Chapter 7

Hydraulic cylinders

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1 Cylinders in hydraulic circuits

Nowadays both the hydraulic motor and the hydraulic cylinder are indispensible units in the hydraulic circuit for converting hydraulic energy into mechanical energy. The cylinder is the link between the hydraulic circuit and the working machine.

The hydraulic cylinder is different to the hydraulic motor which carries out rotary movements, in that it carries out translational (linear) movements, through which forces are transferred

Neglecting friction, the maximum possible cylinder force F is dependent on the maximum operating pressure p and the effective area A.

$$F = p \bullet A \text{ in kN}$$

If the working machine carries out linear movements, the following advantages arise for a drive with hydraulic cylinders:

- Simple design of direct drive with cylinders, easily arranged by installation engineer.
- As a rotary movement does not need to be converted into a linear movement, the cylinder drive has a high efficiency.
- Cylinder force remains constant from the beginning to the end of a stroke.
- The piston velocity which is dependent on the flow entering the piston and the area, is also constant over the whole stroke.
- Depending on the model, a cylinder may exert pushing or pulling forces.
- The dimensions of hydraulic cylinders makes it possible to construct drives with large power but small dimensions.

Lifting, lowering, locking and moving of loads are the main applications for hydraulic cylinders.

2 Types of cylinders with respect to functions

Due to their function, it is possible to categorise cylinders into two groups:

- Single acting cylinders
- Double acting cylinders

2.1 Single acting cylinders

Single acting cylinders can only exert force in one direction. The piston can only be returned by a spring, through the weight of the piston itself or by the action of an external force. Single acting cylinders basically have one effective area.

2.1.1 Plunger cylinders

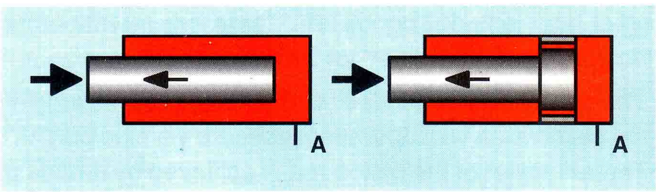


Fig. 1: *Plunger cylinder; left: without internal stop, right: with internal stop (piston guide)*

In this cylinder only pushing forces may be transferred.

Depending on the application, plunger cylinders may be designed with or without an internal stroke limiter. For the model without internal stroke limiter, the pushing force is calculated from the maximum effective piston area and the maximum operating pressure.

It must be noted that for the model with internal stroke limiter only the piston rod area is effective for the calculation of pressure force.

Plunger cylinders are used wherever a definite direction of external force will definitely return the piston to its starting position. Examples of this are upstroke presses, cutter stroke tables and lifting devices.

Pressurising the effective areas via pipe port "A" the piston extends (⇐). Retraction (⇒) of the piston can only occur through the weight of the piston or due to an external force being applied.

2.1.2 Cylinders with spring return

Cylinders with spring returns are used in applications where an external,restoring force does not exist. Return springs may be situated either within the cylinder or mounted onto the cylinder as a separate component. As springs can only carry out limited strokes and exert limited forces, these springs are mainly found in "small cylinders". Applications of this cylinder are pushing cylinders used in installation work or assembly tools used in repairs.

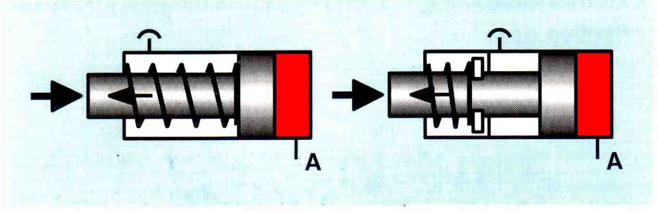


Fig. 2: *Single acting pressure cylinder; left: with internal spring, right: with external spring*

The piston rod is extended (⇐) by means of pressurising the piston area with operating pressure via pipe port "A". The retraction of the piston rod is achieved by means of the return spring.

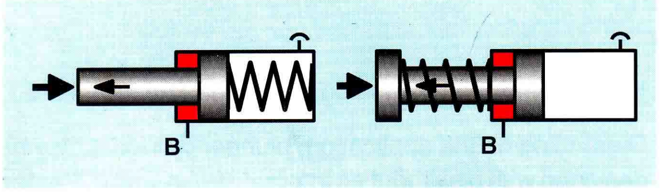


Fig. 3: *Single acting tension cylinder; left: with internal spring, right: with external spring*

By pressurising the effective annulus area with operating pressure via port "B", the piston rod is retracted (⇒). The rod is extended (⇐) by means of the installed return spring.

2.2 Double acting cylinder

Double acting cylinders have two opposing effective areas which are of the same or different sizes. They are fitted with 2 pipe ports which are isolated from each other. By feeding fluid via ports "A" or "B", the piston may transfer pulling and pushing forces in both stroke directions. This type of cylinder may be found in nearly all types of application.

Two categories of double acting cylinder exist: single and double rod cylinders.

2.2.1 Single rod cylinder

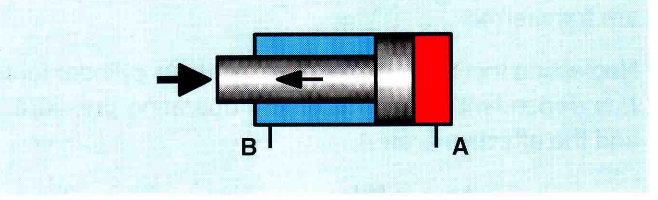


Fig. 4

In most applications cylinders are used with only one piston rod. Single rod cylinders have a piston, which is connected rigidly to a piston rod which has a diameter smaller than that of the piston. In these cylinders the sizes of the effective areas are different. The area ratio of piston area to annulus area is indicated by the factor (φ). The maximum amount of force transferred is dependent on the piston area as the cylinder is extended, on the annulus area as the cylinder is retracted and on the maximum operating pressure. This means that for the same operating pressure the extending force is a factor φ times larger than the retracting force. The chambers being filled are the same length due to the stroke, but because of the differences in piston and annulus areas, their volumes are different. Hence the stroke velocities are inversely proportional to the areas.

This means:

- Large area → slow movement
- Small area → quick movement

2.2.2 Double rod cylinder

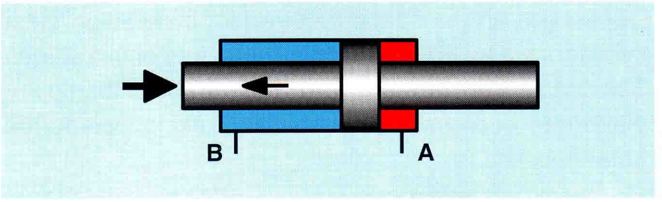


Fig. 5

Double rod cylinders have a piston, which is connected rigidly to two piston rods (often a single continuous through rod) which have diameters smaller than that of the piston. The maximum force transferred is dependent on the annulus areas which are the same size in both directions of movement and on the maximum operating pressure. This means that for the same operating pressure the forces in both directions of movement will be the same size. As the areas and the stroke lengths are the same on both size, the volumes of the chambers being filled must be the same size. Hence, the velocities must also be the same. For special applications, double rod cylinders may be made with different piston rod diameters.

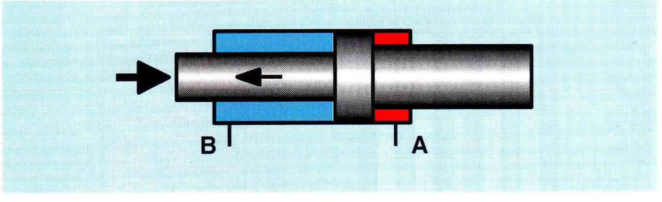


Fig. 6

In this model the forces and velocities (similarly to the single rod cylinder) are in the ratio of the area ratio φ of both annulus areas.

2.3 Special types of single and double acting cylinders

Certain applications exist, where standard single or double acting cylinders may only be used by taking special additional measures involving a lot of effort. The most common of these cases is where long strokes are needed with extremely little installation room or where the largest force is required for the smallest piston diameter. This and other requirements have led to a series of special models being designed, which are partly more difficult and take more effort to produce.

2.3.1 Tandem cylinders

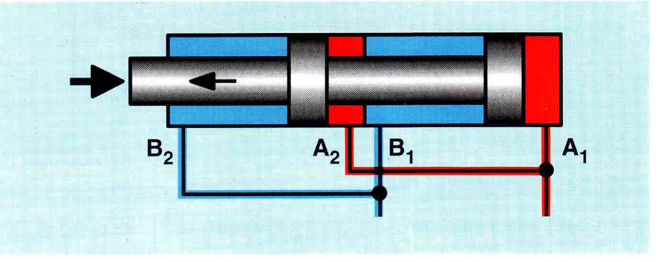


Fig. 7

In double acting cylinders operating in tandem, there are two cylinders which are connected together in such a way that the piston rod of one cylinder pushes through the bottom of the other cylinder to its piston area. By using this arrangement the areas are added together and large forces may be transferred for relatively small external diameters without increasing the operating pressure. However the longer length of this model must be taken into account.

2.3.2 Rapid traverse cylinders

Rapid traverse cylinders are used primarily in presses. In this cylinder, as long as the complete working force is not required, only part of the effective piston area, the co-called rapid traverse piston is placed under pressure. The complete effective piston area is only later connected to the hydraulic pump via a control system by means of pressure control valves or limit switches.

Advantages:

High rapid traverse velocity due to small volume

High pressing force due to large effective piston areas

2.3.2.1 Single acting rapid traverse cylinder

- Rapid traverse (⇐) via port "A1"
- Pressing force (⇐) via port "A2"
- Retracting movement (⇒) via weight of piston itself or through an external force being applied.

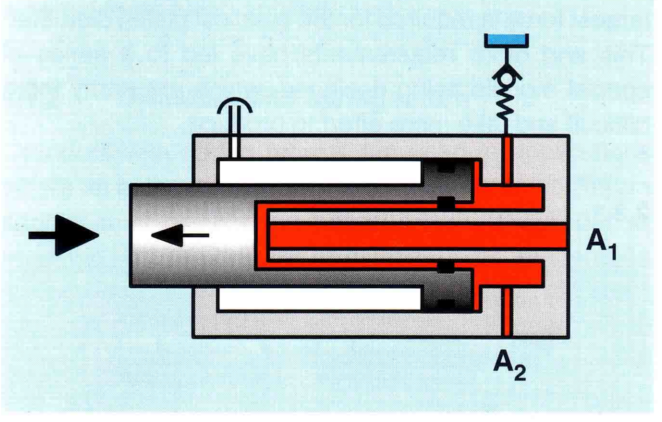


Fig. 8: *Single acting rapid traverse cylinder*

2.3.2.2 Double acting rapid traverse cylinder

- Rapid traverse (⇐) via port "A1"
- Pressing force (⇐) via port "A2"
- Retracting movement (⇒) via port "B".

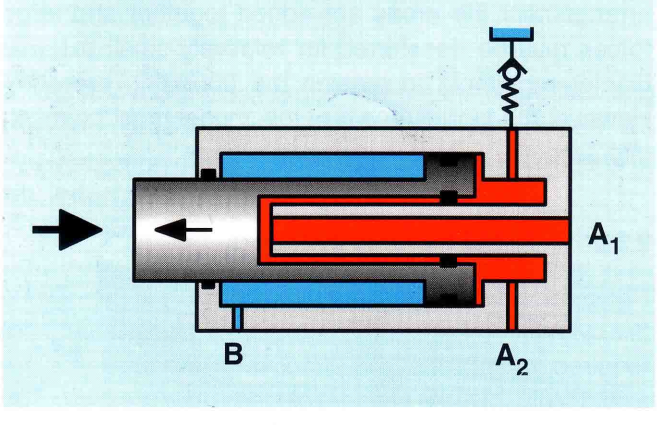


Fig. 9: *Double acting rapid traverse cylinder*

2.3.3 Telescopic cylinder

Telescopic cylinders vary from "normal" cylinders in that they only require a very small amount of space to be installed into when they are retracted in comparison to "normal" cylinders with the same stroke. The reduced space required for installation is due to the piston rods sliding into each other equal to the total length of stroke divided by the number of stages plus the zero stroke measurement (thickness at bottom, guide lengths, seal widths, fixings). This means that the space required for installation is only a little larger than one stage. The retracted length of a telescopic cylinder is normally between half and quarter of the cylinder's stroke. Dependent on the space required for installation these cylinders are available with two, three, four or five stages. Telescopic cylinders are used in hydraulic lifts, tipping platforms, commercial vehicles, lifting platforms, antennas, etc.

2.3.3.1 Single acting telescopic cylinders

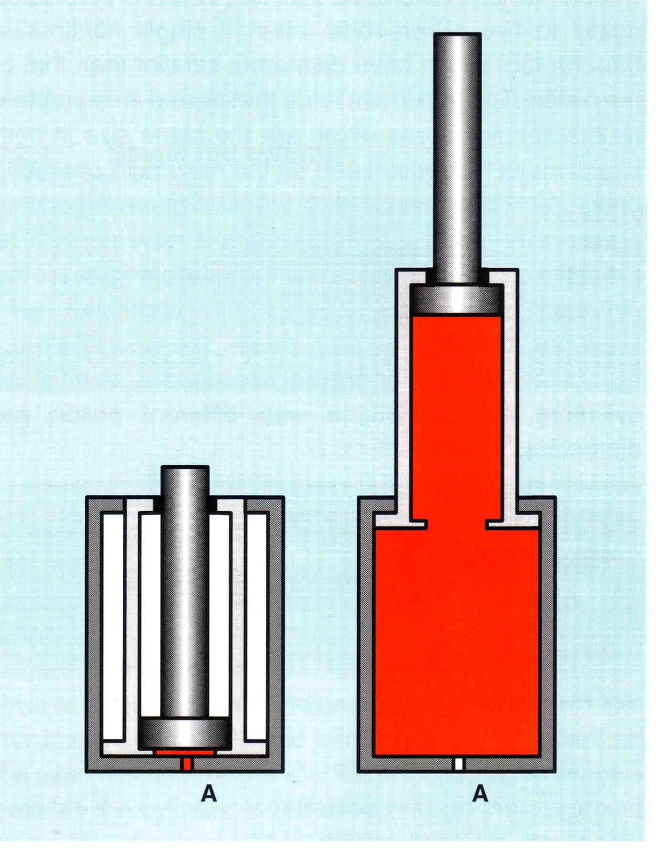


Fig. 10: *Single acting rapid telescopic cylinder*

If the pistons are placed under pressure via port "A", they extend one after another. The pressure is dependent of the size of load and the effective area. Hence the piston with the largest effective area extends first.

At constant pressure and flow the extension begins with the largest force and smallest velocity and finishes with the smallest force and highest velocity.

The stroke force to be used must be designed with the smallest effective piston area in mind. In simple acting telescopic cylinders the order in which the stages are retracted via an external load is reversed. This means, that the piston with the smallest area returns first to its starting position.

2.3.3.2 Double acting telescopic cylinders

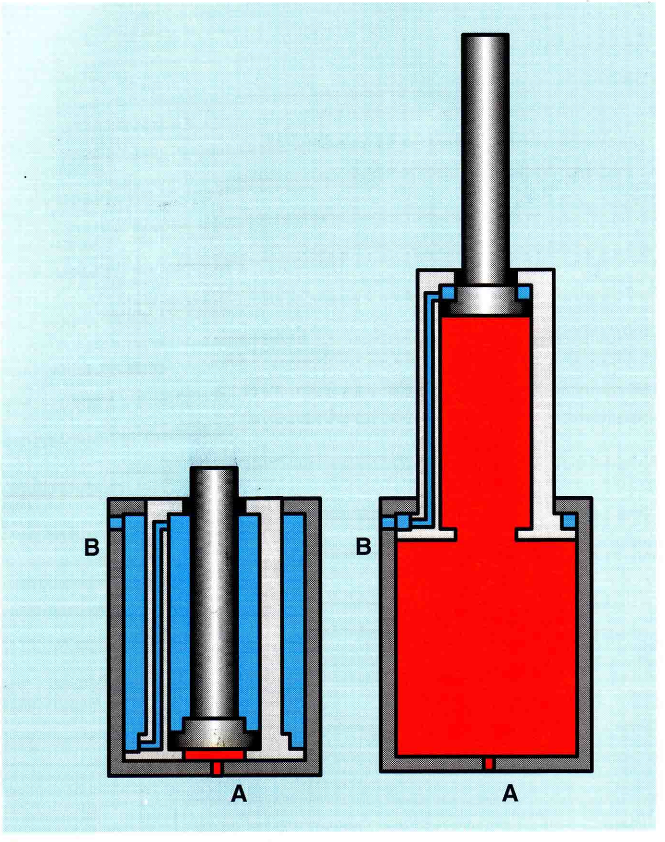


Fig. 11: *Double acting telescopic cylinder*

In double acting cylinders the pistons are extended in the same way as in single acting cylinders. The order in which the individual stages are retracted depends on the size of the annulus area and on the external load. The piston with the largest annulus area first returns to its starting position when it is placed under pressure via pipe port "B". Double acting telescopic cylinders may also be used as synchronised telescopic cylinders. In this model the various stages extend or retract in unison.

3 Basic design

The design of hydraulic cylinders depends to a large extent on the various applications. Cylinders have been developed to suit particular applications. There is a different cylinder design for each of the following examples: machine tools, mobile machines, civil engineering, steel and iron works, etc.

By using the single or double acting single rod cylinder, which is the one mainly used, the most common design principles will be discussed.

There are basically two types of design:

– tie rod cylinders and

– mill type cylinders (screwed or welded design)

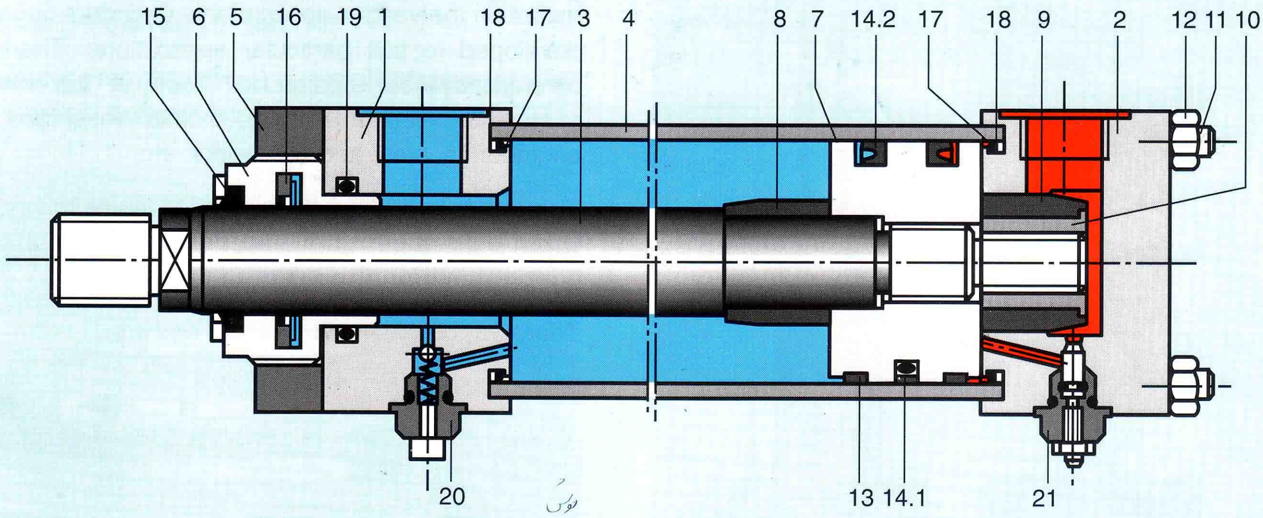
3.1 Tie rod cylinder

In tie rod cylinders the top of the cylinder, the cylinder tube and the bottom of the cylinder are all connected together via a tie rod. The main feature of a tie rod cylinder is its especially compact design.

As these cylinders are compact and space-saving they are primarily used in the machine tool industry and in manufacturing devices, such as conveyor belts and machining centres in the car industry.

Fig. 12: *Tie rod cylinders, series CD160 available in a range of diameters and mounting styles*

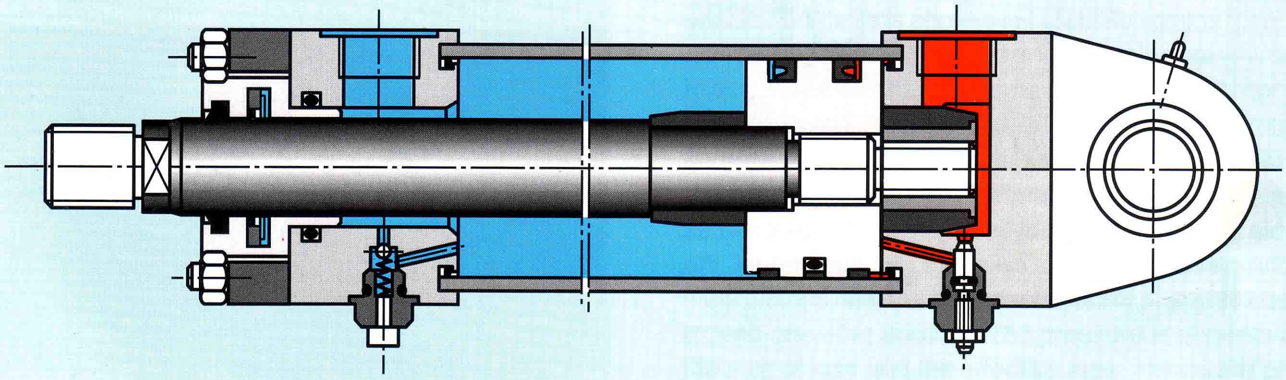
3.1.1 Individual parts and their names



1	Cap	**8**	Damping sleeve	**14.2**	Piston seal (model "A")
2	Base	**9**	Damping sleeve	**15**	Wiper
3	Piston rod	**10**	Threaded sleeve	**16**	Rod seal
4	Cylinder tube	**11**	Tie rod	**17**	O ring
5	Flange	**12**	Nut	**18**	Back up ring
6	Guide bush	**13**	Bearing band	**19**	O ring
7	Piston	**14.1**	Piston seal (model "T")	**20**	Check valve with bleed
				21	Throttle valve

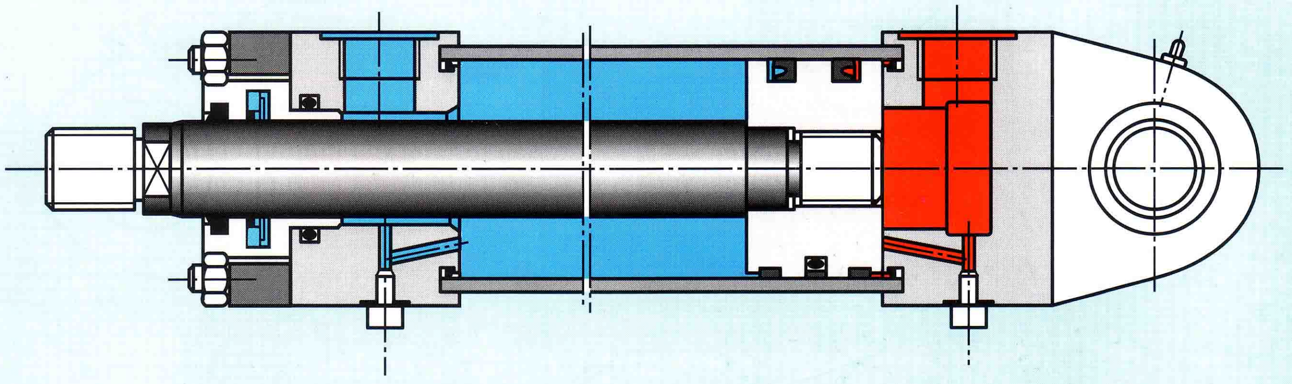
Fig. REF!: *Hydraulic tie rod cylinder with flange mounting*

3.1.2 Design notes



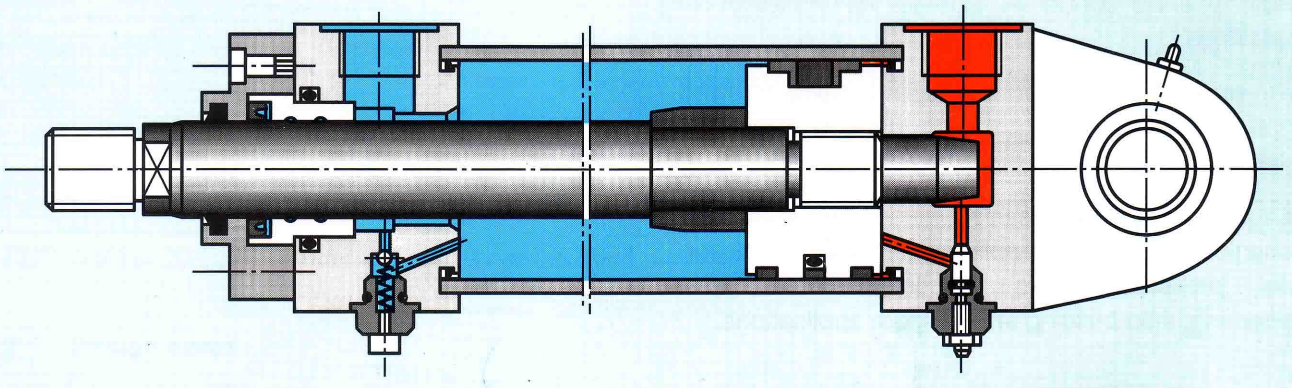
- Cylinder cap and base fixed to cylinder tube via tie rods
- Guide sleeve screwed into cylinder cap
- Seals either glide rings or lip seals
- Cushioning on both ends, damping bush supported by float bearings
- Throttle and check valves on both ends
- Standard bleed valves at both ends

Fig. REF!: *Hydraulic tie rod cylinder with swivel clevis mounting*



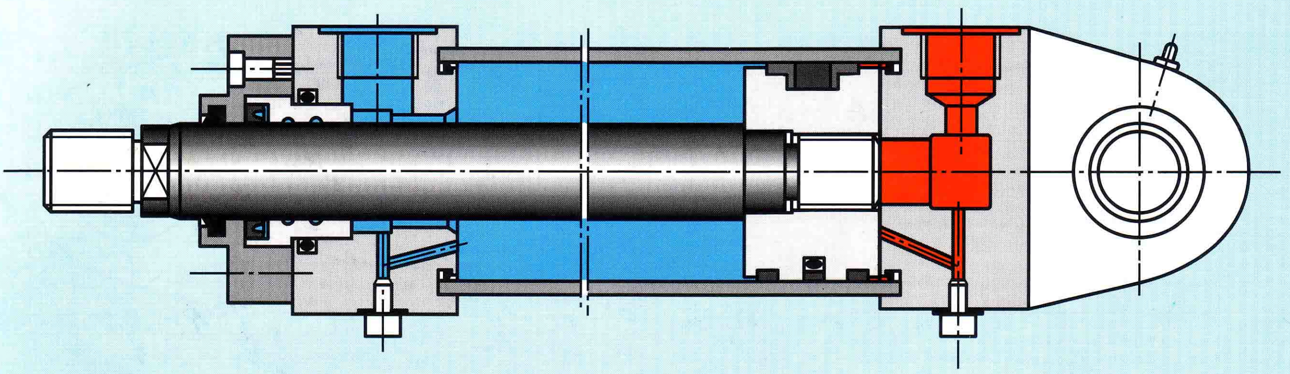
- Without end position cushioning (damping sleeve, throttle and check valves are omitted)
- Standard bleed valves at both ends

Fig. 15



- Cylinder ends are fixed to the cylinder tube via tie rods
- Bearing bush and flange cover pressed into cylinder head
- Seal model: compact lip seal/guide ring or glide ring seal/lip seal
- Cushioning: top: damping bush supported by float bearings, base: damping pivot
- Throttle and check valves on both ends
- Standard bleed valves at both ends

Fig. 16



– Without cushioning (damping sleeve, throttle and check valves are omitted)

– Standard bleed valve at both ends

Fig. 17

3.2 Mill type cylinders

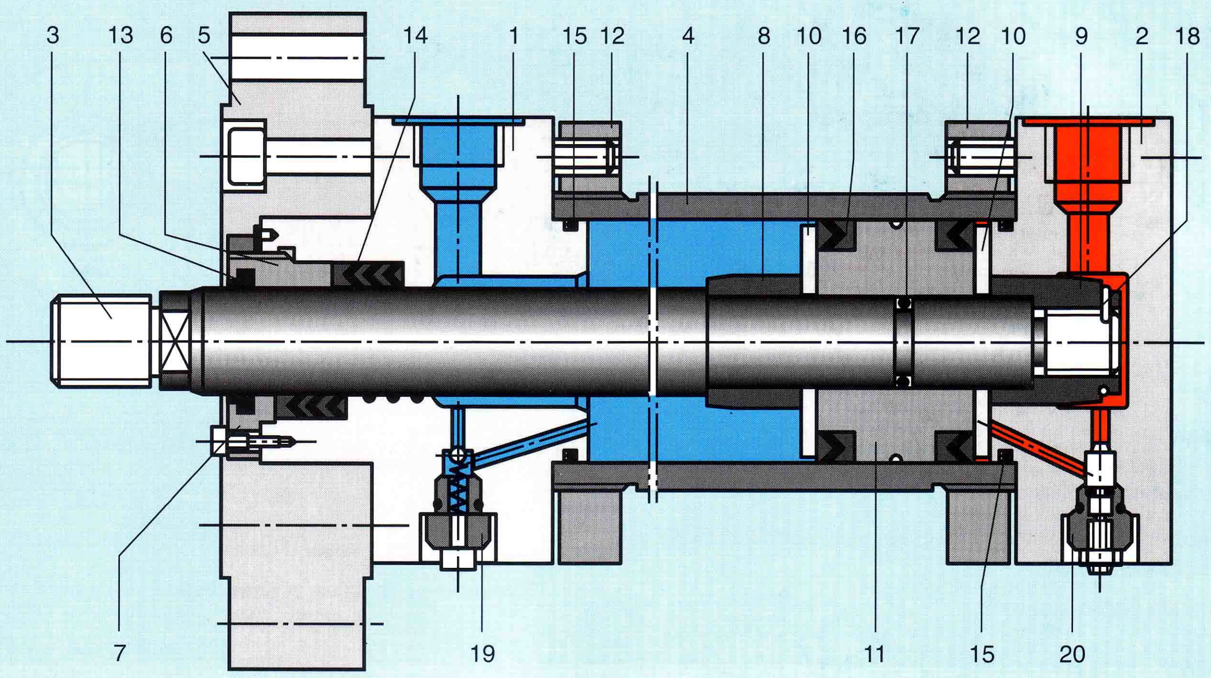
In mill type cylinders, the top and base of the cylinder and cylinder tube are connected together via threads or retaining rings.

Due to its robust design, hydraulic cylinders with screwed or welded constructions are also suitable for use in applications with extreme operating conditions.

The main applications of this cylinder are in general mechanical engineering applications, rolling mills, iron works, presses, cranes, mobile machines, civil engineering, ship-building and offshore applications.

Fig. 18: *Mill type cylinders, series CD 250 and CD 350*

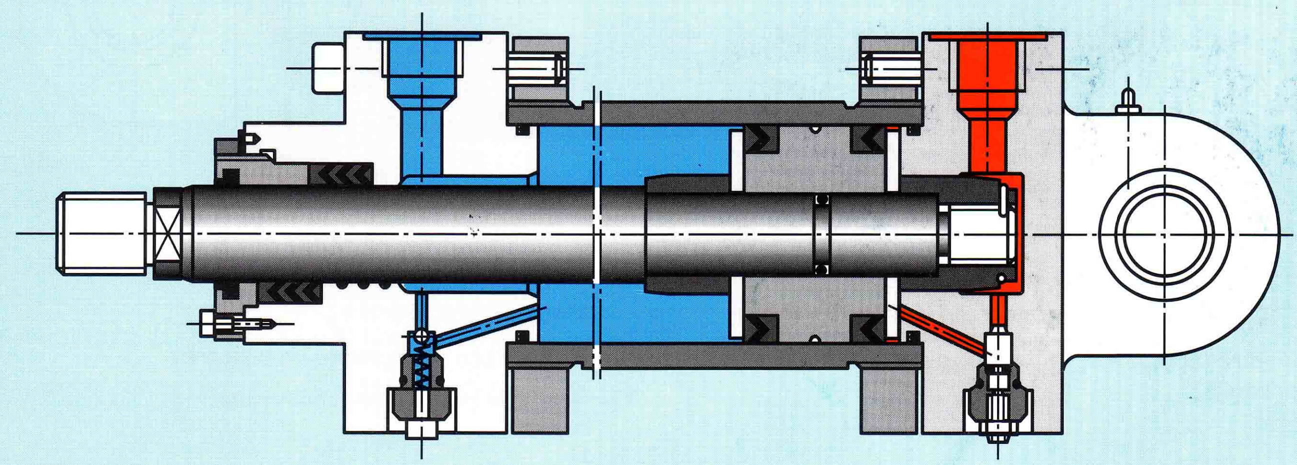
3.2.1 Individual parts and their names



1 Cap
2 Base
3 Piston rod
4 Tube
5 Flange
6 Guide bush
7 Cover
8 Damping bush
9 Damping bush
10 Retaining plate
11 Piston
12 Flange
13 Wiper
14 Rod seal
15 O ring
16 Piston seal (model "A")
17 O ring
18 Spring ring
19 Check valve with bleed
20 Throttle valve

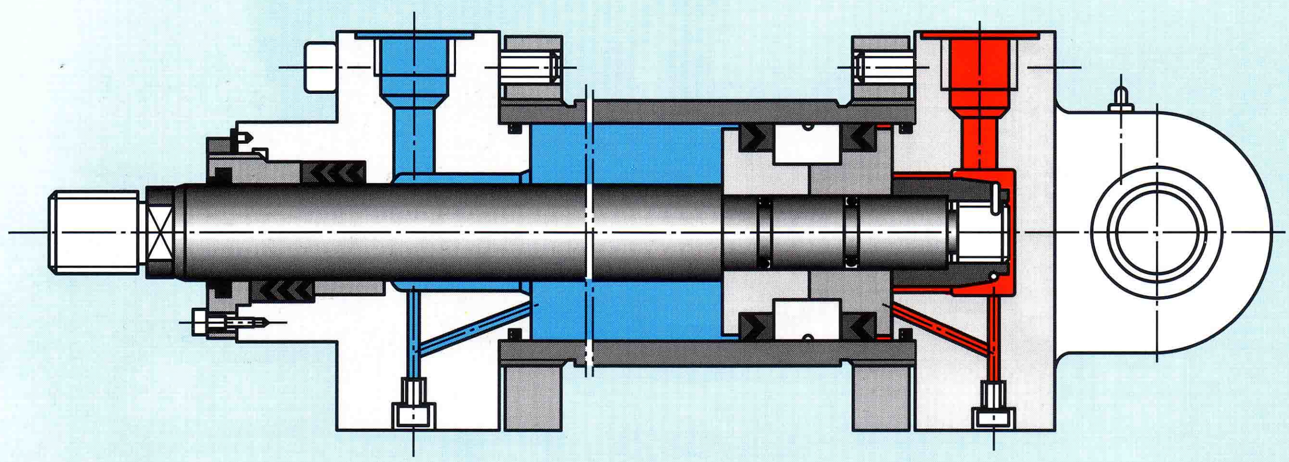
Fig. REF!: *Mill type hydraulic cylinder with front flange mounting*

3.2.2 Design notes



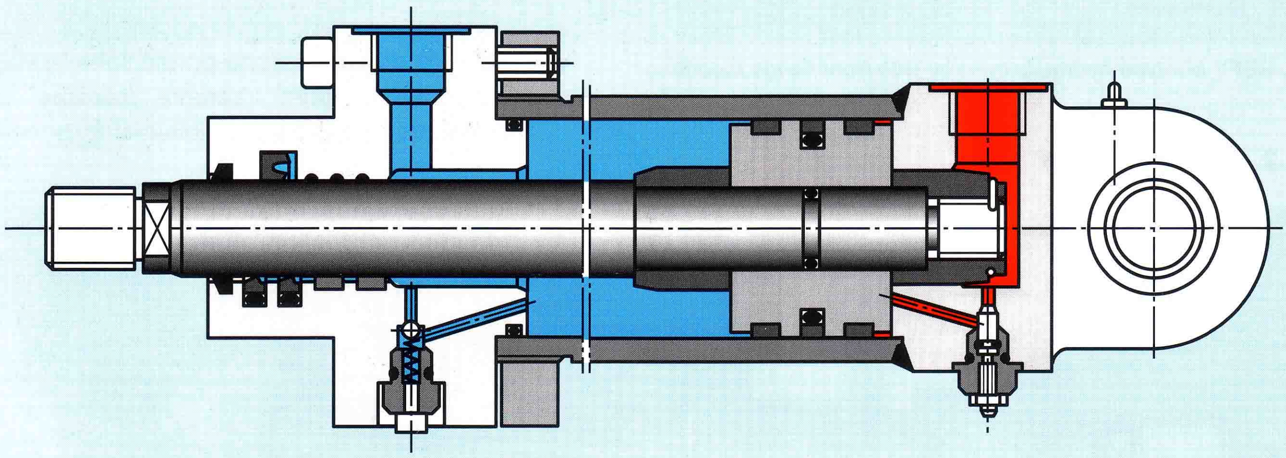
- Both ends of the cylinder are fixed to the cylinder tube by means of flanges
- Bearing integral with cylinder cap or as screw bush within the cylinder cap
- Chevron seals
- Cushioning at both ends
- Throttle and check valves on both ends
- Standard bleed valves at both ends

Fig. REF!: *Mill type cylinder with swivel clevis mounting*



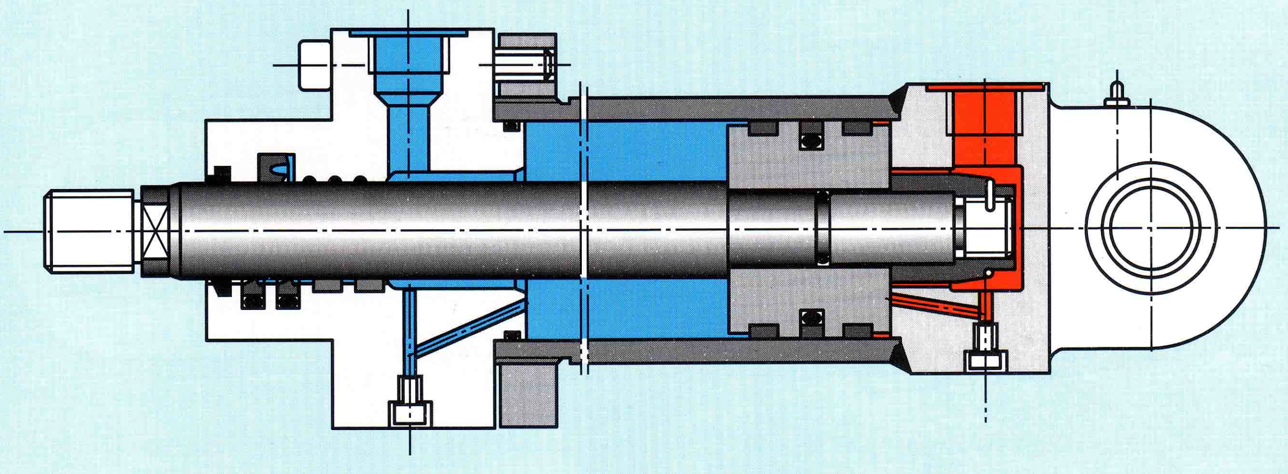
- Both ends of the cylinder are fixed to the cylinder tube by means of flanges
- Bearing integral with cylinder cap or as screw bush within the cylinder cap
- Bronze piston sleeve
- Chevron seals
- Without cushioning
- Piston fired by threaded bush
- Standard bleed valve at both ends

Fig. 21



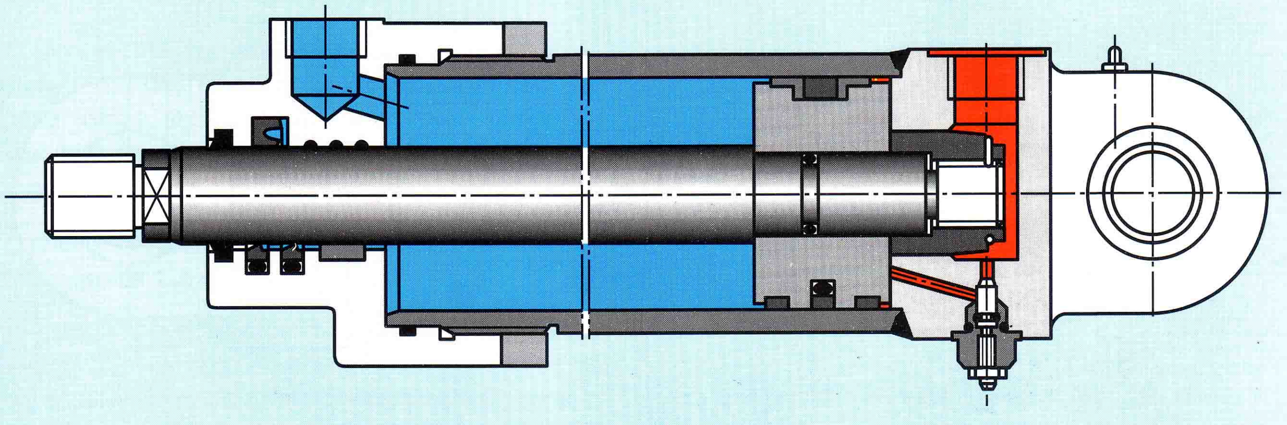
- Cylinder cap is fixed to cylinder tube by a flange
- Cylinder base welded into cylinder tube
- Piston rod bearing is direct in cylinder cap or via guide bands
- Seals: Glide ring seals or glide ring seal/guide bush
- Cushioning at both ends
- Throttle and check valves on both ends
- Standard bleed valve at both ends

Fig. 22



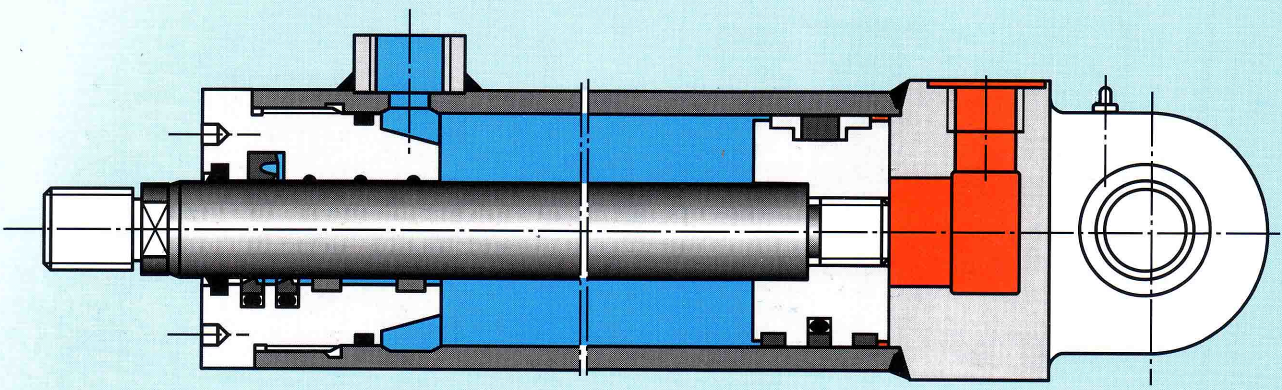
- Without cushioning (cushioning bush, throttle and check valves omitted)
- Piston fixed by threaded bush
- Standard bleed valve at both ends

Fig. 23



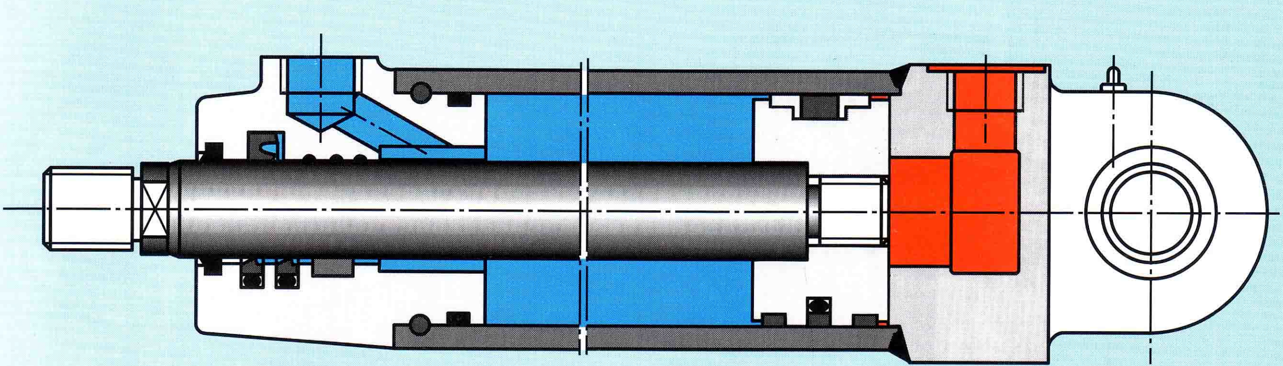
- Cylinder cap screwed onto cylinder tube and locked by a nut
- Cylinder base is welded into cylinder tube
- Piston rod bearing direct in cylinder cap or as guide bands
- Seals: Compact seal/lip seal or glide ring seals
- Cushioning only at base
- Bleed valve only at base

Fig. 24



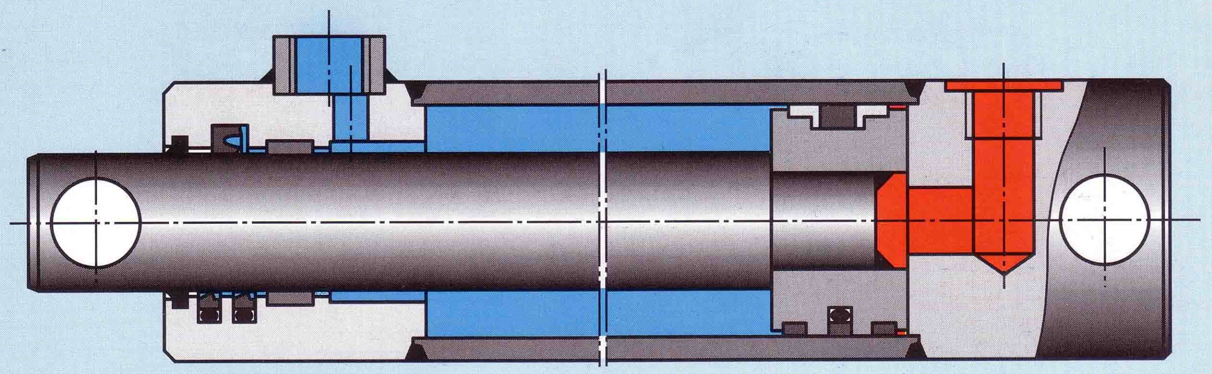
- Cylinder cap screwed into cylinder tube
- Cylinder base welded into cylinder tube
- Piston rod bearing direct in cylinder cap or as guide bands
- Seals: Compact seal/lip seal or glide ring seals
- Without cushioning

Fig. 25



- Cylinder cap fixed to cylinder tube via retaining ring
- Cylinder base welded into cylinder tube
- Piston rod bearing direct in cylinder cap or as guide band
- Seals: Compact seal/lip seal or glide ring seals
- Without cushioning

Fig. 26



- Both cylinder ends welded into cylinder tube
- Piston rod bearing by guide band
- Seals: Compact seal/lip seal or glide ring seals
- Without cushioning

Fig. 27

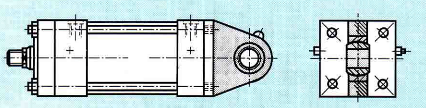
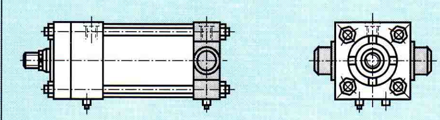
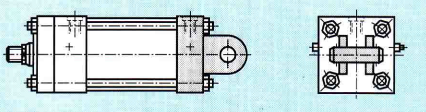
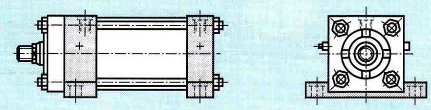
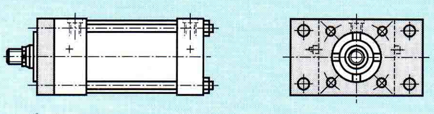
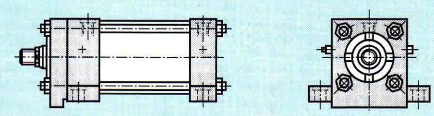
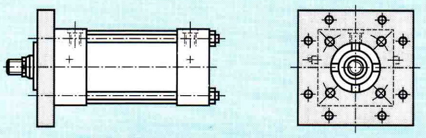
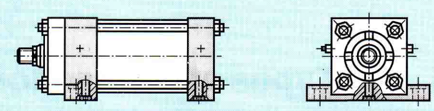
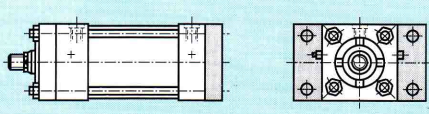
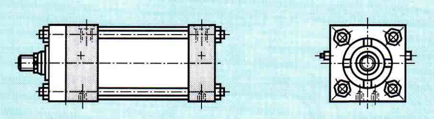
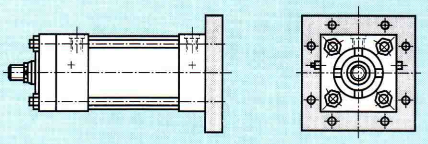
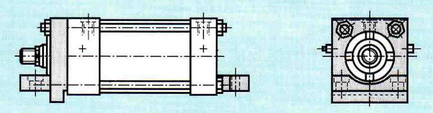
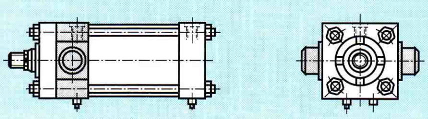
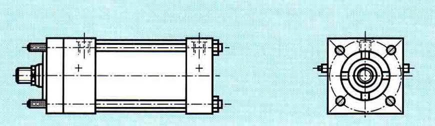
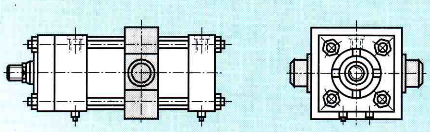
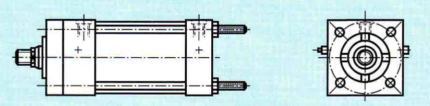
4 Types of connection and notes on installation

In addition to needing to know the operating pressure, piston and rod diameters, stroke length and pulling or pressing forces, it is necessary to know where the cylinder is to be installed, i.e. what type of mounting it requires.

A number of mounting possibilities for cylinders are shown in *tables 1 and 2*.

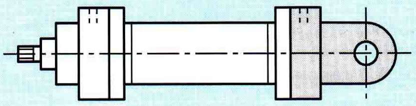
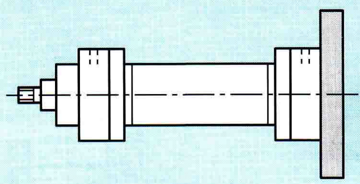
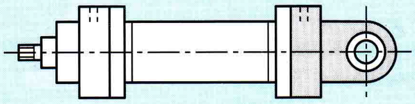
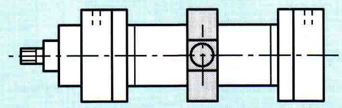
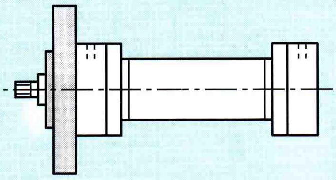
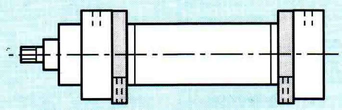
When installing hydraulic cylinders various criteria with respect to the type of mounting must be taken into account. Six of the most commonly used types of mounting with their installation notes are shown in table 3.

Swivel or plain clevis mounting are used at the rear of cylinders for mounting for more than 50 % of cylinders used.

Swivel clevis at cylinder cap		Trunnion mounting at cylinder cap	
Fork clevis at cylinder cap		[1] Foot mounting	
[1] Rectangular flange at cylinder head		[1] Foot mounting with key	
[1] Square flange at cylinder head		[1] Foot mounting with O ring seals for subplate mounting	
Rectangular flange at cylinder cap		[1] Threaded holes in cylinder head and cap	
Square flange at cylinder cap		Foot mounting with key at rod end	
[1] Trunnion mounting at cylinder head		[1] Extended tie rods at cylinder head	
[1] Trunnion mounting at centre of cylinder		Extended tie rods at cylinder cap	

[1] May also be used as double rod cylinder.

Table 1: *Types of mounting for tie rod cylinders*

Plain clevis at cylinder cap		Flange at cylinder cap	
Swivel clevis at cylinder cap		1) Trunnion mounting at centre of cylinder	
1) Flange at cylinder head		1) Foot mounting	

1) May also be used as double rod cylinder.

Table 2: *Types of mounting for cylinders with screwed or welded constructions*

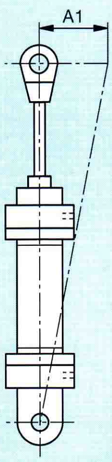
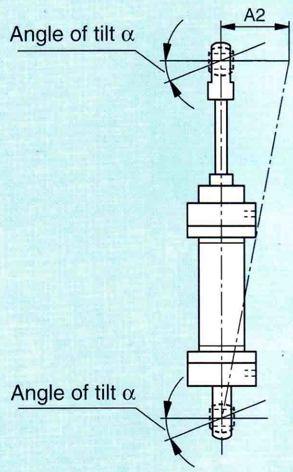
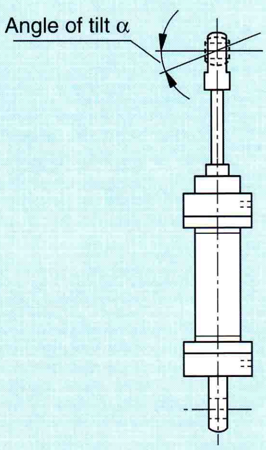
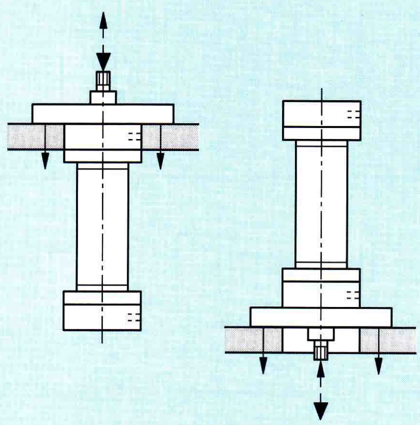
Plain clevis bearing at both ends *Note* Axis may only be moved in the direction of clevis		**Swivel clevis at both ends** *Note* Axis may be moved in any direction with tension free installation	
Plain clevis at cylinder base and swivel clevis at rod bearing *Note* Additional inaccuracies in parallelism of both axis pins are com-pensated for			

Table 3a: *Installation notes*

Front flange mounting

Note
Preferably installed vertically

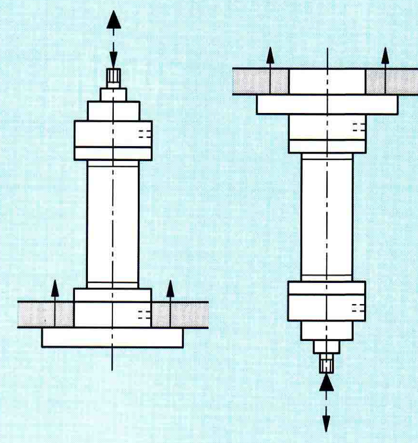
In main loading case (pulling or pushing) fixing screws must not be subject to load at the flange. Hence the types of installation shown are preferable.



Rear flange mounting

Note
Preferably installed vertically

In main loading case (pulling or pushing) fixing screws must not be subject to load at the flange. Hence the types of installation shown are preferable.

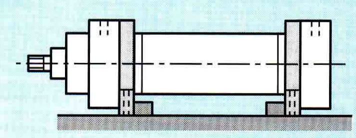


Centre trunnion mounting

Note
If installed horizontally the cylinder suspension at the centre of gravity provides a good loading on the bearing.

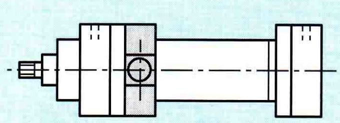
Foot mounting

Note
Fixing screws must be protected from shearing loads. Supports must be used to receive the cylinder forces.



Front trunnion mounting

Note
Due to the shorter bending length this type of mounting may be used with a larger max. stroke.
If installed horizontally, the higher loading on the bearing must be taken into account.



Rear trunnion mounting

Note
Due to the longer bending length this type of mounting is used with a shorter max. stroke.
If installed horizontally, the higher loading on the bearing must be taken into account.

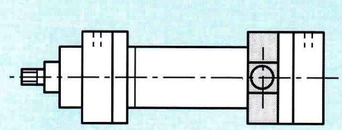


Table 3b: *Installation notes*

5 Buckling

5.1 Buckling without side loading

Special problems to do with stability occur when cylinders with long stroke lengths are used.

For the purpose of calculation these cases are divided into areas:

- Non-elastic buckling loads (Tetmajer's calculation) and
- elastic or Hook's buckling loads (its critical limiting load is determined by Euler's equation)

In hydraulic cylinders Euler's calculation is basically the calculation used, as the piston rod may usually be considered to be a slender strut (negligible diameter).

Buckling load and operating load are then calculated as follows:

Buckling load $$K = \frac{\pi^2 \bullet E \bullet J}{s_K^{\,2}} \text{ in N} \quad (1)$$

i.e. the rod buckles under this load!

Max. operating load $$F = \frac{K}{S} \text{ in N} \quad (2)$$

s_K = free buckling length in mm
E = modulus of elasticity ($2.1 \bullet 10^5$ for steel) in N/mm^2
J = moment of inertia for circular cross-section in mm^4
= $(d^4 \bullet p) / 64 = 0.0491 \bullet d^4$
S = safety factor (3.5)

The length to be used as the free buckling length may be determined from the Euler loading cases (see table 4). In order to simplify the calculation the stiffening due to the cylinder tube is ignored. This provides the required safety margin in standard cylinders, the installation position of which is usually not known, in order to cater for any superimposed bending loads.

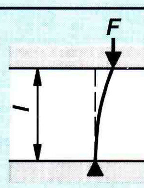
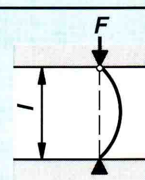
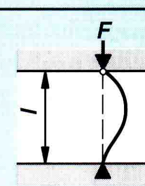
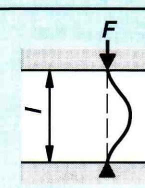
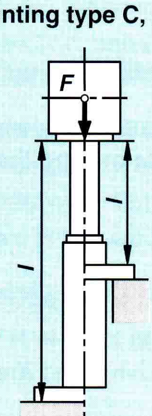
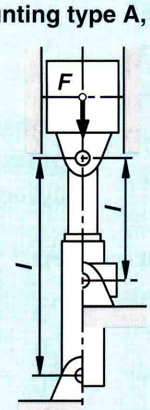
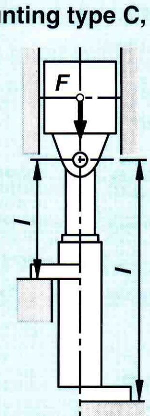
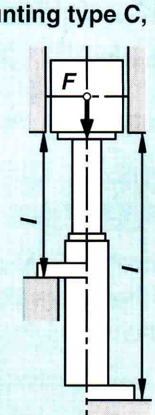
Euler's loading case	**Case 1** One end free, one end rigidly connected.	**Case 2** **(Basic case)** Two ends pivoted.	**Case 3** One end pivoted, one end rigidly connected.	**Case 4** Two ends rigidly connected.
Illustration				
Free buckling length	$s_K = 2\,l$	$s_K = l$	$s_K = l \bullet \sqrt{(l/2)}$	$s_K = l/2$
Installation position for cylinder	**Mounting type C, D, F** 	**Mounting type A, B, E** 	**Mounting type C, D, F** 	**Mounting type C, D, F** 
Note			Load must be carefully guided, or else possible bracing.	Not suitable, as bracing is to be expected.

Table 4: *Euler's loading cases*

5.2 Buckling with side loading

A particular reference must be made to clevis mounted cylinders (Euler case 2), when used either horizontally or inclined at a large angle.

Besides the pure compression loads, bending occurs due to the weight of the cylinder itself.

Particular attention must be paid to large cylinders with long strokes and which are very heavy.

6 Cushioning

6.1 Cushioning at cylinder base (*Fig. 29*)

The piston (1) is fixed onto the piston rod by means of a cushioning bush.

When the tapered cushioning bush (2) enters the bore in cylinder cap (3), the opening for the fluid leaving the piston chamber (4) decreases until it eventually reaches zero. The fluid from the piston chamber (4) can now only drain away via bore (5) and the adjustable throttle valve (6). The cushioning effect is set at the throttle valve (6). The smaller the opening to flow is, the larger is the effect of cushioning at the end positions.

6.1.1 Adjustable throttle valve for cushioning

The design of the throttle valve stops the throttle screw (7) from being unscrewed when the end position cushioning is set. The setting of the cushioning is protected by means of a lock nut (8).

6.1.2 Check valve with bleed screw

Check valve (9) is used to help the cylinder extend from its starting position. Hence the throttling point is by-passed when the cylinder is extended. Any air in the cylinder may be removed by the bleed screw (10).

In cylinders without cushioning the bleed screw is included as standard.

The throttle valve and the check valve are basically built from the same components and hence they may be interchanged.

6.2 Deceleration force

Cushioning must enable a controlled deceleration (braking) of the stroke velocity in both end positions. When damping starts, all effective energies (formed from product of moving mass and stroke velocity) must not exceed the max. working capability of the damping. The energy being decelerated is converted into heat in the cushioning valve, which works by throttling the fluid flow.

6.2.1 Calculation of deceleration force

The deceleration force of a hydraulic cylinder installed horizontally is calculated as follows:

Extension $F_B = m \bullet a + A_K \bullet p$ (3)

Retraction $F_B = m \bullet a + A_R \bullet p$ (4)

F_B = braking force in N
m = moving mass in kg
a = deceleration in m/s^2 ($a = v^2 / (2 \bullet s)$)
v = stroke velocity in m/s
s = cushioning length in m
A_K = piston area in cm^2
A_R = annulus area in cm^2
p = system pressure in N/cm^2

1 bar ≈ 10 N/cm^2

For vertical stroke movements of the cylinder the weight force (comprising external load, piston and piston rod) must be added or subtracted (depending on the direction of movement) to the braking force F_B.

The cylinder internal friction may be ignored in this calculation.

6.2.2 Calculation of mean cushioning pressure

Under normal circumstances the mean cushioning pressure must not exceed the nominal pressure of the cylinder.

$p_D = F_B / A_D$

p_D = mean cushioning pressure in N/cm^2
F_B = deceleration force in N
A_D = effective cushioning area in cm^2

1 bar ≈ 10 N/cm^2

If the calculation produces a cushioning pressure which is too high, either the cushioning length must be made larger or the system pressure must be decreased.

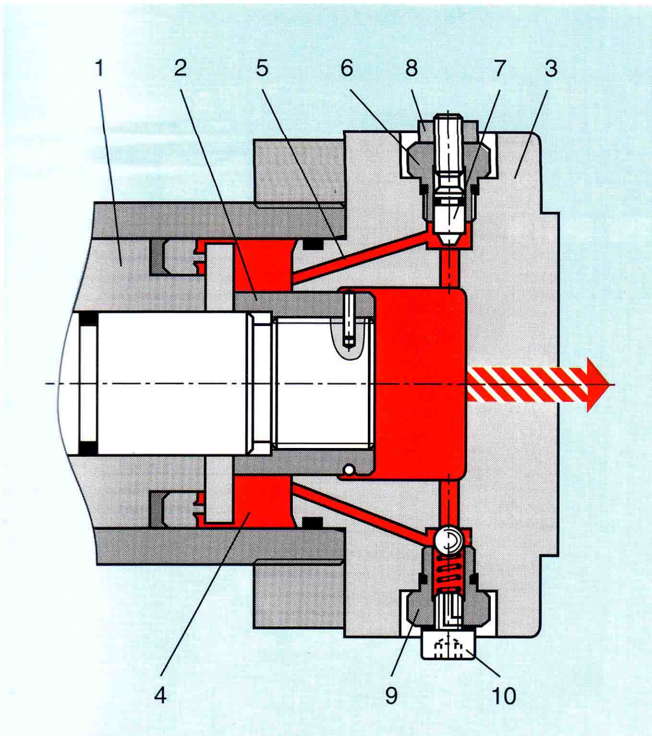


Fig. 29: *Adjustable cushioning at cylinder base*

7 Servo cylinder systems

Servo cylinder systems are a unique sub-group of cylinders.

They are not categorised in accordance with their general techical design as industrial and mobile cylinders are, but instead they are categorised in accordance with the type of bearing of the piston rod (hydrostatic bearing).

Cylinders with hydrostatic bearings are used in applications where low friction and/or high oscillation frequencies with small amplitudes are required.

Servo cylinder systems are primarily used in movement simulators, material and component testing devices and anywhere where the highest of dynamic responses and accuracy of the linear drive is required.

Servo cylinder systems basically comprise the following devices:

- servo cylinder
- servo manifold and
- control electronics

7.1 Servo cylinder

Four characteristics are used to determine which type of cylinder is to be used:

- Permissible amount of friction of cylinder under operating conditions
- Side loads on the piston rod
- Required velocities of the cylinder
- Smallest amplitude or control movements

Dependent on the conditions of use there are basically two designs which are used:

- Servo cylinder with hydrostatic tapered gap bearings of the piston rod without pressurised seals.
- Servo cylinder with full hydrostatic bearings (cavity bearings) of the piston rod without pressurised seals.

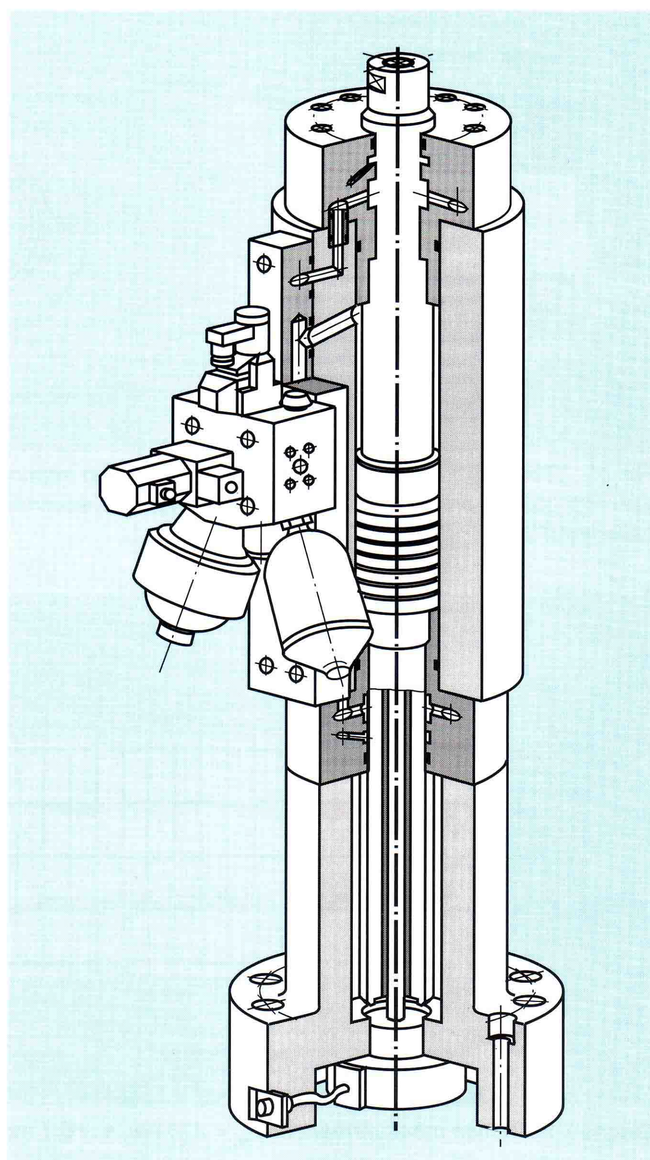


Fig. 30: *Servo cylinder with mounted servo manifold*

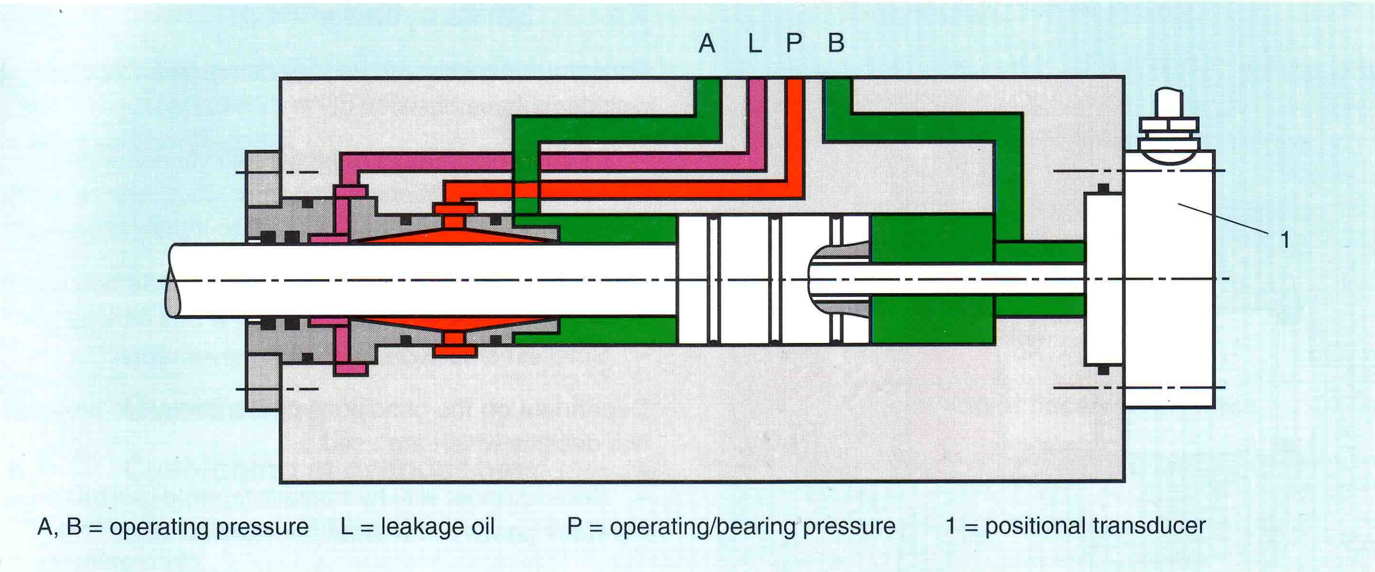


Fig. 32: *Schematic diagram of servo cylinder with hydrostatic tapered gap bearing supporting piston rod*

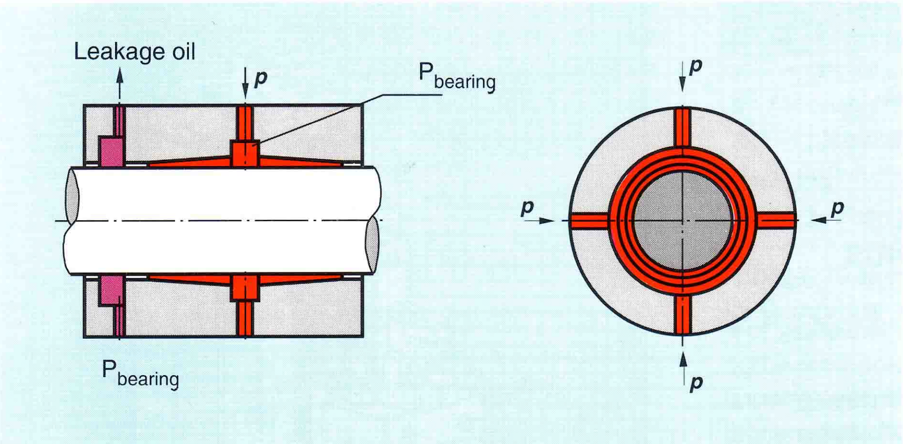


Fig. 33: *Schematic diagram of hydrostatic tapered gap bearing supporting piston rod. The bearing pressure in the taper gap bearing is equivalent to the operating pressure (P)*

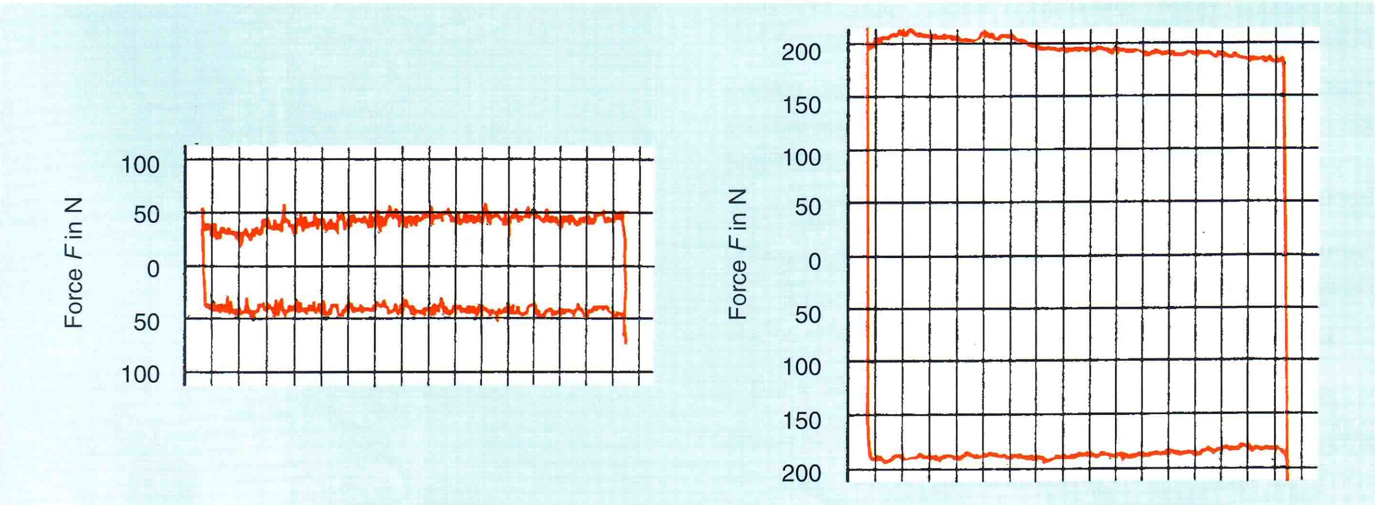


Diagram 1: *Friction measurement at p_{St} = 210 bar, v = 0.1 m/s and s = ± 100 mm; (left) servo cylinder with hydrostatic taper gap bearing, (right) hydraulic cylinder with glide ring seal*

7.1.1 Hydrostatic tapered gap bearings

Servo cylinders with tapered gap bearings are used in applications with velocities of up to v_{max} = 2 m/s and small side loads (e.g. effects of mass of cylinder and moments of inertia).

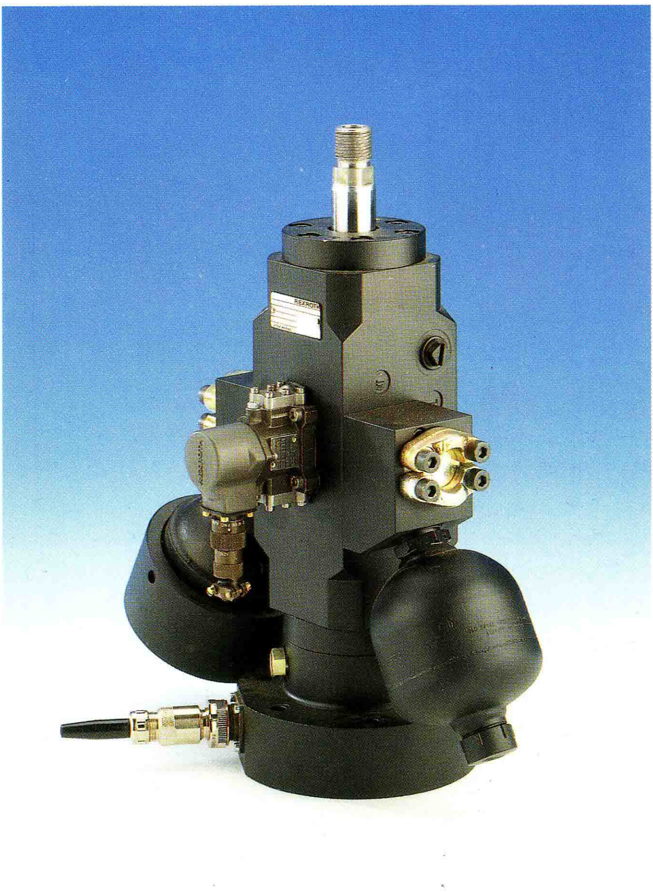


Fig. 31: Servo cylinder with tapered gap bearing

The series is designed for operating pressures of up to 210 bar and for nominal forces of 1 to 4000 kN.

Possible ways of mounting are: clevis bearings at either end, flanges at either end, base mounting or trunnion mounting.

The servo cylinders are supplied with an internal, stationary, inductive positional measuring system as standard. With this measuring system, the piston stroke is measured and the actual value is sent to the control electronics.

The seals built into the servo cylinders are not pressurised by the working pressure. Hence very low friction is produced in this type of bearing. Disruptive stick-slip effects are avoided. These avantageous characteristics are shown in the friction diagrams (*Diagram 1*).

The comparison shows that friction is 3 or 4 times lower in servo cylinders.

is ignored. If a side load acts on the piston rod, the bearing pressure is increased in the opposing cavity. Hence the piston rod is still held in the central position.

The amount of friction occuring in full hydrostatic bearings (cavity bearings) is the same as for tapered gap bearings (shown in *diagram 1*). However this amount of friction is also valid in cavity bearings under side loads, as the piston rod is not able to rub against the bearing surfaces and hence friction remains at a constant low level.

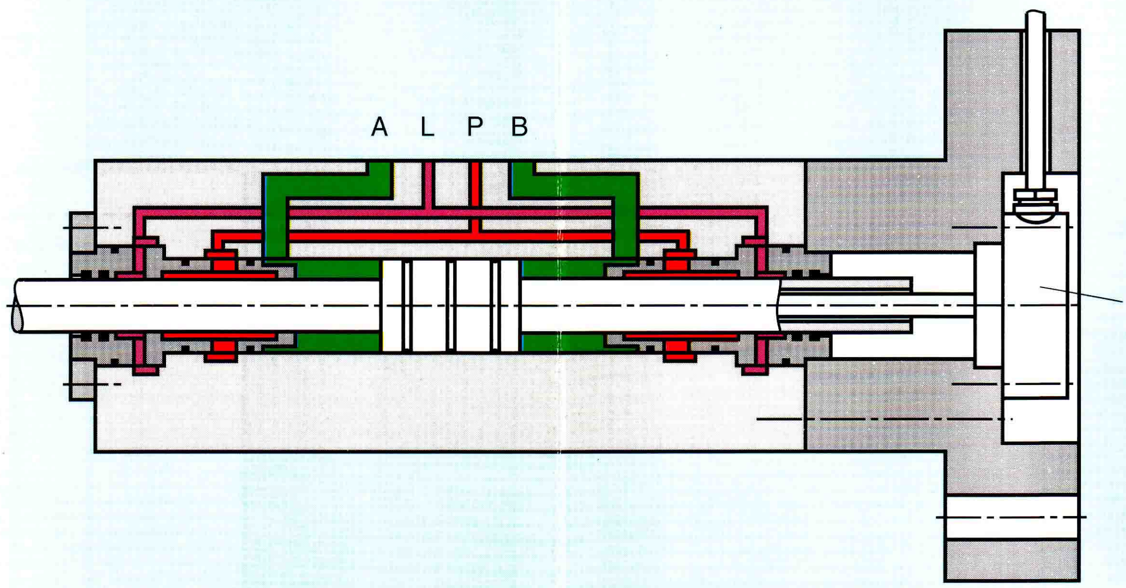


Fig. 35: *Schematic diagram of servo cylinder with full hydrostatic bearings (cavity bearings) supporting the piston rod*

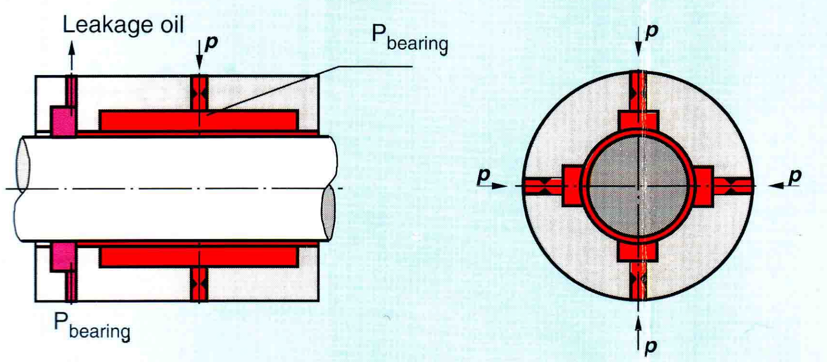


Fig. 36: *Schematic diagram of full hydrostatic bearings (cavity bearings) supporting the piston rod*

7.1.2 Full hydrostatic bearings (cavity bearings)

In hydraulic cylinders which are used at high as well as low velocities and which may be under high side loads full hydrostatic bearings (cavity bearings) are used.

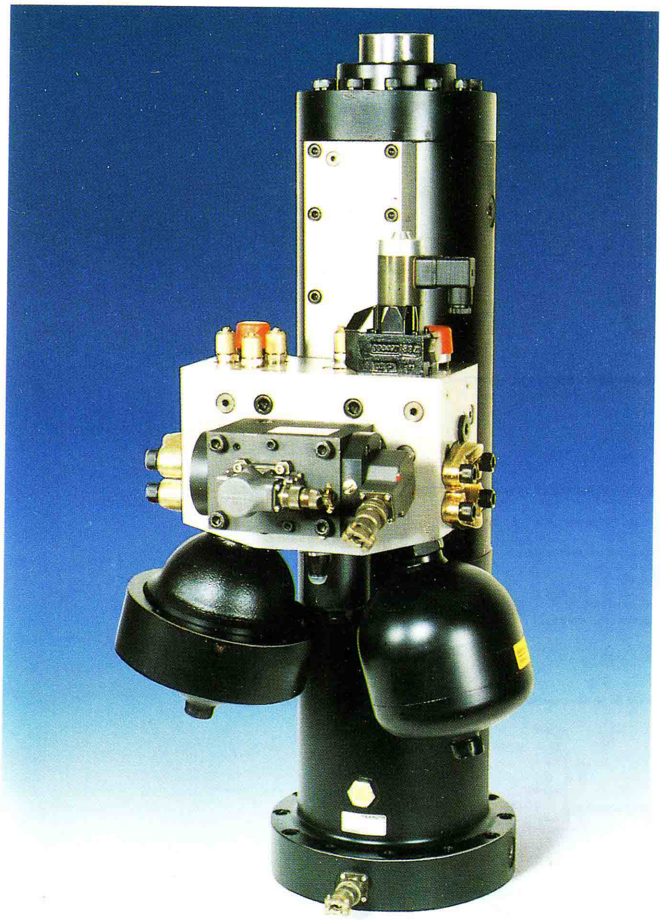


Fig. 34: *Servo cylinder with full hydrostatic bearings (cavity bearings) and mounted servo manifold*

The series is designed for operating pressures of up to 280 bar and for nominal forces of 10 to 10 000 kN.

Possible ways of mounting are: flange at either end or clevis or trunnion mounting. The types of mounting may be combined.

Servo cylinders are supplied with an internal, stationary, inductive positional measuring system as standard. With this measuring system, the piston stroke is measured and the actual value is sent to the control electronics.

This design has four cavities arranged around the circumference of the bearing, which provide the piston rod with four coupled pressure fields hence holding the rod in the central position.

The bearing pressure in the cavity is equivalent to 50% of the operating pressure (*P*) if the effect of the side loading

7.2 Servo manifold

In order not to unnecessarily reduce the good dynamic characteristics of hydraulic drives, the pipe lengths between the control and servo cylinder must be kept as show as possible. In order to achieve this, the servo manifold is mounted directly onto the servo cylinder.

The piping to the power unit or to the isolating system is via a servo manifold. Additional functions, such as force limiting, pilot oil and bearing oil filtration and pressure storage are included within this manifold.

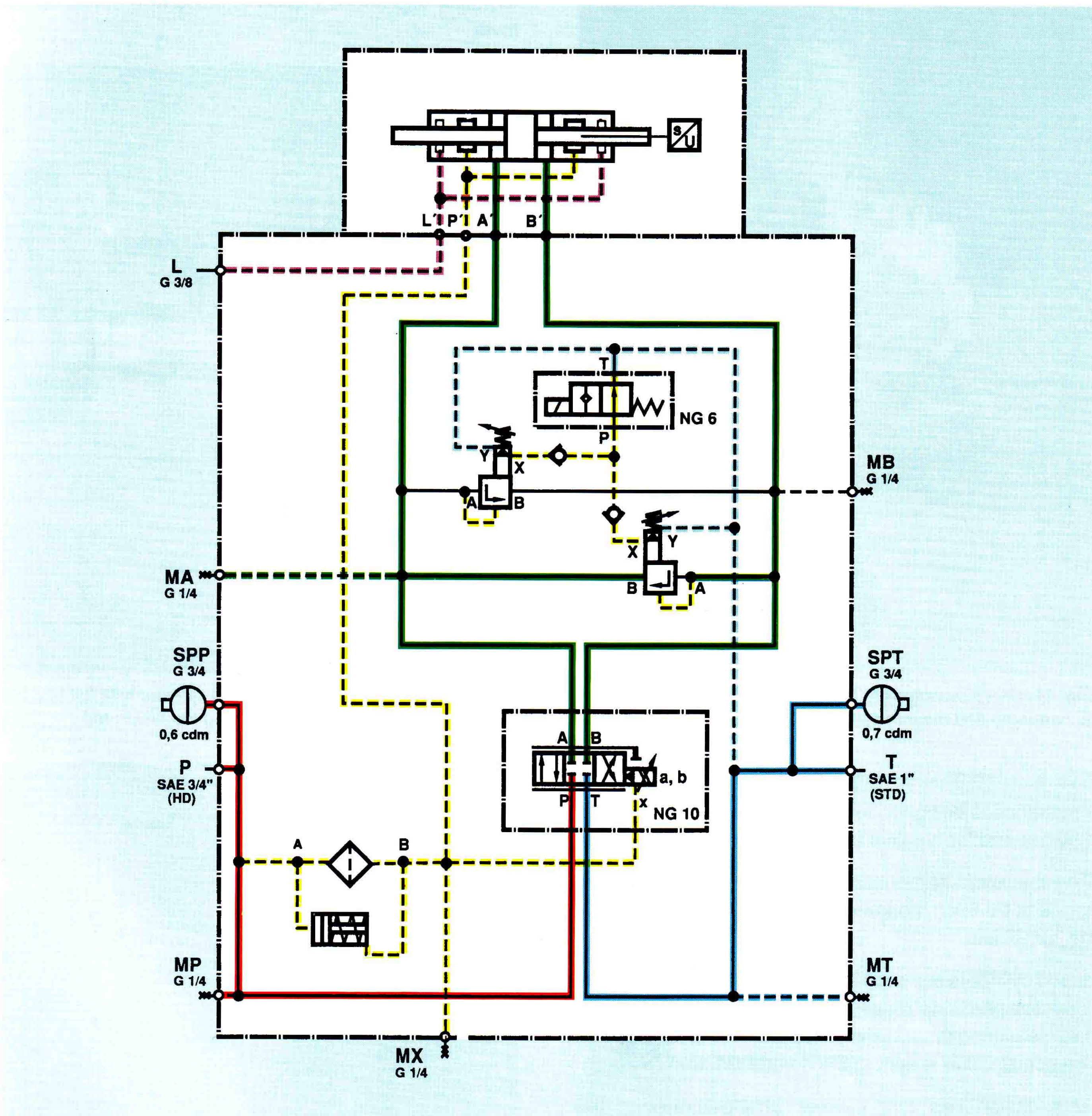


Fig. 37: *Typical circuit diagram of a servo cylinder with mounted servo manifold*