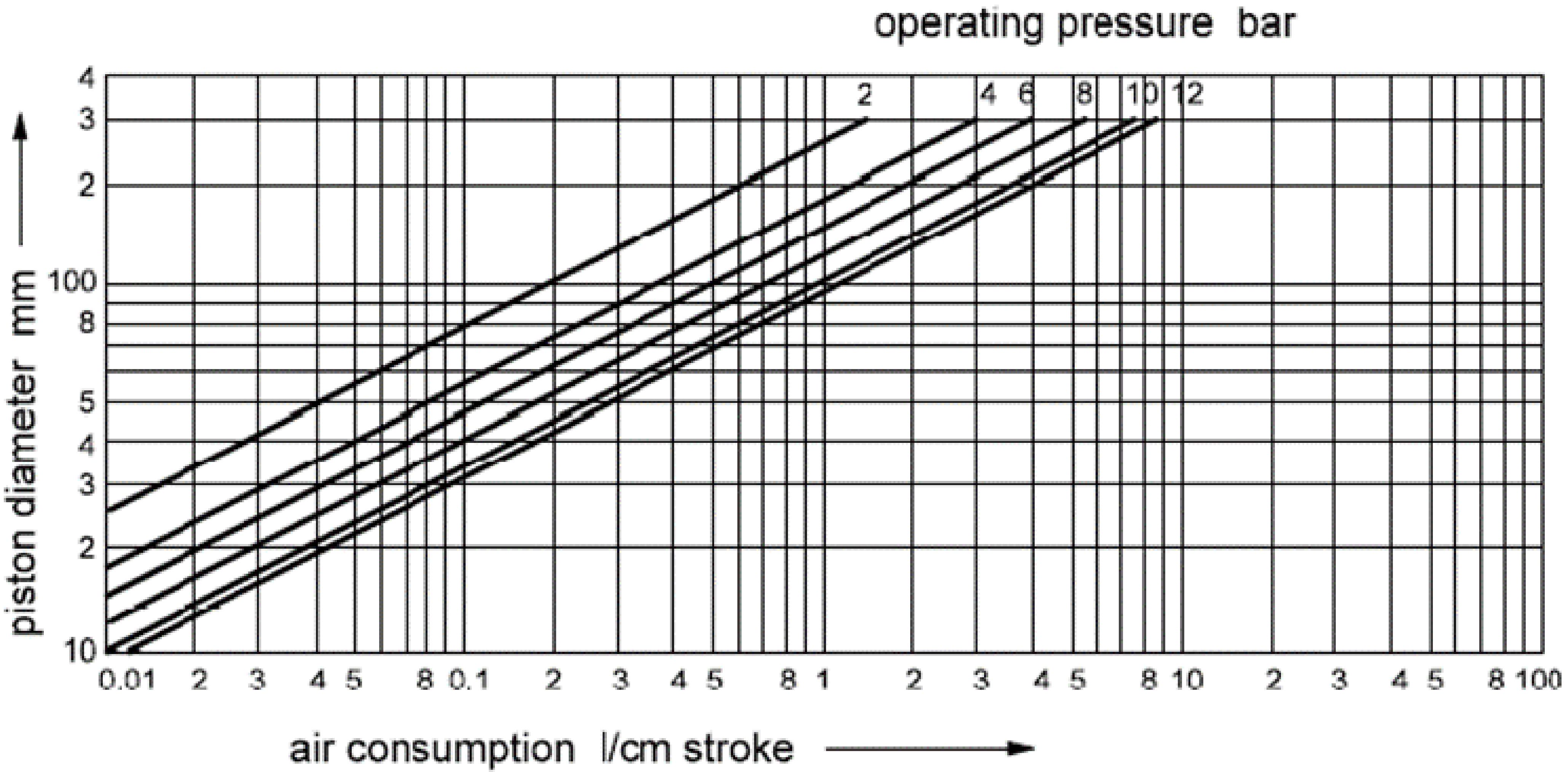
Air consumption

- For the preparation of the air, and to obtain facts concerning power costs, it is important to know the air consumption of the system.
- The air consumption is specified in liters of air drawn in per minute.
- For a particular operating pressure, piston diameter, stroke and stroke number, the air consumption is calculated by:

$$\text{Air consumption} = \text{Compression ratio} \bullet \text{Piston surface} \bullet \text{Stroke} \bullet \text{Stroke number per minute}$$

$$\text{Compression ratio} = \frac{101.3 + \text{Operating pressure (in kPa)}}{101.3}$$

Air consumption



Air consumption

The formulae for the calculation of air consumption in accordance with the air consumption diagram are as follows:

for single-acting cylinders

$$q_B = s \bullet n \bullet q_H$$

for double-acting cylinders

$$q_B = 2 \bullet s \bullet n \bullet q_H$$

q_B = Air consumption (l/min)

s = Stroke (cm)

n = Number of strokes per minute (1/min)

q_H = Air consumption per cm of stroke (l/cm)

Air consumption

Piston diameter in mm	Cover side in cm^3	Base side in cm^3
12	1	0.5
16	1	1.2
25	5	6
35	10	13
50	16	19

Piston diameter in mm	Cover side in cm^3	Base side in cm^3
70	27	31
100	80	88
140	128	150
200	425	448
250	2005	2337