The Hydraulic Cylinder

Ton Huinink

1 General

What is a hydraulic cylinder?

The glossary for "Fluid Power", ANSI Standard B.92.21971 gives the following definition:

> A hydraulic cylinder is a mechanism that converts hydraulic energy into a linear force and movement. In other words, it is a linear hydraulic motor. Usually this consists of a moving element such as piston with a piston rod or a plunger operating in a cylindrical bore.

As the hydraulic cylinder is a hydraulic motor, one may also speak of functions, types, models and specific qualities of the hydraulic cylinder. This motor also has a specific power, efficiency, medium, working temperature, adjustment and control.

Hydraulic cylinders are normally designed for working pressures of up to 350 - 400 bar and occassionally up to 600 bar and more for special purposes.

Apart from its function to a linear hydraulic motor, the cylinder is also structural element. As structural element it must not only generate forces but also absorb forces.

The hydraulic cylinder, as a linear motor and structural element, is greatly influenced by environmental circumstances. Elements such as temperature, humidity and corrosive influences largely determine to what extent the cylinder comes up to one's expectations and are therefore decisive with respect to quality. Therefore, in the design and construction of a cylinder, the following will must be closely considered:

1 function as a hydraulic motor
2 function as structural element
3 influences from immediate surroundings

2 Cylinder Types

Basically, there are two types.

Judged by the nature of the generated force the cylinders may be classified as follows:

1 Single-acting cylinders
2 Double-acting cylinders

1 Single-acting cylinders

The pressure medium moves the cylinder into one direction, outgoing or ingoing, and can therefore exert a pushing force or a pulling force. The single-acting cylinder has only one oil connection, the other side has an air supply through an airfilter. The return movement is effected as a result of gravity (own weight possibly with ballast) or by means of a return spring.

2 Double-acting cylinders

The double-acting cylinder has two oil connection ports and the pressure medium moves the cylinder in both directions. The cylinder exerts both a pushing and pulling force.

3 Cylinder Models

There are two main types of cylinder models to be distinguished:

1 Single rod construction
2 Double rod construction (through rod)

1 The usual cylinder model is the single rod construction. These cylinders have a piston connected to a piston rod of a smaller diameter. This creates two areas on which a pressure may be excerted. Consequently, at constant pressure the cylinder produces a greater force at the extending movement than at the retracting movement. The ratio between piston area and ring area is called the phi-factor.

2 Cylinders with double rod construction are applied when:

a the pulling and pushing speed must be equal without special control components.

b a pulling and pushing force are required simultaneously, for example, the operation slide of a grinding machine.

By the application of dissimilar rod diameters the forces (pulling and pushing) and speeds may be arranged in a specific ratio.

3 Derivative cylinder models

a Plunger cylinder

This is a special single-acting cylinder in which piston and rod diameter are the same. The cylinder can only exert a pushing force.

b Telescopic cylinder

These cylinders can have both a single-acting and a double-acting design. They are applied when there is not enough room for the desired stroke. The telescoped length may vary from 1/4 to 1/2 of the stroke.

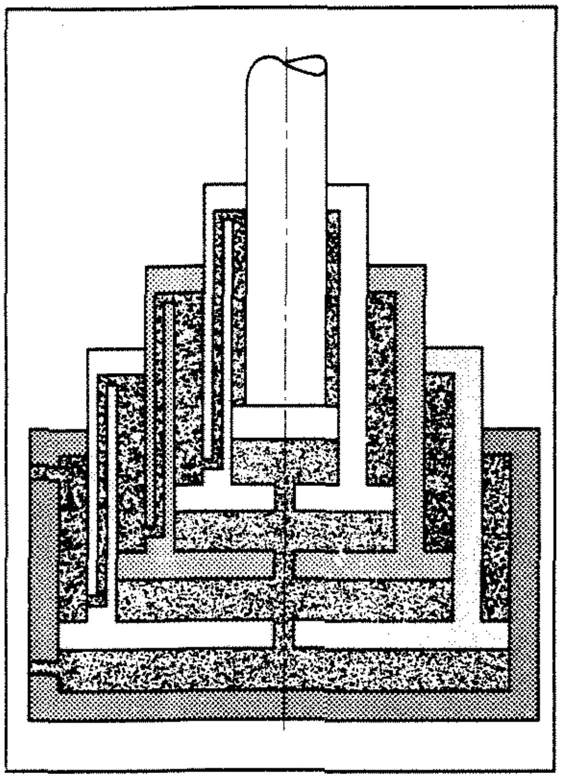


Fig. 1: *Principal diagram of 4 stage - double acting - telescopic cylinder*

4 Efficiency of the Hydraulic Cylinder

The mechanical efficiency of the cylinders depends on several factors.

Influential factors at constant viscosity:

a Influence of surface roughness of piston rod, cylinder walls and bearings.

b Type of sealing and sealing material.

c Amount of occuring lateral forces.

d Function (type) and regulation of the cylinder such as single-acting, double-acting or regenerative regulation.

e Working pressure.

f Bore and phi-ratio.

g Cylinder model (single rod/through rod)

Remark: $\varphi = \frac{\text{piston area}}{\text{ring area}}$

With respect to the above the following may be stated:

1 High working pressures lead to higher efficiency.

2 Larger bores at a certain working pressure have a higher efficiency.

3 The lower the surface roughness and lateral forces, the higher the efficiency.

4 Regenerative regulation gives a lower efficiency with a pushing function.

5 Cylinder with a through rod has a lower efficiency.

6 High phi-ratio gives a lower efficiency with a pulling function.

7 Full rubber sealing gives a lower efficiency than a rubber fabric sealing. Teflon compound sealing gives a higher efficiency than rubber fabric. Moreover, the efficiency is highly determined, not only by the material choosen, but also by the form of the sealing.

Table 1: *Mechanical efficiency of hydraulic cylinders*

Piston Ø		φ	Mechanical Efficiency																			
			Pushing										Pulling									
			functions K, N, P, at a working pressure of					function L at a working pressure of					functions K, L M at a working pressure of					function R at a working pressure of				
in mm	in inches		50 bar	100 bar	200 bar	250 bar	320 bar	50 bar	100 bar	200 bar	250 bar	320 bar	50 bar	100 bar	200 bar	250 bar	320 bar	50 bar	100 bar	200 bar	250 bar	320 bar
32≤50	1,26 1.97	1.4	0,93	0,95	0,96	0,97	—	0,74	0,83	0,89	0,90	—	0,85	0,89	0,92	0,93	—	0,84	0,89	0,92	0,92	—
32 50	1,26 1.97	2	0,93	0,95	0,96	0,97	—	0,80	0,87	0,91	0,92	—	0,76	0,83	0,87	0,89	—	0,73	0,81	0,87	0,88	—
65 100	2.56 3.93	1.4	0,95	0,97	0,97	0,98	—	0,82	0,88	0,92	0,93	—	0,89	0,92	0,94	0,95	—	0,88	0,92	0,94	0,94	—
65 100	2.56 3.93	12	0,95	0,97	0,97	0,98	—	0,85	0,90	0,94	0,94	—	0,84	0,89	0,92	0,92	—	0,82	0,88	0,91	0,92	—
125 200	4.92 7.87	1.25	0,96	9,97	—	—	—	0,76	0,85	0,90	—	—	0,91	0,94	0,96	—	—	0,92	0,94	0,96	—	—
125 200	4.92 7.87	1.33	0,96	0,97	0,98	—	—	0,80	0,87	0,92	0,93	0,94	0,90	0,93	0,95	0,96	—	0,93	0,95	0,96	0,96	—
125 200	4.92 7.87	1.4	0,96	0,97	0,98	0,98	0,98	0,83	0,89	0,93	0,94	0,95	0,89	0,92	0,94	0,95	0,96	0,89	0,93	0,95	0,95	0,96
125 200	4.92 7.87	1.6	0,96	0,97	0,98	0,98	0,98	0,85	0,90	0,94	0,94	0,95	0,89	0,92	0,94	0,95	0,95	0,88	0,91	0,94	0,95	0,95
125 200	4.92 7.87	2	0,96	0,97	0,98	0,98	0,98	0,87	0,91	0,94	0,95	0,96	0,86	0,90	0,93	0,94	0,94	0,84	0,90	0,93	0,93	0,94
220 360	8.66 14.17	1.25	0,96	0,98	—	—	—	0,86	0,91	0,95	—	—	0,94	0,96	0,97	—	—	0,95	0,96	0,97	—	—
220 360	8.66 14.17	1.33	0,96	0,98	0,98	—	—	0,86	0,93	0,95	0,96	0,96	0,93	0,95	0,97	0,97	—	0,94	0,96	0,97	0,97	—
220 360	8.66 14.17	1.4	0,96	0,98	0,98	0,98	0,99	0,89	0,93	0,95	0,96	0,96	0,92	0,94	0,96	0,96	0,97	0,90	0,93	0,95	0,96	0,96
220 360	8.66 14.17	1.6	0,96	0,98	0,98	0,98	0,99	0,90	0,94	0,96	0,96	0,97	0,92	0,94	0,96	0,96	0,97	0,91	0,94	0,96	0,96	0,98
220 360	8.66 14.17	2	0,96	0,98	0,98	0,98	0,99	0,92	0,94	0,96	0,96	0,97	0,90	0,93	0,94	0,95	0,96	0,88	0,92	0,94	0,95	0,95
400 630	15.75 24.8	1.25	0,97	0,98	—	—	—	0,89	0,93	0,96	—	—	0,96	0,97	0,98	—	—	0,96	0,97	0,98	—	—
400 630	15.75 24.8	1.33	0,97	0,98	0,99	—	—	0,91	0,94	0,96	0,97	0,97	0,95	0,96	0,97	0,98	—	0,95	0,97	0,98	0,98	—
400 630	15.75 24.8	1.4	0,97	0,98	0,99	0,99	0,99	0,91	0,94	0,96	0,96	0,97	0,94	0,96	0,97	0,97	0,97	0,94	0,96	0,97	0,97	0,97
400 630	15.75 24.8	1.6	0,97	0,98	0,99	0,99	0,99	0,92	0,95	0,96	0,97	0,97	0,94	0,95	0,97	0,97	0,97	0,93	0,95	0,96	0,97	0,97
400 630	15.75 24.8	2	0,97	0,98	0,99	0,99	0,99	0,93	0,96	0,97	0,97	0,98	0,92	0,94	0,96	0,96	0,97	0,91	0,94	0,95	0,96	0,96

Functions
K = double acting
L = regenertaive
M = single acting pulling
N = single acting pushing
P = single acting
R = double piston rod end

$$\varphi = \frac{\text{piston area}}{\text{annulus area}}$$

Note: (Piston rod not sideways thrusted)
hydraulic oil viscosity 5 •E

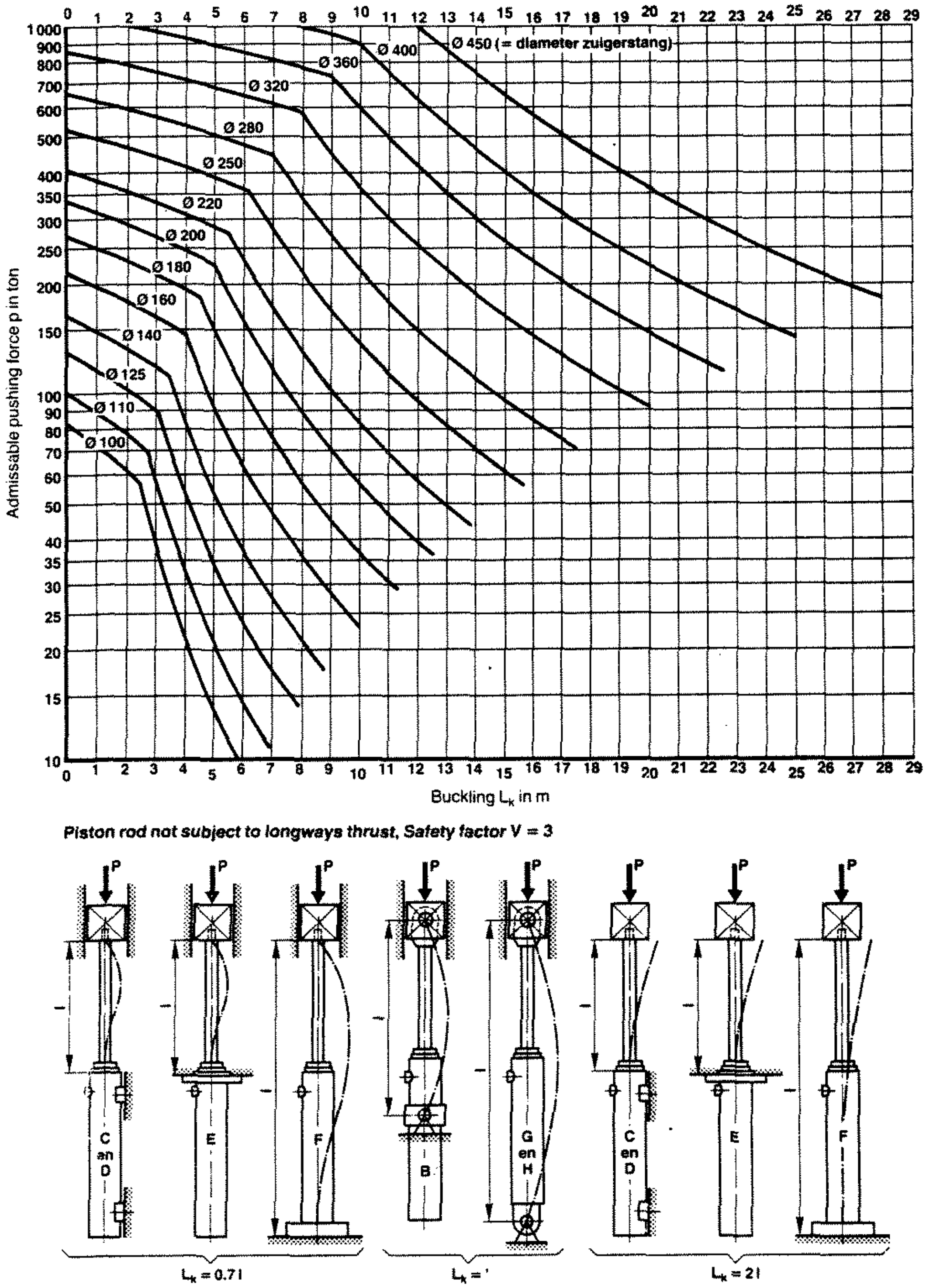


Fig. 2: *Graph showing how to calculate the piston rod on buckling*

5 The Hydraulic Medium

Hydraulic cylinders may work with several types of fluids. Usually we find the mineral oils of the type HLP. The correct type is usually determined by the pump make and the service temperature at which the system is to operate. The cylinder has a greater acceptable range of viscosities than the pump which may, in the case of a badly chosen oil, soon lead to cavitation.

Apart from the usual mineral oils, it is also possible to apply synthetic oils, water glycols, water-oil emulsion, and water. These are usually applied in surroundings with fire hazards such as steel works, oil rigs, etc.
The medium, in combination with design and construction of the cylinder, determines the working pressure and consequently the force that can be supplied.

With synthetic oil, water glycol or phosphate ester special attention is to be paid to the choice of the sealing material.

If the medium water emulsion is used or oil-water emulsion with a water content of over 95%, the inner surface of the cylinder must receive a processing. This processing may consist of special chromium-plating or of chemical nickel-plating. Obviously, stainless steel cylinders may also be used.

Water Based and Synthetic Fluids

1 General

Within the very wide range of special fluids water based and synthetic fluids represent a subgrouping of fire-resistant fluids.

DIN 51502 (Issue 79) divides fire resistant fluids into the groups HFA, HFB, HFC and HFD.
This division corresponds to ISO/DJS 6071 and Cetop RP 77 H. Thecode "HF" is made up of the "H" for "hydraulic fluids" and the "F" for fire resistant. Groups A, B and C are water based fluids and group D water-free fluids.

They are used in all cases where, for safety reasons, the use of fluids on a mineral oil base is not possible, and also where a possible financial advantage might be obtained.

When compared with hydraulic fluids on a mineral oil base, fire resistant fluids display properties of a somewhat different structures, which very often adversely affect the hydraulic elements.

The following are of valuable assistance:

DIN 24320 (Prelim. standard-corresponds to RN 118.20) and VDMA 24317 (corresponds to RN 118.17).

These properties must be given due attention in the project engineering, operation and maintenance of hydraulic systems.

This applies equally to existing systems which have to be changed over to a different operating fluid (see Cetop RP86H and VDMA 24314 corresp. to RN 118.14).

2 Fire Resistant Fluids

Classification of these hydraulic fluids:

a Water based fluids with the (Cetop) type codes HFA, HFB, HFC.

b Water-free fluids with the (Cetop) type code HFD.

The various type codes in greater detail:

HFA

- Oil-in-water emulsion and micro-emulsion with a combustible proportion of 20% max.
- Operating temperatures between +5 and +55 °C. *
- The data sheet RE 09 297/6.84 gives a summary of the "Operating and Wear Characteristics of Hydraulic Components in Use with HFA Fluids".

HFB

- Water-in-oil emulsion with a combustible proportion of 60% max.
- Operating temperatures between +5 and +60 °C.*

HFC

- Watery polymer solutions with a water proportion of at least 35%.
- Operating temperatures between -20 and +60 °C.*

* The temperatures given above refer to the hottest point in the system. This could be throttle valves, bearings in pumps, etc.

HFA fluids are further sub-divided as follows:

Oil-in-Water Emulsion

- Approx. 5% additive (normally on mineral oil base) which serves as emulsifier and also as wear, foam and axidation inhibitor.
- Droplet size: ≈ 40 to 250 µm
- Appearance: opaque
- Standing for long periods causes separation (precipi tation)

95/5 Micro-Emulsion

- As oil-in-water emulsion
- Droplet size: ≈ 2 to 25 µm
- Appearance: translucent
- Emulsion stability greater than for oil-in-water emulsion, however separation (precipitation) is still possible.

Solutions

- Contain up to 5% additives on a synthetic base.
- Droplet size: < 0.1 µm
- Appearance: clear
- Fluid is stable, i.e. no separation (precipitation).

HFD

- Water-free fluids on a synthetic base
- This group is sub-divided into 4 further groups as proposed by Cetop and ISO:
  - HFD - R = phosphate-ester
  - HFD - S = chlorinated hydrocarbons
  - HFD - T = mixture of R + S
  - HFD - U = other combinations

Normally, Viton seals are perfectly suitable for these fluids. However, this material is not obtainable for accumulator bladders, which must therefore be manufactured from Buthyl. Buthyl is, however, absolutely incompatible with mineral oils or grease on a mineral oil base.

When changing systems from mineral oil to phosphate ester, therefore, under no circumstances are the residual oil quantities quoted in the VDMA sheets admissible. A residual oil proportion of even 0.2 to 0.4% causes Buthyl bladders to swell to such an extent that they become completely unusable within a short period of operation. For this reason bladder type accumulators must not, under any circumstances, be switched into the system during the flushing process (when residual amounts of mineral oil are still present in the phosphate-ester). Above all, make sure that there are no dead spaces in which larger amounts of mineral oil can gather.

Where the HFD fluid in its most popular use is concerned, it should be pointed out (because of compatibility with seals) that there are three types of phosphate ester.

These are:

- Triaryl - Ph.Ester
- Trialkyl - Ph.Ester
- Alkylaryl - PH.Ester (mixed)

When using HFD - U fluids which are not based on HFD - R, HFD - S or HFD - T fluids, seal compatibility must be checked.

3 Hydraulic Elements and Their Suitability

It is necessary to investigate the suitability of the hydraulic components for operation on water based and synthetic fluids.

Seal and hose material, coatings, paint and other protective layers must be compatible with the fluid.

If anti-corrosion and -oxidation agents are present in the fluid, then under certain circumstances it may be possible to dispense with surface protection for this purpose in the relevant area. If in doubt, consult the manufacturer.

Because of the low heat absorption capacity of water based (HFA, HFB and HFC) fluids and the poor viscosity/temperature characteristics of synthetic fluids (HFD), suitable measures must be taken to ensure that the correct operating temperature according to VDMA sheet 24 317 is maintained.

4 Filters

Carefully and continuously monitored filtration is necessary. Filters should be fitted in the return line whenever possible. Suction filtration should be avoided.
Pore size is 10 µm.

Please consult the filter manufacturer!

5 Pumps

When selecting pumps the pump manufacturer must be consulted concerning their suitability.

For axial piston pumps from HYDROMATIK, for example, see RE 90 223/10.83 and API 067.

Seal compatibility with the operating fluid must be assured, as already mentioned.

Any non-ferrous metals, or other metals and alloys, in the pump which come into contact with the operating fluid must not be corroded by it.

If possible, the fluid should possess corrosion and oxidation inhibiting properties.

In order to keep the vacuum pressure in the suction area low, it is important that suitably large opening sections with minimum throttling and diversions are present.

This applies not only to the pumps themselves, but also to the complete suction line.

Manufacturing instructions on this point must be strictly adhered to.

Since pumps place the most stringent requirements on the hydraulic fluid, consideration must be given to the required duties, having regard to the wear characteristics with HFC and HFD fluids, as outlined in VDMA, sheet 24 317, point 11 - 11.2.

HFD fluids on a sebacic acid-ester basis (e.g. oleic acid-ester) should not, in our experience, be allowed to come into contact with lead (Pb), lead alloys or non-ferrous metal alloys containing lead since this component will become corroded.

HFA Approved only for axial piston pumps (see RE 90 223/10.83 and API 067)

HFB Used primarily in Great Britain. Please contact Rexroth/St. Neots.

HFC Long-term tests not yet completed (consultation with Dept. "PU" necessary

HFD Some pump models released (consultation with Dept. "PU" necessary)

6 Valves

HFA

The introduction to the HFA Hydraulic Programme from Rexroth (data sheet RE 09 450/10.83) outlines the most important points concerning the use of hydraulic components with HFA fluids. The valves listed in the data sheet have been optimised specially for use with HFA fluids and in long-term tests have run for more than 10,000 hours without complaint. An important point to note is that the valves may only be used with a max. pressure drop of Δp = 50...60 bar.

At almost all major automobile manufacturers, our valves have been integrated and tested in pilot systems with a max. operating pressure of 70 bar without problem. As far as the hydraulic fluids are concerned, it should be mentioned that during long-term testing in our works the greatest success was with micro emulsions. For example, fluid type BPX 5448 has been in use for 2 years without any problems in spite of widely spaced inspection intervals.

HFB

These fluids are in extensive use in the mining industries of various countries, and also in some steel making industries.

With the exception of DBD type relief valves which suffer from servere erosion if in continuous operation, we are aware of no other problems with these fluids.

Service life is, however, generally reduced when compared to that obtained with mineral oils.

HFC

The use of Rexroth valves with HFC fluids has not yet led to any complaints. For years now, HFC fluids have been used almost exclusively in hydraulic mining machines with open hydrostatic circuits with both vane pumps and axial piston pumps (peak pressure 250 bar).

Rexroth valves are in use on machines from the following companies:

HAUSHERR
DEILMANN
WESTFALIA, Lünen
BECURIT
EICKHOFF
PAURAT

In addition, some valves are in use with HFC fluids in heat treatment plants and die casting machines (max. pressure 140 - 150 bar).
In the experience of our Service Dept., particularly when using the valves in heat treatment plants care must be taken that the max. temperature limits at the warmest point in the system are not exceeded, otherwise the result will be the sticking of spools in directional valves and also in pressure and flow valves.

HFD

With HFD fluids, the pressure range can be aligned to that for use with mineral oil for nominal pressures up to 315 bar.

7 Cylinders

When ordering, it is imperative to state the fluid to be used!

8 Change over of Fluid in a Hydraulic System

It must first be checked that the components of the system are suitable for use with the replacement fluid, as discussed in paragraphs 3, 4 and 5.

Emptying and Cleaning of the System

The system and all its components must be emptied and cleaned.
Pumps, motors, accumulators, cylinders and other accessories, insofar as the fluid flows through or wets these, must be dismantled and carefully cleaned. Filter elements and filter cartridges should be replaced by new, suitable ones.

Flushing fluids, and also suitable cleaning agents, must comply with VDMA sheet 24 314, page 2 (November 1981).

Flushing the System

For economical reasons, the system need only be filled with the minimum amount of replacement fluid to allow it to function.

For flushing, the system should be run at low power. Power is then gradually increased until full power is reached within 50% of the flushing time.

During the flushing process, continuous bleeding is necessary when operating the various system components. The max. permissible operating temperature should be reached if possible.

Recommended flushing times are as follows:

When changing from

Mineral oil to HFD:	1 - 2 hours
Mineral oil to HFA:	8 hours
Mineral oil to HFB/HFC:	16 - 24 hours
HFA/HFB/HFC to HFD	
1. Flushing with mineral oil:	16 - 24 hours
2. Flsuhing with HFA/HFB/HFC:	14 - 24 hours

Draining of the flushing fluid should take place while the system is still warm if possible. The condition of the flushing fluid should be checked and if necessary, a second flushing operation carried out with new flushing fluid.

Coolers and filters should be cleaned and filter elements replaced if necessary.

Re-use flushing fluid only after regeneration and with the prior permission of the fluid manufacturer.

6 Temperature

The normal working temperature for the cylinder is between -10 °C and +80 °C. With service temperatures below or above these values, proper materials for cylinder main components and sealings have to be selected carefully. With low temperatures the several cylinder components will have to be made of materials with increased impact values. Furthermore, the cylinder has to be fitted with ice-scrapers and possibly sealings that are made from a special rubber compound.
High temperatures require a viton-based sealing.

With greatly varying temperatures, both expansion and shrinkage will occur that influence the cylinder mountings and overall dimensions. This implies an additional load for cylinder and parts.

7 Construction of Hydraulic Cylinders

The quality of a hydraulic cylinder is determined by the several detailed constructions of the main components that a cylinder consists of and their assembly. Various methods of assembly are possible and they depend on the intended applications, operating conditions, installation, regulations and possibilities of maintenance.

Cylinder for heavy industry with high pressures and/or long strokes, cylinders for bridges, sluices and off-shore are characterized by a bolted head and bottom. For maritime application, a smooth exterior without projections is often chosen .
For mobile, agricultural and related industry applications, the cylinder must be light and compact.

The main components that the cylinders consist or are:

- Piston
- Piston rod
- Cylinder head (front head/gland)
- Bottom (rear end)
- Mountings
- Cushioning

Piston Construction

The piston is fitted with a liner and a sealing. The liners may be of bronze, cast iron, or plastic. Bronze and cast iron bearings are characterized by good heat dissipation and can be made accurately to size. The permissible surface pressures rise from 300 N/cm^2 to 1200 N/cm^2, depending on the chosen material and the nature of the load, dynamic or static.

Bronze gives a high permissible piston speed, is shock-resistant and wear-resistant. Moreover, it has a lower frictional resistance with irregular lubrication.

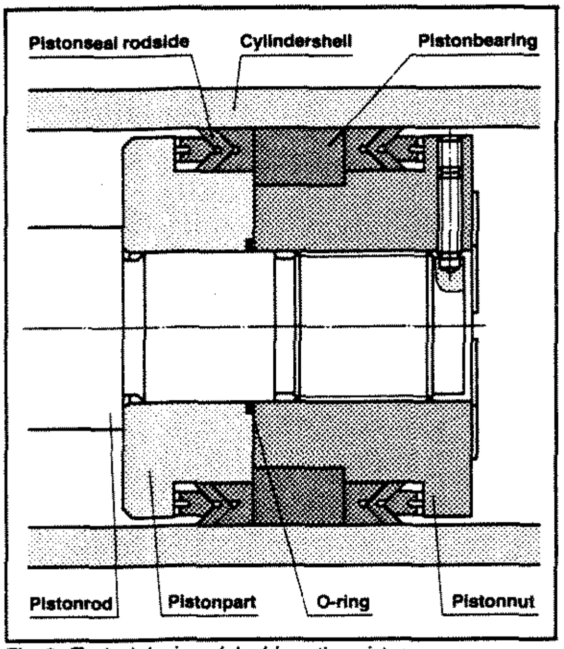


Fig. 3: *Typical design of double acting piston*

Artifical liners, in combination with compact sealings, offer a possibility of a simple piston construction. They can absorb vibrations and shocks. Also because of their resistance to corrosion and their self-lubricating quality, they may be used in water hydraulics applications. In the design, however, the low heat conduction coefficients and moisture absorption resulting in dimensional variations have to be taken into account.

The most frequently used artificial liners are PTFE, reinforced with bronze, glass, carbon, polyamides and phenol resins reinforced with fabric. With the single-acting cylinder the piston is fitted with one sealing on the pressure side. The double-acting cylinder has a piston with a sealing on both sides. Between these two sealings is the piston liner. This liner receives optimum protection because both sealings, in the case of soiled oil, also prevent the soil from getting between the bearing and the casing.

In order to effect optimum lubrication, rubber-fabric sealings are chosen. The fabric allows sufficient lubricant to pass the sealing. Full rubber sealings on the piston may lead to problems in this respect. With compact piston construction the starting point can be a one-part piston. The sealing is drawn over the piston and the liner strips are placed around the piston. Applications with high piston-speed, metal or artificial piston rings must be used.

Allowable speeds, based on sealing material

Rubber (NBR) / Polymethane	0.2 - 0.5 m/sec.
Rubber-fabric	0.5 - 1.0 m/sec.
PTFE-compounds	up to 15 m/sec.
Metal (Cast-iron)	up to 18 m/sec.

Piston rod

On of the most important parts of the hydraulic cylinder is the piston rod.

The hydraulic force generated by the cylinder must be taken up by the rod and transmitted. Apart from the mechanical qualities that are determined by these forces, the finish of the rod must be such that the sealing can function properly.

Furthermore, the piston rod must be sufficiently wear-resistant, scratch-resistant and corrosion-proof. The piston rod is therefore grinded or honed, and furnished with a wear-resistant and/or wear-resistant/corrosion-proof top layer. In the case of extremely high lateral forces and bearing loads, or when there is risk of external damage to the piston rod, e.g. through falling material, the piston rod surface is usually hardened. Depending on the intended field of application, the right material and the protective layer must be chosen.

A Non-corrosive surroundings

The piston rod is made of a high-grade carbon steel and furnished with a hard chromium plating of 25/35 µm, generally suited for industrial applications where no acids and chlorides occur in the environment. Also for outside installation, when the cylinders are mostly drawn in and/or move frequently, this quality may be used (one might think of earth-moving machines).

B Medium corrosive surroundings

Here the basic material is also carbon steel; the rods are furnished with 2 x 25 µm hardchromium plating. It is better suited for cylinders that are exposed to moisture for a prolonged period; less suitable for maritime purposes.

C Highly corrosive surroundings

With applications where the cylinder comes into contact with soiled river water, sea water or air pollution, a choice of thickness must be made for a layer of nickel-chromium. Depending on the agressiveness, the carbon-steel is protected with 60 µm nickel and 40 µm hard-chromium up to 100 µm nickel and 60 µm hardchromium. With underwater applications 100/50 µm is always preferred. The nickel layer will always cover the parent material completely and protect it from the corrosive influences of the surroundings. In contrast with a chromium layer which always has micro-cracks as a result of the process, this nickel layer gives full sealing. Possible irregularities (faults) in the layer can be repaired by dot-welding. As the wear-resistance and scratch-resistance of the nickel layer are poor, a chromium layer is placed on top of this layer. The nickel layer is placed in view of protection from corrosion. The chromium layer is placed in view of the operating qualities.

D Extremely corrosive surroundings

Here a choice is made for stainless steel. The quality AISI 431 (X22CrNi17) has high mechanical values and offers good resistance to seawater and a large number of chemicals. In order to obtain sufficient resistance to wear and scratching it is recommended to furnish the piston rod with a hard chromium layer of 25/30 µm. Apart from the piston rod constructions mentioned above there are various alternatives that are suitable for special applications. For hydro-electric power stations in lakes and rivers AISI 420 (1.4021) is often applied. This steel does not contain any nickel and is therefore not suited for seawater. In harbour areas with a high level of air pollution together with a maritime atmosphere, stainless steel with a nickel chromium layer may be required.

Checking of the protective layer can take place by a visual check but also by means of a salt sprinkling test on a rod sample, in accordance with ASTM regulation B117. The duration of the test can be made dependent of the intended field of application and the environmental conditions (500-1200 h), acceptation criterions in acc. with ISO standard 1462.

Cylinder Head Construction

The cylinder head contains the piston rod liner, the piston rod sealing and the wiper ring. As with the piston liner, the piston rod layer may be bronze, cast iron (or) artificial material. The piston rod liner however, will always be more heavily loaded than the piston liner and is subject to edge loads, especially when the cylinder is in horizontal position. Therefore, a bronze liner is to be highly recommended. The sealing must be absolutely positive, because, unlike the piston sealing, a leak may be harmful to the surroundings in this case. As the piston rod, certainly with long-stroke cylinders, is rather flexible, multiple lip sealings are to be preferred. As a result of the great length of the sealing, it follows the piston rod adequately. For low friction and higher speeds a piston rod sealing must be made from an artificial material such as PTFE. These have the disadvantage that they do not offer fully positive sealing. This can usually be countered by a separate oil-leak connection. The dirt wiper ring prevents the penetration of dirt into the cylinder. If there is a possibility of a layer of ice forming on the piston rod or if mud and shellfish deposits occur, an additional metal wiper ring has to be projected besides the rubber wiper ring. With underwater application of cylinders an extra sealing will has to be fitted in the cylinder head to prevent the inflow of water into the cylinder. The sealing lip of this sealing is therefore positioned outwards.

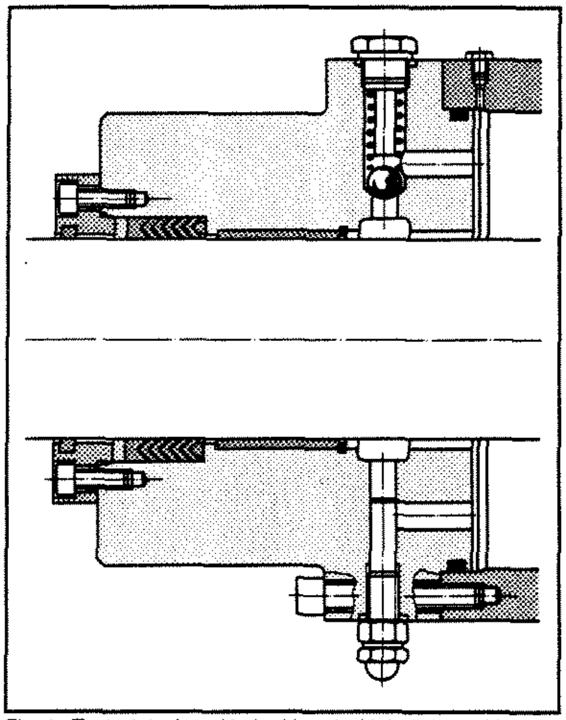


Fig. 4: *Typical design of bolted head with built in cushioning device*

Bottom Construction

The bottom may be welded, bolted or threaded. At the same time the bottom may be part of the mounting. With long-stroke cylinders the bolted bottom has advantages with respect to cleaning, inspection and maintenance possibilities. The sealing of a bolted or threaded bottom is achieved by means of an O-ring with a back-up ring or a groove ring sealing with larger dimensions. Usually the bottom is used for the mounting of the control block, or is constructed as the control block. It is important in this respect to construct the bottom in such a way that deformations do not influence the movements of the slides and valves of the built-in valve apparatus. Things become more critical if the same bottom also comprises the cylinder mounting. Extra attention is to be paid then to the relief grooves in the bottom. Preferably, the bottom is to be made from cast or forged materials, in which laminar faults, which occur in rolled plates, are avoided.

Casing

1 Casing constructions

The casing is made of a seamless steel tube, possibility fitted with mounting flanges for the cylinder head and bottom. This tube may be welded, rolled or drawn. The tube is processed through turning, deep drilling and honing in such a way that an accurate running surface and sealing surface are effected.

The piston sealing moves along the cylinder casing and provides sealing along this surface. As a result of the internal pressure, the casing will expand which will turn give the piston increased clearance. This extra clearance, besides the tolerance, must be bridged by the piston sealing.

The casing must be calculated on this internal pressure. By application of materials with high mechanical values, a relatively thin wall may be chosen. However, the expansion of the casing does not depend on the tensile stress and yield point of the material, but is determined by the thickness of the wall, internal diameter, pressure and elasticity module. Because of technical and mechanical properties in cinjunction with a reduction of the expansion, it may be necessary to increase the wall's thickness. If the wall is at the same time subject to a bending moment, e.g. with a foot mounting of the casing, this will have to be included in the calculation of strength. The casing is finished by means of honing and rolling. With rolling a deformation of surface tops takes place in the lower sections. As a result of wear on the running surface, this leads to roughening, in contrast with a honed surface which becomes less rough.

2 Calculations of cylinder casings

The basis of the calculation of cylinders is found in several standards and regulations specific order documentation or instructions from several inspecting authorities.

σ_t = Stress in tangential direction
σ_r = Stress in radial direction
σ_x = Stress in axial direction
σ_{red} = *reduced stress*
σ_i = ideal stress

$$\sigma_{red}{}^2 = \sigma_t - \sigma_r$$

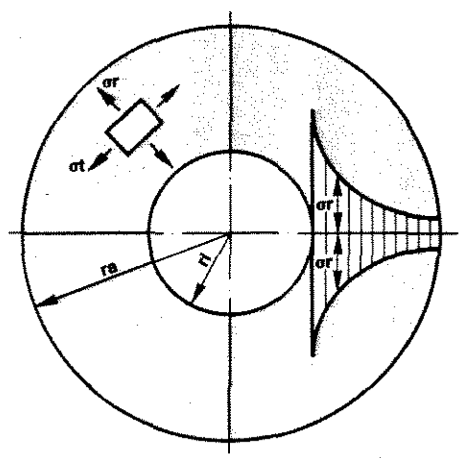
$$\sigma_{red}{}^2 = \frac{1}{2}[(\sigma_t - \sigma_r)^2 + (\sigma_r + \sigma_x)^2 + (\sigma_x - \sigma_t)^2]$$

$$\sigma_t = \max\sigma_t = Pi\frac{\eta^2 + 1}{\eta^2 - 1} \qquad \sigma_r = \max\sigma_r = -Pi$$

$$\sigma_x = \frac{Pi}{\eta^2 - 1}$$

$$\sigma_{red} = Pi \cdot \frac{2\eta^2}{\eta^2 - 1} \qquad \eta = \frac{ra}{ri}$$

$$\sigma_i = \frac{P \cdot \sqrt{3} \cdot \eta^2}{\eta^2 - 1}$$



Expansion formula:

$$\Delta d = \frac{Di + s}{E \cdot s} \cdot Pi \cdot Di(\frac{1}{2} - \frac{1}{4}\mu)$$

for steel μ = 0,3

Table 2: *Formulas of mainstress and defection at cylinder shell*

1) A.B.S.
U.S.C.G. **Calculation according to A.S.M.E.**

$$\sigma\ \text{longitudinal} = \frac{2 \cdot S \cdot E \cdot T}{R - 0{,}4 \cdot t}\ (N/mm^2) \qquad E = 0{,}85$$

$$\sigma\ \text{circumferential} = \frac{S \cdot E \cdot T}{R + 0{,}6 \cdot T} = (N/mm^2) \qquad E = 1$$

$$\sigma\ \text{burst stress} = \frac{S \cdot 2 \cdot T}{Di} = (N/mm^2)$$

$$\overline{\sigma} = S = \frac{\sigma\ \text{burst}}{4}\ (N/mm^2)$$

$$\text{Min. wallthickness is: } T = \frac{W \cdot Ri}{10 \cdot S \cdot E - (1 - y) x W}\ (mm)$$

$E = 1$

$Ri = \frac{Di}{2}\ (mm)$

$y = 0{,}4$

W = pressure (bar)

2) D.N.V.

$$\text{Min. wallthickness is: } T = \frac{P \cdot Ri}{10 \cdot e \cdot \overline{\sigma} - 0{,}5 \cdot P} + C$$

$e = 1\ (N/mm^2)$

$Ri = \frac{Di}{2}\ (mm)$

$C = 1$

P = pressure (bar)

$$\overline{\sigma} = \frac{\sigma 0.2}{1.8}\ \text{or}\ \frac{\sigma\ \text{burst}}{2.7}\ (N/mm^2)$$

Table 3: *Summary of calculation norms for cylinder shells, according to the several approval authorities*

Mounting

The way in which a cylinder is mounted or suspended is important. It partly determines the size of the piston rod diameter and the choice of mounting also influences the life expectancy, maintenance frequency and the general proper functioning of the machine. Improper mounting not only destroys the cylinder but can cause serious damage to the machine in which the cylinder is mounted. Incorrect choices of mounting cause excessive and unnecessary lateral forces, resulting in piston and piston rod. Moreover the mounting determines their buckling length and consequently the max. permissible pressure load. The following mountings may be distinguished.

A *Casing mounting*

1 Rigid mounting

a Front flange (flange at head end

b Bottom flange (flange at cap end)

c Center line mouning

d Foot mounting

With the first three types of mountings the reaction force runs through the centerline of the cylinder. With the mounting device the casing is loaded on bending. If the load (force) is guided, the alignment will have to be accurate in order to eliminate lateral forces.

2 Oscillating mounting (free in one direction)

e Trunnion mounting

f Steel clevis/double blade clevis

With this mounting the cylinder can adjust in one direction of movement. Here too, attention is to be paid to the alignment transverse to the free direction of movement.

3 *The self-aligning oscillating mounting*

g Steel clevis with spherical bearing (pivot mounting)

f Cardan on casing

With these mountings the cylinder is free to adjust to the guiding. The lateral forces are minimized here and only comprise the friction in the points of suspension and as a result of their own weight.

B Piston rod mounting

1 Rigid mounting

a Flange mounting (threaded on rod or forged)

b Machine element threaded directly to rod end. Here the forces have to be as centric as possible. Excentric load results in increased bending moment on the piston rod and introduces additional load on the piston rod liner, and consequently influences the life expectancy.

2 Oscillating mounting

a Steel clevis/double blade clevis

b Trunnion (special). Here the cylinder is only free in one direction of movement and attention is therefore required for the alignment transverse to the free direction of movements.

3 Self-adjusting oscillating mounting

a Steel clevis with spherical bearing (pivot mounting)

b Socket/spherical joint on rod. Here optimum freedom for cylinder resulting in minimized lateral forces.

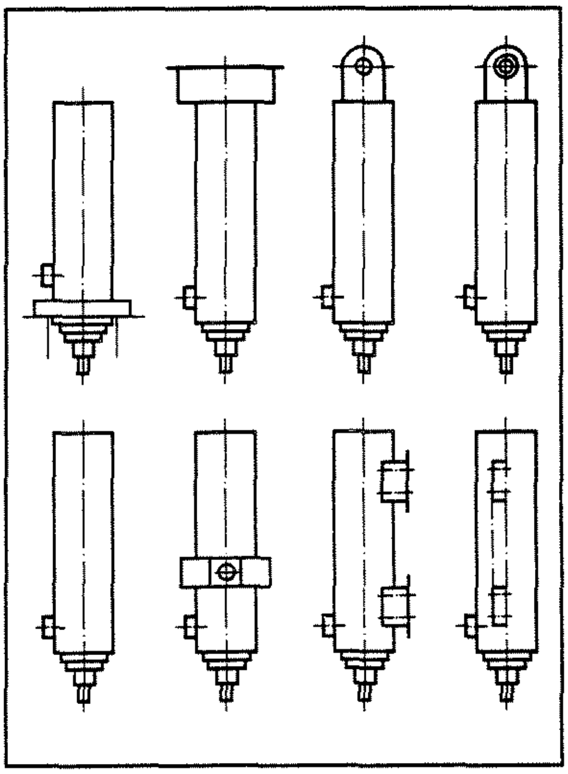


Fig. 5: *Typical mounting of cylinder shells*

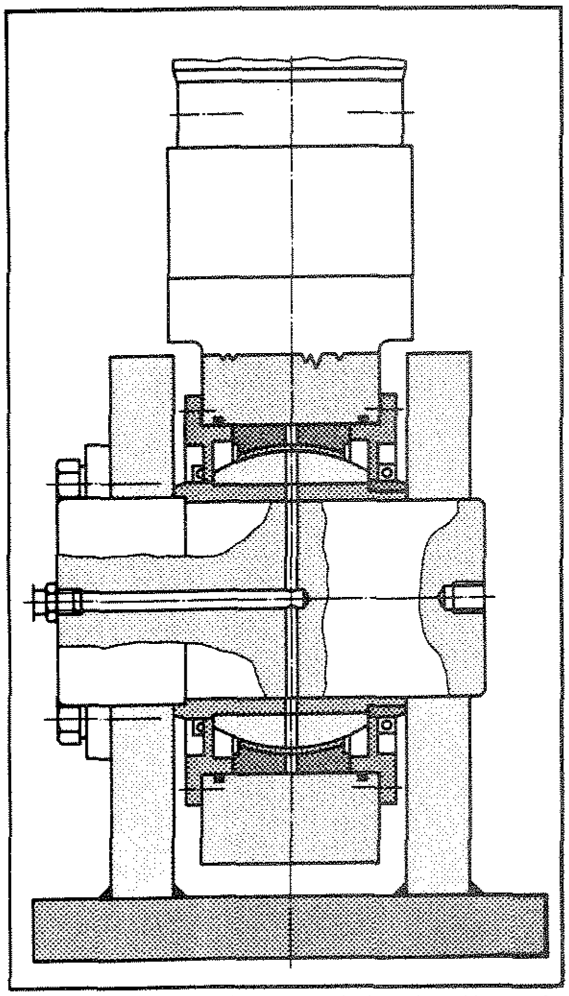


Fig. 6: *Self-aligning clevis with spherical bearing with seals for underwater use*

Assembling main components into hydraulic cylinders

Several methods of assembly are possible and strongly depend on the intended applications. The most simple construction is that in which head and bottom are welded to the cylinder. This obviously has the disadvantage that it is not possible to replace the piston seals. For industrial application and especially with tool-machines tierod cylinders are often used. The head and the bottom are fastened to the cylinder casing by means of tie rods. Both head and bottom are usually of a square construction. At the same time mounting elements can also be fastened to the cylinder by means of these tie rods. Cylinders for high pressures and cylinders with a long stroke are constructed with a bottom and head which are mounted by means of thread or with bolts, studs, etc. In this way, optimum service and assembly possibilities are acquired.

Another method of assembly is that with a welded bottom and a threaded or bolted head. This gives the cylinder a smooth casing which may be an advantage in many built-in applications. Depending on the package of requirements, determined by operating conditions, environmental influences, field of application, life and service possibilities an optimum construction of the cylinder must be chosen.

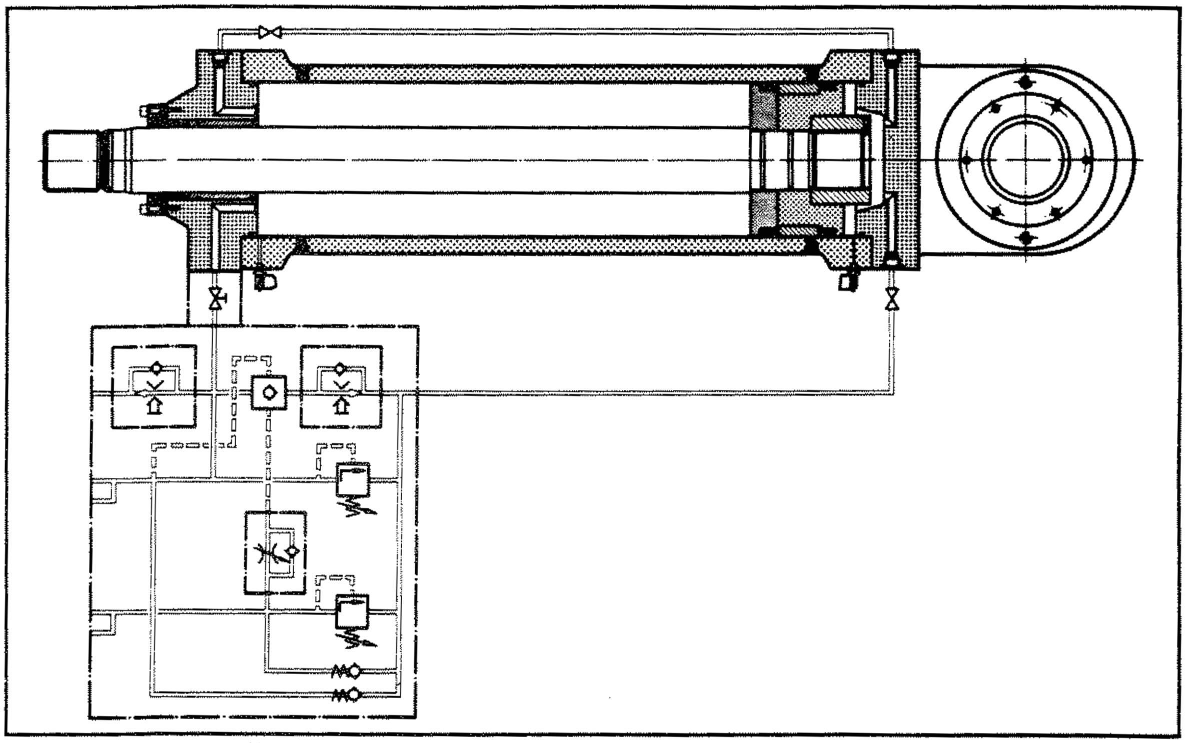


Fig. 7: *Cylinder with control block mounted directly on cylinder*

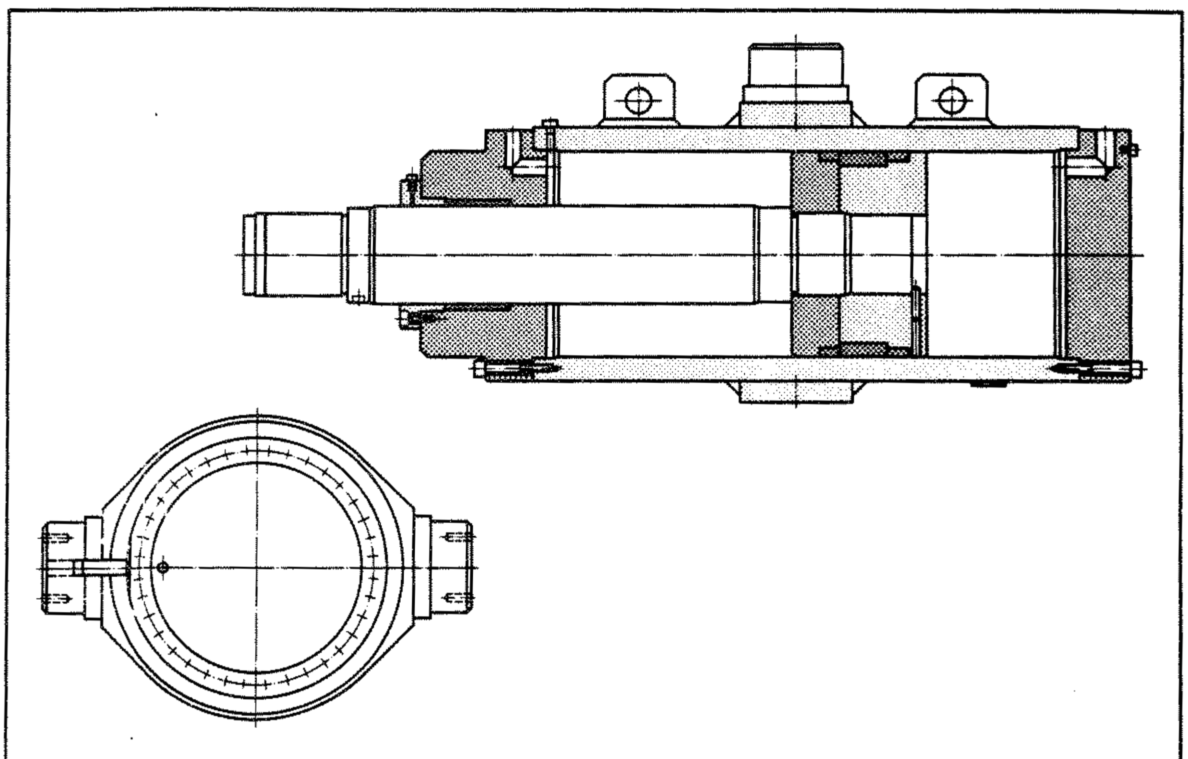


Fig. 8: *Double acting hydrulic cylinder with bolted head and bottom*

8 Hydraulic cylinder as a part in a closed-loop circuit

Caused by the automation of machines, implements and installations also the demands, which are set to the hydraulic systems, have changed. The cylinders should be moved faster, should be positioned more precisely and more functions in the cylinders should be combined. The hydraulic cylinder is also more often a part of a closed-loop circuit or even is a loop itself.

Definition of regulation

Regulating engineering control systems, that are aimed to let certain quantities within a proces develop in a way that has been determined beforehand.

This means that a re-notification about the changed quantity, containing a comparison between this quantity and the one desired, has to be given. This is the major difference between "steering" and closed-loop systems.

Feed-back

The feed-back quantities can be:

- movement
- speed
- force (of cylinder, product or construction)
- acceleration
- p (pressure-difference bottom/rod side)

In reality, the groups' "movement"- and "speed" - transducers are combined in one transducer, from which, out of the electrical output signal, movement as well as speed can be differentiated.

As general term we use "measuring devices".

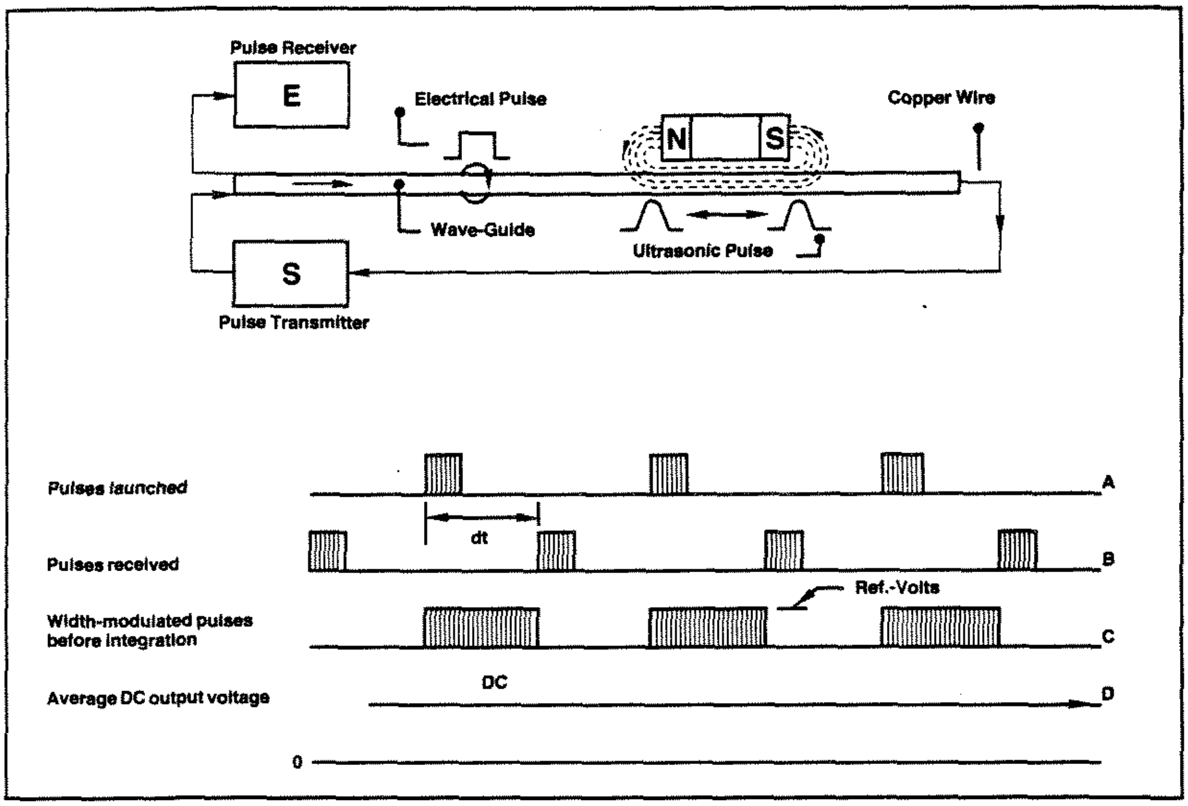


Fig. 9: B5 - magnetic/ultrasonic position / velocity indicating device

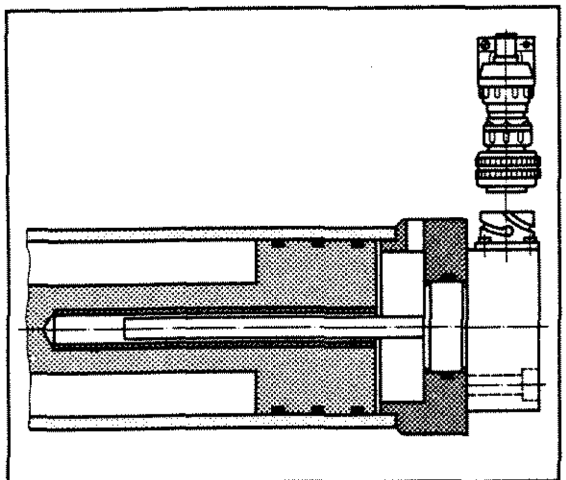


Fig. 10: Eddy - current position / velocity indicating device (Vibro-meter)

Main groups

A Mechanical or mechanical electronic position indicators

B Electronical position indicators/ blank contact measuring devices

Besides, a distinction must be made between digital, analogous, absolute and incremental.

Digital

It is always possible to give an exact value in figures at every moment, however, there will always be values or positions to chose in between (f.e. x N).

Analogous

It gives a continuous indication of the quantity to be indicated, without any intermediate stages; in connection with the extremes.

Absolute

It is always possible to get information about the position out of the positioning signal, without any knowledge of earlier positions.

Incremental

Indication is linked to an earlier position, so this gives "relative" information".

A1 Externally, by means of a thread-unroll-mechanism

This mechanism (barrel, prestrained by a spring) is connected with a potentiometer or pulsecounter, which counts as the incoming signal to the reading device (Accuracy ± 1%).

Advantage:

1 simple assembly

2 simple accessibility

Disadvantage:
sensitive for damages, stretch and temperature.

A2 Internal, by means of a hellix in the piston rod

It is forced to rotate during a translating movement by a tracer pin. This rotation is being pushed outside via a straight or square gear-wheel transmission, where a rotary-potentiometer is driven (Accuracy ± 0,5%).

Advantage:

1 Optimum protection against influences from outside

2 The electrical part is positioned on the outside of the cylinder and is very accessible and exchangeable.

3 The mechanical part can (under influence of pressure) grow with the dimensions of the cylinder.

Electrical/electronical position indicators have a limited length and so they are stroke-limited.

Disadvantage:

Not suited for small pistonroddiameter
(suitable from piston rod diameter ø 90 mm).

B1 Inductive position indicator

A core with a bridge circuit is brought in a measuring rod. The inductive influence of this measuring rod, which is positioned in a drilled hole in the rod, causes a change of the output signal, which is also a measure for the position. Accuracy 0,1 - 0,5%.

Advantage:

1 simple assembly

2 suitable for small cylinder dimensions

Disadvantage:

1 limited stroke length (max. 1250 mm)

2 not very accessible, an electrical failure requires a complete disassembling of the cylinder

B2 Eddy current position indicator

This principle is comparable with above mentioned inductive position indicator. The difference is that eddy currents are used as a signal former instead of induction. Accuracy 0,5 - 1 %.

Advantages and disadvantages are the same as mentioned under **B1**, Inductive position indicator.

B3 Sound position indicator

An ultrasone "soundtransmitter" gives a pulse, which is controlled by the cylinder or accumulator. A built-in measuring reference is taking care of stabilization of the temperature influences, and is also taking care of the possibility of functioning independently from the medium.
Accuracy 1 %.

B4 Magnetic position indicator

A magnet(s) moves along a non-magnetic pipe, where a number of "Reed"-contacts are connected with a resistor-chain. Depending on which contact is shut or made, a voltage-divider, which shows the position, is originated.
Accuracy: 3 mm.

B5 Magnetic/ultrasone

By sending an electrical pulse into a thread, a magnetic field originates. Inside a stainless steel protecting pipe, which is situated around it, this magnetic field stimulates an ultrasone shock wave, which reflects in the direction of the sender/receiver. The time between this is an indication of the movement.
Accuracy 0.02 - 0.05 %.

B6 Optical position indicator

By means of a very fine screen on a glass or a steel reflecting surface, a ray is transmitted or interrupted (c.q.) reflected/absorbed. By an absolute or incremental division of the screen, an indication of the position can be given.
Accuracy up to 0.005 mm.

9 Sealings

With respect to the cylinder two groups of sealings are distinguished:

a Static sealing

b Dynamic sealing

a Static sealing

This concerns cylinder bottom, cylinder head and flange sealings. The usual sealing is the O-ring sealing with or without back-up ring. The rubber O-ring provides the sealing and the back-up ring has an anti-extrusion function to prevent the O-ring from flowing into the clearance. For low pressure, a rubber hardness is used of 70 °Shore. For high pressure, 90 °Shore is required. The back-up ring is made of PTFE or synthetic resin bonded fabric. The diameter of the O-ring varies with the diameter of the bores to be sealed. High pressure and large diameter require a complete seal (groove ring or chevron) instead of an O-ring. Here too, depending on the circumstances, the seal is supported by a back-up ring.

b Dynamic sealing

This type of sealing has a double sealing action. One side (diameter) of the sealing has a static sealing function whereas the other side (diameter) has a dynamic sealing function. The following may be distinguished.

1 Rod sealing

2 Piston sealing

1 Rod sealing

The rod sealing must be leak proof, however, it must also leave a thin oil film on the piston rod. The following types can be applied depending on the operating conditions.

a Multiple lip sealings

(chevron) for heavy duty operating conditions, long cylinder stroke.

applicable:	Pressures up to 400-600 bar v=0.5 m/sec. t = 30 °C to 100 °C.
Material:	full rubber/rubber fabric
Advantage:	follows the bending line of the piston rod well, high operational reliability.
Disadvantage:	High friction risk of running dry (certainly with full rubber) risk of stick-slip

b Groove ring sealing

The pre-stress is acquired by deformation on push or pull in the circumference of the sealing lip. They are made in symmetrical and asymmetrical form. The asymmetrical form has the advantage that it does not tilt so easily in the groove. The longer lip provides the static sealing, whereas the shorter lip has the dynamic sealing function. The sealing consists of one sealing lip and is therefore not suited for long stroke cylinders or for cylinders that are subject to vibrations.

c Compact sealing

The pre-stress is affected by the radial deformation of the total sealing section. The sealings can usually be placed in a closed sealing chamber (goove), and therefore are often called shap-seals. (Short length, sealing not suited for long stroke cylinder.

d Teflon sealing ring

The pre-stress is effected by the radial deformation of a rubber ring. This exerts a radial force on the Teflon sealing ring. As a result of increased pressure the rubber pre-stress has more deformation which presses the sealing ring more strongly against the area to be sealed.

The PTFE sealing ring is reinforced with metal oxydes, metal powder, glass, carbon, graphite, molybdenum-disulphide etc.

Advantage: slight friction
stick-slip free running cylinder movement
high permissible speed

Applicable: pressures up to 600-800 bar
v = 15 m/sec
t = 54 °C up to 200 °C

2 Piston sealing

For the piston sealing the same types of sealing apply as for the rod sealing. Preferably no full rubber sealing is projected on the sealing. This applies especially if the liners are situated between the sealing, since this results in dry running of the liners.

Moreover, these sealings may burn as a result of high sliding pressures.

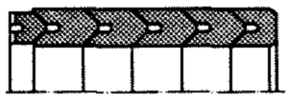
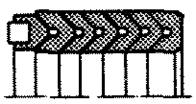
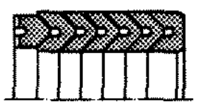
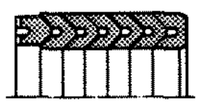
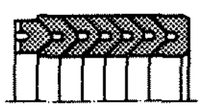
Applications	Cross Section	Material	Parameter			Fluid
			p bar	t °C	v m/S	
Heavy Duty Hydraulics	Style 1000 	NR+fabric	630	–30 to 160	0.5	Water, emulsion
		NBR+fabric	630	–30 to 120	0.5	Oil
Heavy Duty Hydraulics	Style 1500 	NR+fabric	630	–30 to 160	0.5	Water, emulsion
		NBR+fabric	630	–30 to 120	0.5	Oil
Presses: split rings specially for non-adjustable housings	Series E5 	NBR+fabric	630	–30 to 120	0.5	Oil, water, emulsion
Presses Ram seals	Series E4 	NBR+fabric	630	–30 to 120	0.5	Oil, water, emulsion
Hydraulic Cylinders for Stationary and Mobile Hydraulic Equipment	Series E2 and E2V 	NBR+fabric	400	–30 to 100	0.5	Oil, water, emulsion
		FPM+fabric	400	–15 to 160	0.5	Oil, HFD
Hydraulic Cylinders for Stationary and Mobile Hydraulic Equipment	Series E1 and E1V 	NBR+fabric	250	–30 to 100	0.5	Oil, water, emulsion
		FPM+fabric	250	–15 to 100	0.5	Oil, HFD

Table 4: *Rod seals*

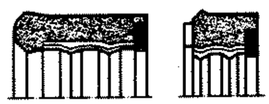
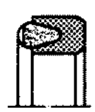
Applications	Cross Section	Material	Parameter			Fluid
			p bar	t °C	v m/S	
Earthmoving Equipment Mining Equipment Telscopic Cylinders Fork Lift Trucks	Series S 25 and Style 0155 	NBR+fabric	250	–30 to 100	0.5	Oil, water, emulsion
Mining Equipment Agricultural Equipment Fork Lift Trucks	Series S 24 	NBR+fabric	250	–30 to 100	0.5	Oil, water, emulsion
Mining Equipment Jacks Agricultural Equipment Control Equipment	Series S 8 	NBR+fabric	200	–30 to 100	0.5	Oil, water, emulsion
Heavy Duty Hydraulics Rod and Plunger seal	Style 1524 	NBR+fabric	200	–20 to 100	0.5	Oil, water, emulsion
Heavy Duty Hydraulics	Style 1120 	NBR+fabric	250	–30 to 120	0.5	Oil, water, emulsion
Hydraulic Cylinders	Series G 10 	NBR+fabric	250	–30 to 120	0.5	Oil, water emulsion
Telescopic Cylinders	Style 0141 	Nbr+fabric	220	–20 to 100	0.5	Oil, water, emulsion

Table 5: *Rod seals*

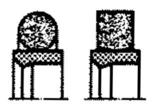
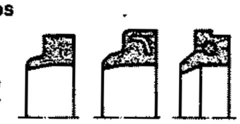
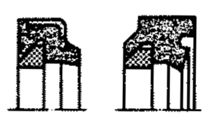
Applications	Cross Section	Material	Parameter p bar	t °C	v m/S	Fluid
Pneumatics Hydraulic Cylinders	Style 2250 	NBR	160	–30 to 100	0.5	Oil, water, emulsion, air
Extremely low Friction Hydraulic and Pneumatic Cylinders	Omegat Style OMS Style OMS-MR Style OMS-S 	NBR+PTFE	400	–30 to 120	1	Oil, water, emulsion, air
Pneumatics Rod seals Pneumatic gate valve	AIRZET Typ PR 	NBR	10	–20 to 100	2	Air
Wiper rings for rods and pistons Style 0157 split	Series P 0 P 7 Style 0157 	NBR		–30 to 100	0.5	Dirt, oil, water, emulsion
High efficiency double lip wiper seal	Style 0147 Style 0148 	NBR+PA	250	–30 to 100	0.5	Dirt, oil, water, emulsion

Table 6: *Rod seals*

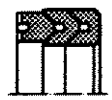
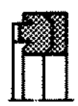
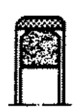
Applications	Cross Section	Material	Parameter p bar	Parameter t °C	Parameter v m/S	Fluid
Earthmoving Equipment Die Casting Machinery Injection Moulding Machinery	Series E3 and E3V 	NBR+fabric	250	–30 to 120	0.5	Oil, water, emulsion
		FPM+fabric	400	–15 to 160	0.5	Oil, HFD
Pneumatics Hydraulic Cylinders	Style 1525 	NBR+fabric	200	–20 to 100	0.5	Oil, water, emulsion air
Earthmoving Equipment Fork Lift Trucks Die Casting Machinery Injection Moulding Machinery	Series G 18 	NBR+fabric	400	–30 to 120	0.5	Oil, water, emulsion
Agriculture Equipment Ships Hydraulics	Series G 11 	NBR+fabric	250	–30 to 120	0.5	Oil, water, emulsion
Fork Lift Trucks Mobile Cranes Agricultural Euipment	Series L 26 and Style 0143  	NBR+fabric	400	–30 to 100	0.5	Oil, water, emulsion
Machine Tools Pneumatics Agriculture Equipment	OMEGAT Style OMK Style OMK-MR Style OMK-S  	NBR+PTFE	400	–30 to 120	0.5	Oil, water, emulsion air
Pneumatics	AIRZET Style PK 	NBR	10	–20 to 100	2	Air

Table 7: *Piston seals*

Notes