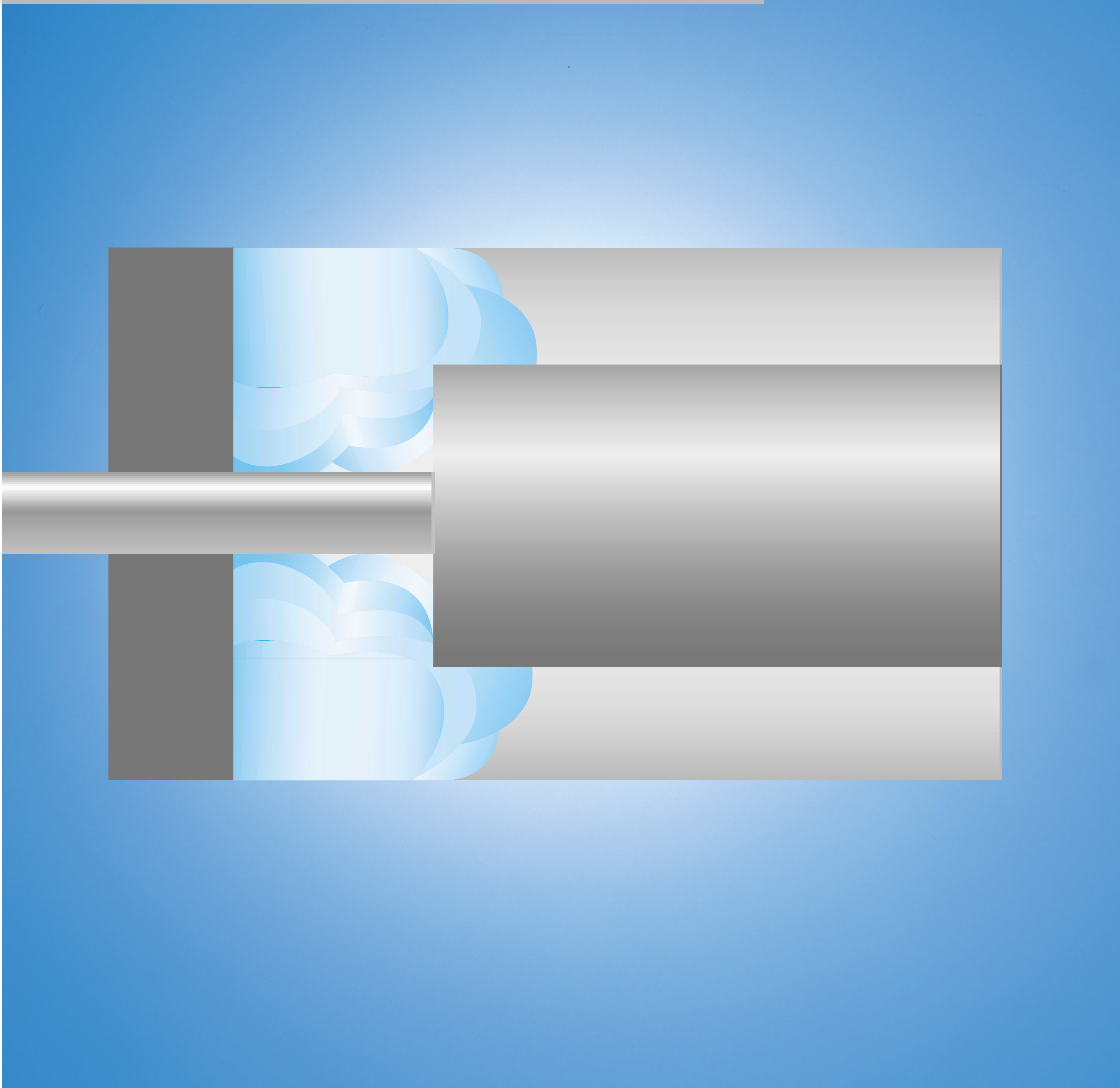
Rexroth
Bosch Group

An ABC of cylinder cushioning

The Drive & Control Company



Why is cylinder cushioning necessary?

Some form of cushioning is normally required to reduce the rate of travel of a cylinder before the piston strikes the end cover. Reducing the piston velocity at the end of its travel lowers the stresses on the cylinder while reducing vibration in the structure of which it is part. Efficient cushioning is usually necessary in applications in which precision is a must.

Basically, this problem can be solved in one of three ways: by means of simple impact cushioning, by pneumatic cushioning or by fitting shock absorbers. The following discussion will deal mainly with pneumatic cushioning.

This manual is intended to serve as an instruction on how to achieve ideal cushioning; in other words, how to optimise the degree of cushioning for a given mass.

We hope that readers who use pneumatic cylinders on a practical level in their daily work, as well as those who design machines using them, will find the information useful.

Achieving ideal pneumatic cushioning

What is ideal pneumatic cushioning

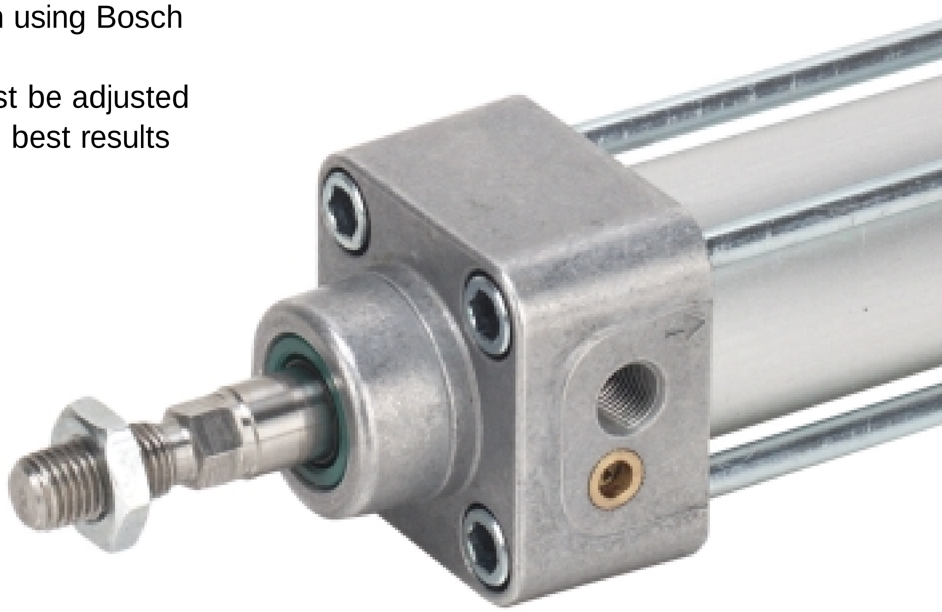
Ideal pneumatic cushioning means that the direction of travel of the piston is the same throughout the entire cushioning sequence and that its velocity is exactly zero when it reaches the end of its travel. The sound of end cover contact is negligible and the total cycle time is minimised. Thus, properly adjusted pneumatic cushioning can have positive effects on the working environment and on the total working cycle time.

How is ideal pneumatic cushioning achieved?

Assuming that the operating pressure is 6.3 bar and that a cylinder with a specified piston diameter is to cushion a specified mass, the first step is to ensure that the piston velocity corresponds to that specified in the cushioning chart in the main catalogue or when using Bosch Rexroth calculation system.

The piston velocity must be adjusted correctly in every case. The best results are obtained by installing throttling non-return valves directly in the connection ports in the cylinder ends. This affords a free inlet flow while enabling the outlet pressure to be adjusted simply by altering the area of the exhaust port with an adjusting screw. Alternatively, directional control valves with integral restrictors may be used.

Since the velocity of the piston in a cylinder may be difficult to detect by eye, an electronic aid which can be attached to the outside of the cylinder tube is now available and this enables the true velocity of the piston to be determined quickly and easily. It is also possible to measure the time for all sequences in a cylinder cycle. Ideal pneumatic cushioning can only be achieved when maximum kinetic energy is used.

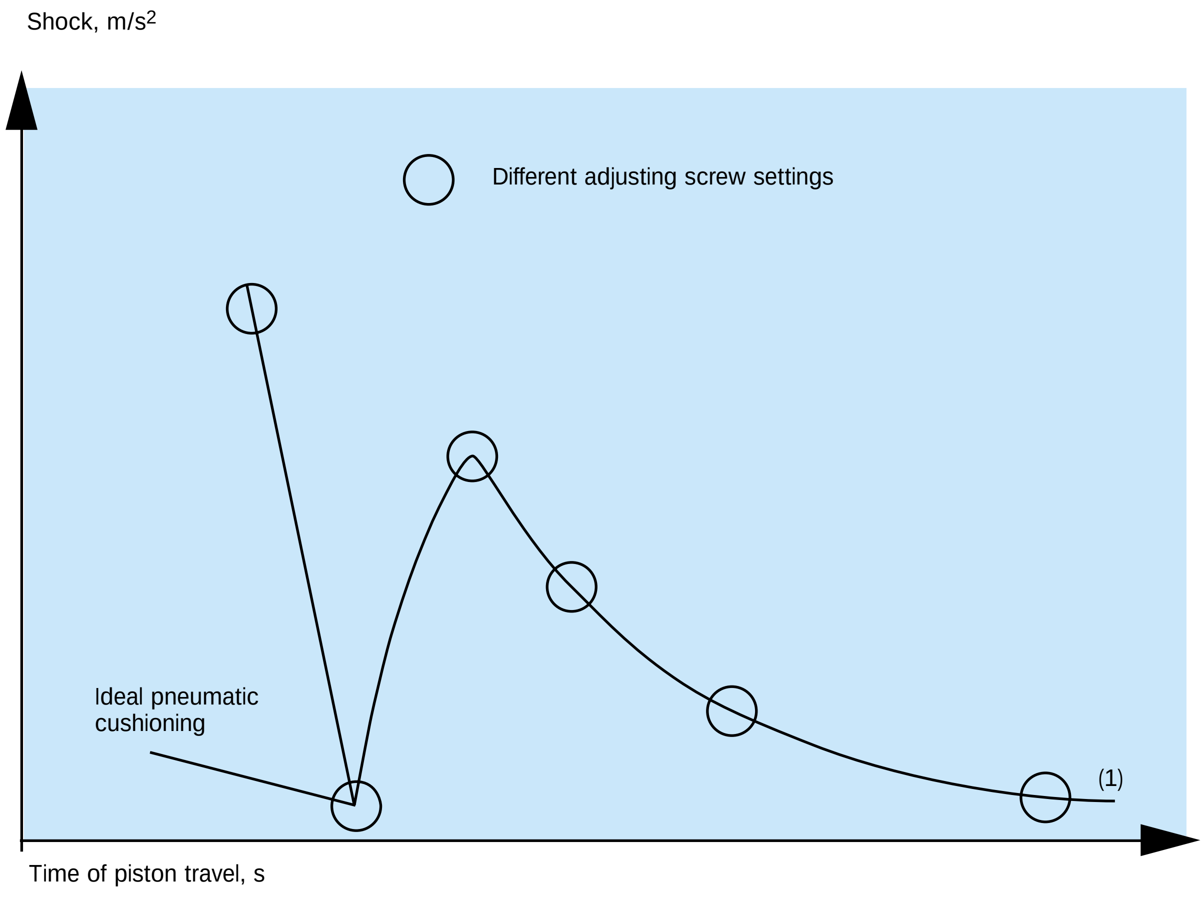


Since Rexroth cylinders with variable cushioning are supplied with the adjusting screw open by only a half to one turn, the cylinder is overdamped following adjustment of the piston velocity. Although the basic adjustment does prevent the piston from striking the end cover freely on its first stroke, eliminating the risk of damage, the cushioning is far from ideal. In addition, the extended cushioning sequence may make it difficult to maintain the cycle time.

The following diagram illustrates the sequence of events which occurs when the adjusting screw is opened, all other parameters being constant.

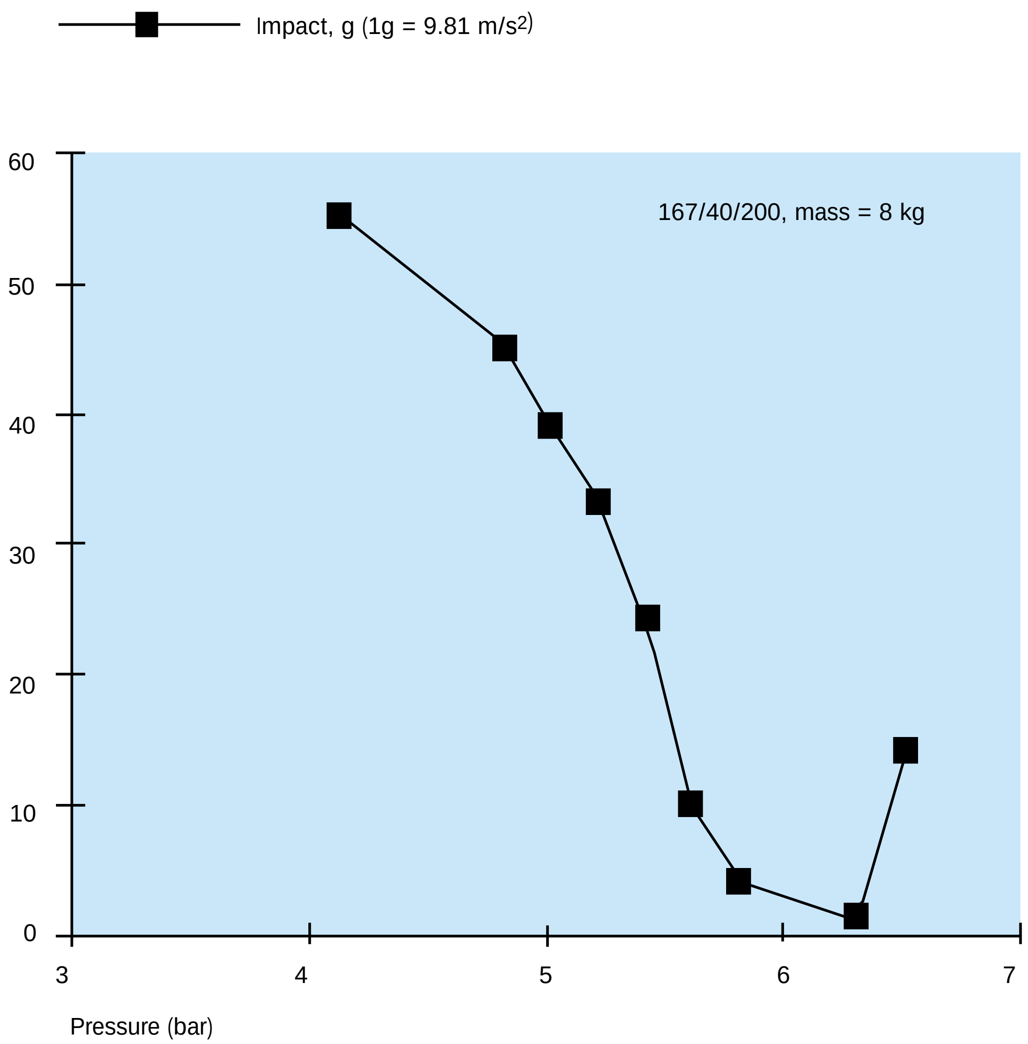
Opening the adjusting screw a turn at a time moves the point to the left from the initial point (1), which corresponds to the initial adjuster setting. During the first 2–3 turns, the cushioning sequence is clearly seen to become progressively shorter. However, the end impact becomes greater. The usual reaction is to cease adjustment at this point and to return the adjusting screw towards the original setting to counteract the severe shocks.

However, ideal cushioning is achieved by continuing to open the screw a further 1–2 turns, at which point – as the diagram shows – the end impact is minimal, with low noise and vibration levels. If the adjusting screw is now opened further, the end impact will become considerably greater without reducing the cycle time significantly. However, at the ideal pneumatic cushioning point, the total cycle time will be reduced substantially as a result of the much faster cushioning sequence (a 20–40% reduction is not unusual).



Effect of varying operating pressure

In the foregoing description, all of the parameters are assumed to be constant and only the cushioning setting is adjusted. However, the operating pressure may fluctuate in large pneumatic systems with many users. The effects of this (see below) may make it worthwhile to install large numbers of pressure regulators in critical applications. Also consider the dimensioning of the pneumatic system to avoid high pressure drops. The effects of reducing the operating pressure are illustrated clearly in the following diagram. Starting with ideal pneumatic cushioning, with a minimum end impact at 6.3 bar, the shock increase sharply until, at 5 bar, the cylinder is subjected to a shock equivalent to 30–40 times the mass the cylinder is intended to cushion. Apart from a high noise level, severe vibrations and a longer cycle time, this shortens the life of the cylinder appreciably. Unfortunately, increasing the pressure has the same result.



Correcting cylinder overdamping

The characteristic of an overdamped cylinder is that ideal pneumatic cushioning cannot be achieved; the effects will become progressively worse regardless of the amount of adjustment. Three actions may be taken to solve this problem. Two of these derive from the relationship of kinetic energy:

$$w = \frac{m \cdot v^2}{2}$$

1. Increase the piston velocity
The piston velocity can be increased by increasing the area of the cylinder outlet port, for example by adjusting the throttling non-return valves or altering the restrictors in the outlet ports of the directional control valves. Sufficient kinetic energy for ideal cushioning can be developed by this means.

2. Reduce the operating pressure
As the following diagram shows, 100% of the maximum cushioning energy is utilised at 6.3 bar.

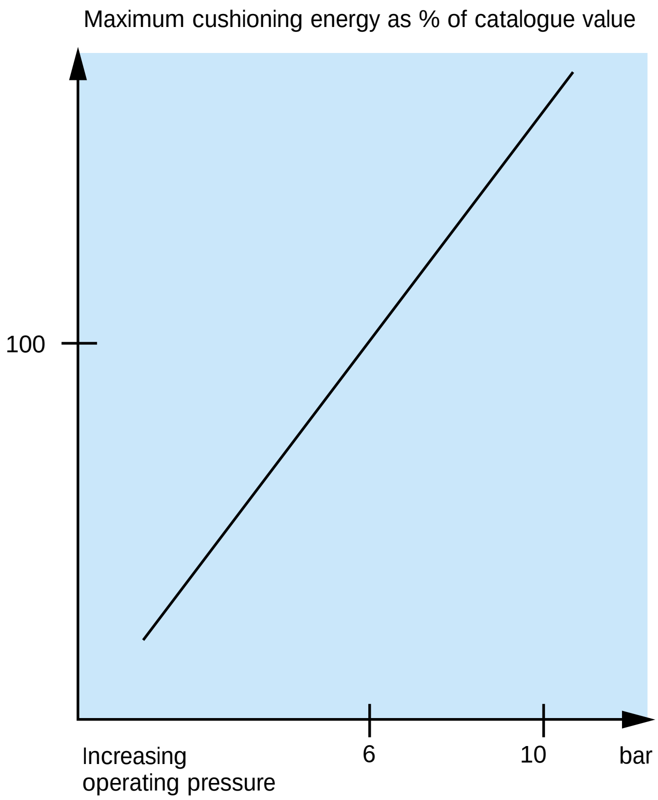
3. Increase the moving mass
A higher kinetic energy can naturally be achieved by increasing the moving mass, although this is not always so easy to achieve in practice.

Correcting cylinder underdamping

If severe shock occurs regardless of the adjuster setting, the cylinder is underdamped. In this case, the possible courses of action are basically the opposite of those described in the foregoing section. In other words, the following action may be taken to solve the problem:

1. Reduce the piston velocity
2. Increase the operating pressure
3. Reduce the mass

A final alternative is to equip the cylinder with external hydraulic shock absorbers.



Can ideal pneumatic cushioning actually be achieved?

At present, the cylinder diameter is often specified on the basis of a specified thrust requirement, without allowing for the kinetic energy. Usually, this produces a cylinder cushioning capacity which is well in excess of that necessary for the application. In such cases, ideal pneumatic cushioning is either not required or is unachievable in every case.

If the cushioning energy does not exceed 10% of the permissible value, it is possible to open the adjusting screw sufficiently for the piston to strike the end cover. The shock will be moderate due to the low load, while the impact time will be short and the braking effect of the pneumatic cushioning will be low due to the short time available for back pressure to develop.

The following will apply if the cushioning energy is between 10% and 80% of the maximum permissible value: At the lower value, the piston can be cushioned partially with air, with impact cushioning accounting for the remainder of the energy absorption, although a certain shock will naturally occur. In this case, the adjusting screw will be almost completely open and the direction of piston travel will be unchanged.

At the upper value, the adjusting screw will be almost completely closed. The kinetic energy will be damped and the piston will travel towards the end cover at a certain velocity. However, the shock will be less than in the first case. This is referred to as rebound cushioning since the piston changes direction two or three times while cushioning is in progress. In this case, the total cycle time will be somewhat longer.

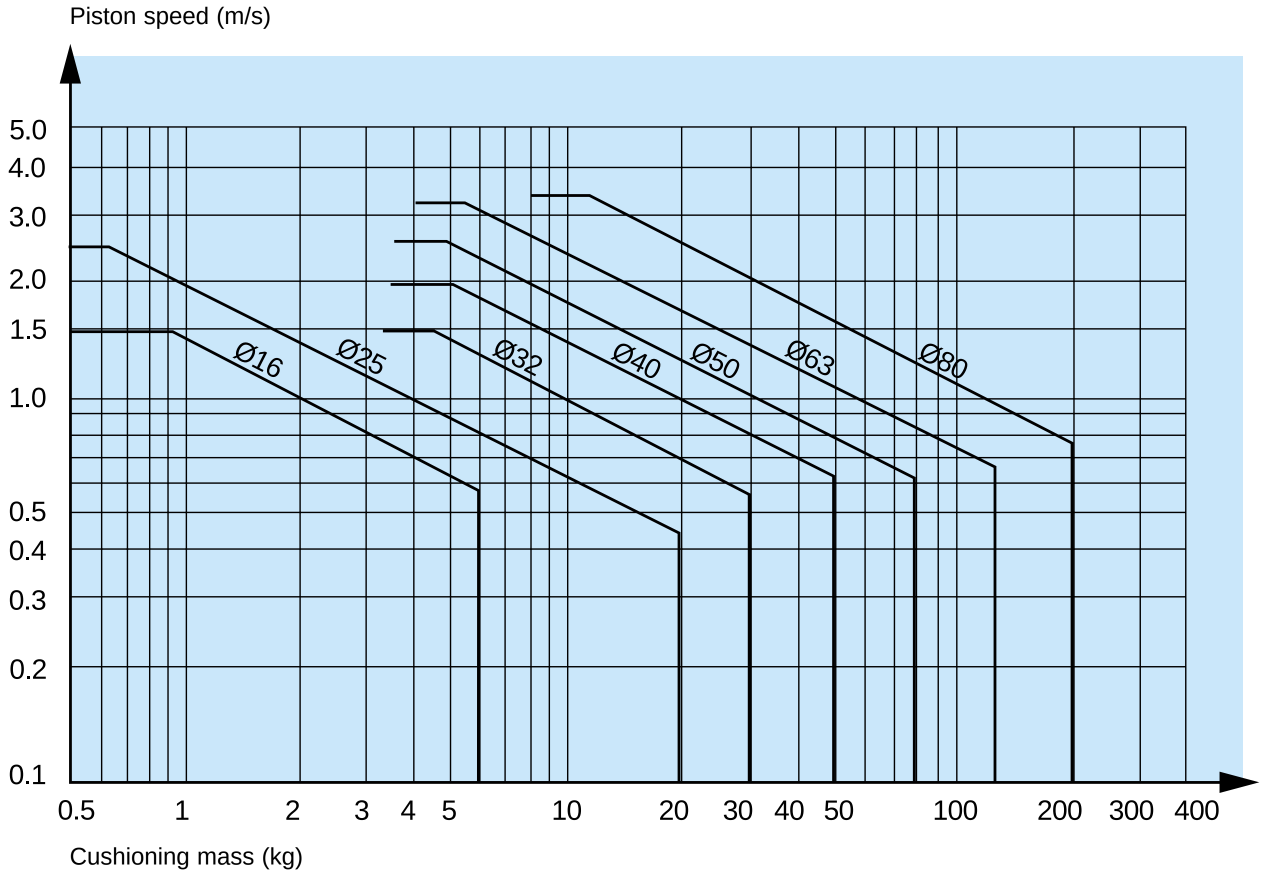
Until now, the discussion has dealt with cases in which the machine is already installed and the pneumatic cushioning must be adjusted. At this point, it may be appropriate to describe the action which can be taken before that stage; in other words, the factors which should be taken into account when designing the machine and specifying the cylinders.

Getting it right from the beginning

Design for ideal pneumatic cushioning

As a basic principle, the cylinders should be specified in accordance with the cushioning charts in the catalogue. These apply to horizontal installation, at a minimum stroke of 200 mm and at an operating pressure of 6.3 bar.

Plot the known velocity and mass in the chart. Ideal cushioning will be possible to achieve, without changing the operating pressure, if the intersection of mass and velocity is on or just below the leaning line in the chart.



An excellent rule of thumb for choosing the correct cylinder is that the ratio between the moving mass in kg and the piston area in cm² should not exceed 4. In other words:

$$\frac{\text{Mass in kg}}{\text{Piston area in cm}^2} < 4$$

and this is given by the vertical restriction line.

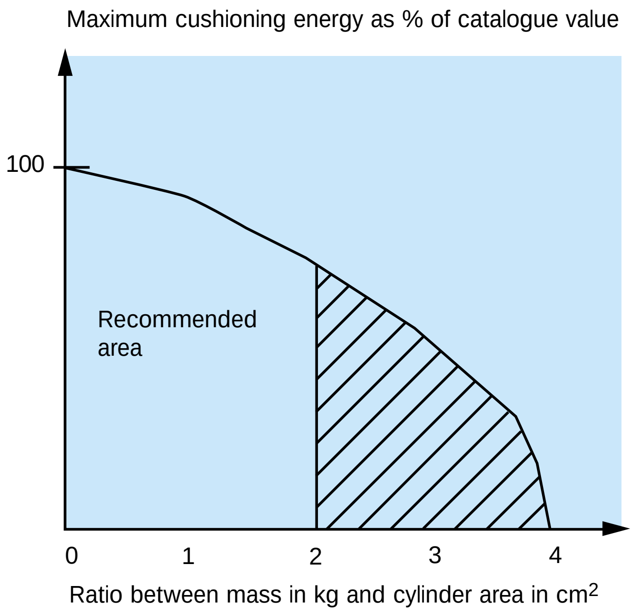
Effect of mounting configuration

Basically, the horizontal cushioning charts can be used when the piston operates vertically downward. The chart on previous page is a typical example for a specific cylinder series.

If the cylinder is installed vertically and the piston travel is upward, the cushioning capacity will be reduced due to the reduction in cushioning pressure. The force of gravity, which acts in the opposite direction, also reduces the cushioning capacity. The figure below may serve as a guide.

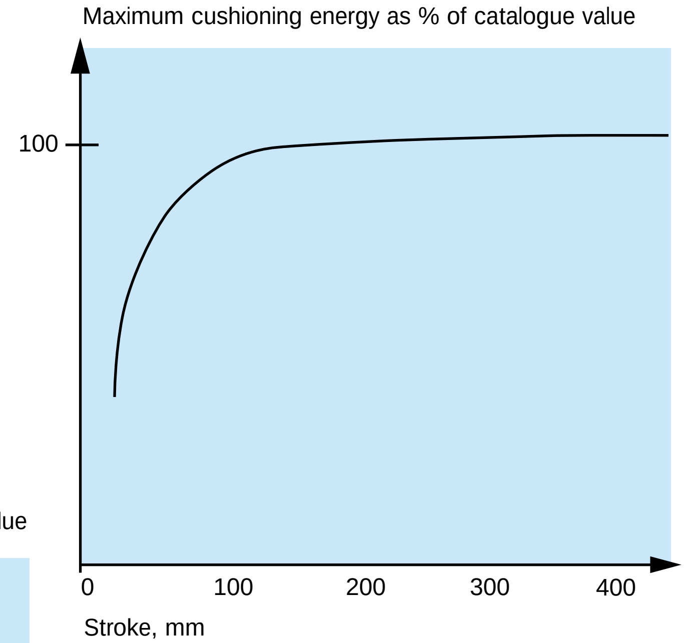
The following rule of thumb applies to vertical upward movement:

$$\frac{\text{Mass in kg}}{\text{Piston area in cm}^2} < 2$$



Influence of cylinder stroke

The following diagram shows that full cushioning capacity is achieved only when the cylinder has described a stroke of approx. 200 mm, at which steady-state conditions (i.e. stabilised operating pressure and back pressure) are achieved. It should be noted that the cushioning energy decreases at shorter strokes.



Importance of steady-state conditions

As already described, the operating pressure, mass and velocity are the factors which govern the achievement of ideal pneumatic cushioning. Once this has been achieved, the parameters must remain unchanged since every alteration basically means that the cushioning energy must be readjusted.

MecSpeed for gentler, more precise end cushioning

Optimum end cushioning in a pneumatic cylinder – or the shortest possible stroke time – easy to set precisely when the piston speed can be determined.

The MecSpeed unit enables the piston speed to be measured externally.

Optimum end cushioning reduces noise and prolongs cylinder life.

Machine designers can now specify the speed and stroke times of all pneumatic movements, with the assurance that these can be fine-tuned easily when the equipment is commissioned.

- Maintenance is simplified and downtime shortened when the piston speed of a replacement directional control valve or throttling valve is known, and can be adjusted simply to the correct value.
- Capital and operating costs are reduced by making it easier to specify optimum valve size.
- Simpler installation and commissioning.
- Optimized cylinder speed and end cushioning increase productivity.
- All or, part of the sequence or total cycle time can be analysed.

The cylinder is equipped not only with conventional pneumatic cushioning, but with elastic cushioning rings in the end covers, reducing piston-to-end cover contact – a unique solution which combines two cushioning concepts.

The Rexroth concept

In principle, all new Rexroth cylinders are provided with some type of cushioning. This may take the form of simple impact cushioning, more sophisticated pneumatic cushioning or a combination of both.

However, since the early 1980s, Bosch Rexroth has consistently fitted elastic elements between the piston and end cover, either in the form of cushioning rings in the end covers or an integral, elastic element on the piston. This reduces the effect of piston-to-end cover contact; in other words, the frequency and noise level of the sound wave generated by the shock are reduced dramatically. Noise level reductions of 20–30 dBA, which means 4–8 times lower noise level, have been achieved in laboratory tests. The shock also causes less vibration than in cylinders in which contact produces metal-to-metal contact.

The most advanced type of cushioning is used in Rexroth ISO/VDMA cylinders.

Rexroth
Bosch Group

Bosch Rexroth AG
Bartweg 13
DE-30453 Hannover
Postfach 91 07 62
DE-30427 Hannover
Phone +49 (0) 511 - 2136 - 0
Fax +49 (0) 511 - 2136 - 269
www.boschrexroth.com

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