A new design for a water hydraulic cylinder

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Abstract: Water is used as a fluid in hydraulic systems in order to comply with environmental and/or safety regulations. The high costs, compared to oil hydraulics, are a result of using corrosion-resistant materials. Furthermore, the lifetimes of the dynamic seals are reduced, because the lubricating effect of the fluid is missing. This paper, presents a new construction of a water hydraulic cylinder, which does not show the above-named disadvantages.

Keywords: Hydraulics, water hydraulics, hydraulic cylinders, design

1 Introduction

The presently-used hydraulic cylinders regarding water hydraulics have a cost disadvantage of about 3:1 compared to conventional oil hydraulic cylinders. One reason for this high cost is that most of the components must be manufactured from corrosion-resistant material, so as to be resistant to water, as the fluid in the hydraulic system.

Based on a study conducted by Mark HAINZL Industrial Systems, a service-life of two million cycles at a load of 140 bar is defined as the objective target. This pressure of 140 bar results from the fact, that all other components in water hydraulics (pumps, valves, etc.) are also designed for this pressure. A load of 100 bar at two million load cycles was defined as a minimum target. A test-bench was used in order to check the defined goals, where two hydraulic cylinders could be tested simultaneously. Control of the two hydraulic cylinders is possible with either a servo or with a 3-way proportional pressure-reducing valve. Another option for controlling the hydro cylinders, is a 4/4 way valve.

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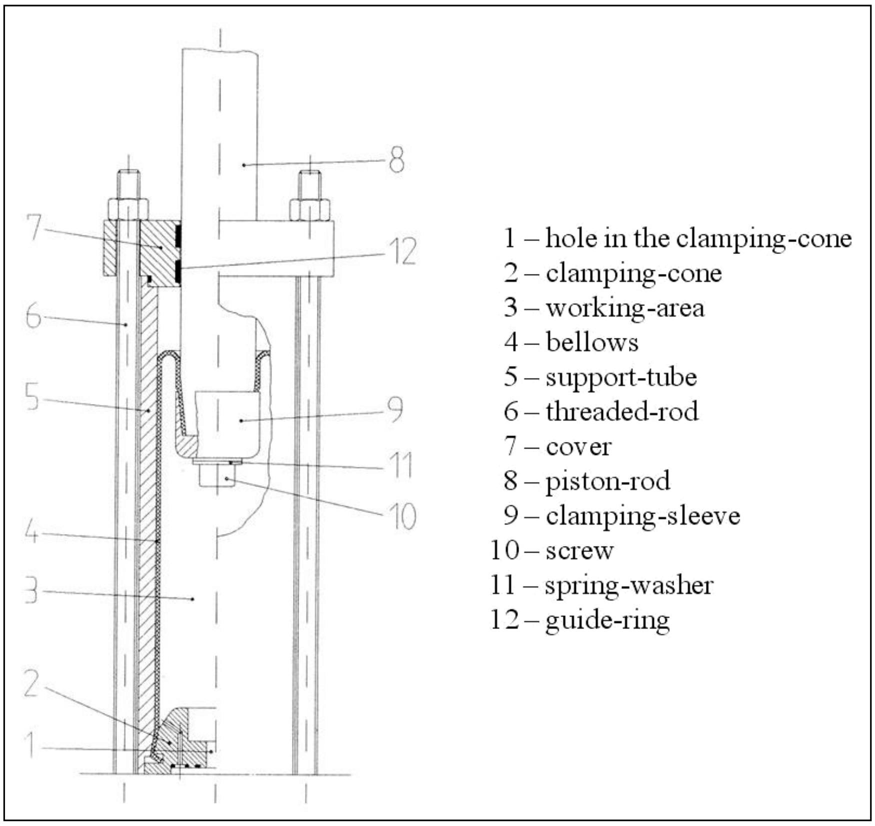

Figure 1. *Construction of the hydro-cylinder*

The innovative part of the designed cy-linder is the use of a bellows within the working space of the cylinder. This minimizes any contact of the fluid with the cylinder. It is possible to produce the piston-rod and cylinder of conventional materials and the dynamic seal between the piston and the cylinders surface, can be omitted [1].

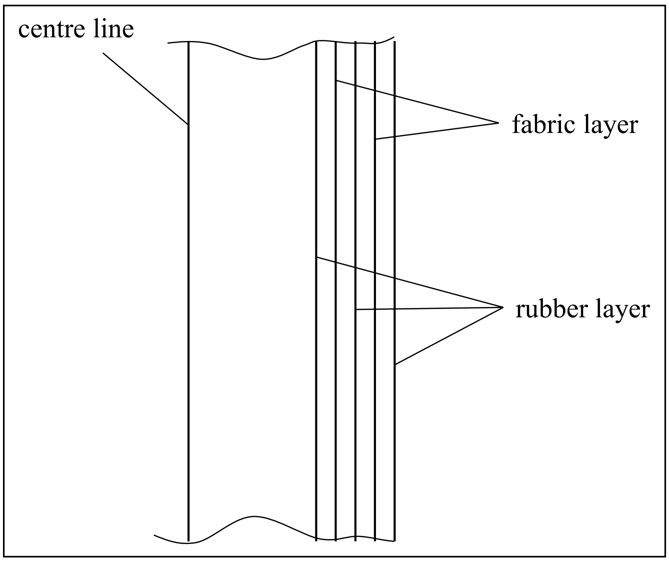

Figure 2. *Construction of the air-bellows*

2 Construction

Figure 1 shows the bellows-cylinder as a single-acting hydraulic cylinder. The hydraulic fluid passes through a hole (1) in the clamping cone (2) into the working area (3), which is limited by the bellows (4). The support tube (5) is designed for absorbing the radial compressive forces and limits the lateral extent of the bellows. The whole pressure acts on the bellows in axial direction and the bellows rolls off between the support tube and the piston rod. The clamping force between the support tube/ clamping cone is applied by four threaded-rods (6) on the support-tube. The clamping of the bellows between the piston rod (8) and clamping-sleeve (9) is done by a screw (10). Two spring-washers (11) are necessary, in orders to keep the preload force of the clamping upright. The guidance of the piston is realized by two guide-rings (12), which are fixed in the cover (7). No dynamic seals are required because of self-sealing the bellows between the support tube/ clamping-cone and the rod/bushing.

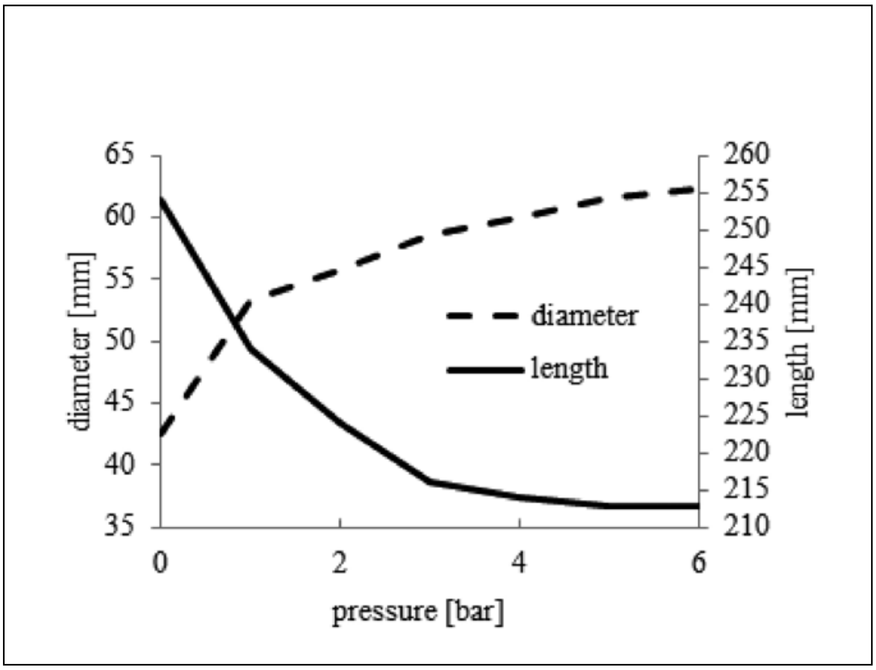

Figure 3. *Expansion behaviour of the bellows*

Table 1. *Roughness [µm] of the inner support tube's surface*

	R_a	$R_{z,D}$	$R_{z,I}$	$R_{z,J}$	$R_{m,D}$	$R_{m,J}$	R_t
tube A	0.23	3.28	4.01	5.91	4.34	6.06	4.56
tube B	4.48	24.8	28.2	30.35	30.06	32.37	30.06

The bellows are produced by CONTITECH air-spring systems and are used as light air-actuators in several industrial applications. The advantage of these air-bellows is there simple design, low space requirements, lateral flexibility, simple installation, simultaneous vibration isolation and low-cost. Since air actuators have no moving parts and seals, there is no static friction (stick-slip effect) [2]. The bellows, as shown in *Figure 2*, are made of two fabric layers acting as carrier materials, inside and outside rubber layers and rubber between the two fabric layers.

A bellows was loaded with compressed air in order to investigate the expansion characteristics of the bellows under pressure, a bellows was loaded with compressed air. The change in diameter and length of the bellows as a function of the pressure was investigated (*Figure 3*).

Based on the results, the support pipe of the hydro-cylinder was dimensioned with an inside diameter of 55 mm. This ensures, that the flexible membrane touches the support tube at a pressure of 2 bar.

One tube (tube B) was roughened on the inner surface in order to assess any influence of the surface roughness on the support tube (see *Table 1*). Experiments shows that in those areas where the bellows rolls on

Figure 4. *Wear of the bellow*

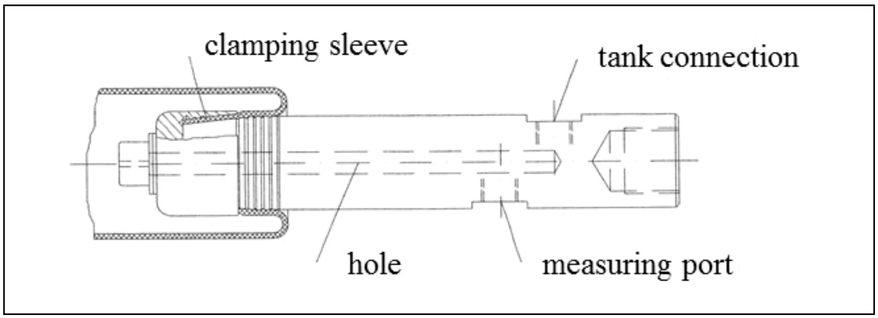

Figure 5. *Piston-rod*

the support pipe an increased wear occurs on the surface of the bellows (*Figure 4*).

Through a hole in the piston rod (see *Figure 5*), the measuring connector (***p***, ***t***) at the end of the piston rod is supplied with the pressure medium. A second connection is provided for a tank pipe. The resulting circulation is used for cooling the pressure medium at small strokes or zero strokes.

3 Test-rig and test procedure

The test-rig in *Figure 6* was designed so that the two test units, directly attached to the valve block, can be operated in parallel. Test unit 1, hydro-cylinder A, is pressurized by a cylinder using an external force. Test unit 2, hydro-cylinder B, is supported by the piston-rod to a bracket and, therefore, the piston has no stroke (zero stroke).

It is possible to use a 3-way proportional pressure reducing valve instead of the servo valve in order to keep the pressure in the test unit constant (Figure 6 shows the variant with servo valves). The test cylinder is operated by load control. Bubble memories are placed in front of the servo valves in order to pressure fluctuations in the supply line (*Figure 6* and *7*).

The following points were determined:

Test unit 1 (hydro-cylinder A)
- Burst pressure
- Stiffness of the bellows-type hydro cylinder
- Endurance strength due to dynamic load application
- Frequency dependence on the load application
- Lifetime of the bellows as a function of constantly controlled-pressures and strokes.
- Selected test series to the determine differences between water and oil as fluid

Test unit 2 (zero-stroke, hydro-cylinder B):
- Dynamic pressure loads with different pressure amplitudes
- Determination of surface roughness influence

4 Results

4.1 Burst pressure

During the three carried out experiments, the bursting pressure was determined between 190 and 192 bar (*Table 2*). The safety, when using up to 140 bar, is thus 1.36. The producer value for these bellows is 225 bar. This value was indicated by CONTITECH air suspension systems.

4.2 Spring rate and spring stiffness

Three different substrate materials of the bellows (polyamide, polyester and aramid) were used in order to determine the spring characteristics. The bellows-cylinders with the aramid support material had the highest spring stiffness. The cylinder with polyester as backing material had a slightly lower stiffness, but would be satisfactory for many applications. The lowest stiffness was achieved by the polyamide support material.

4.3 Endurance strength

The first experiments were carried-out at test units 1 and 2 at 140 bar.

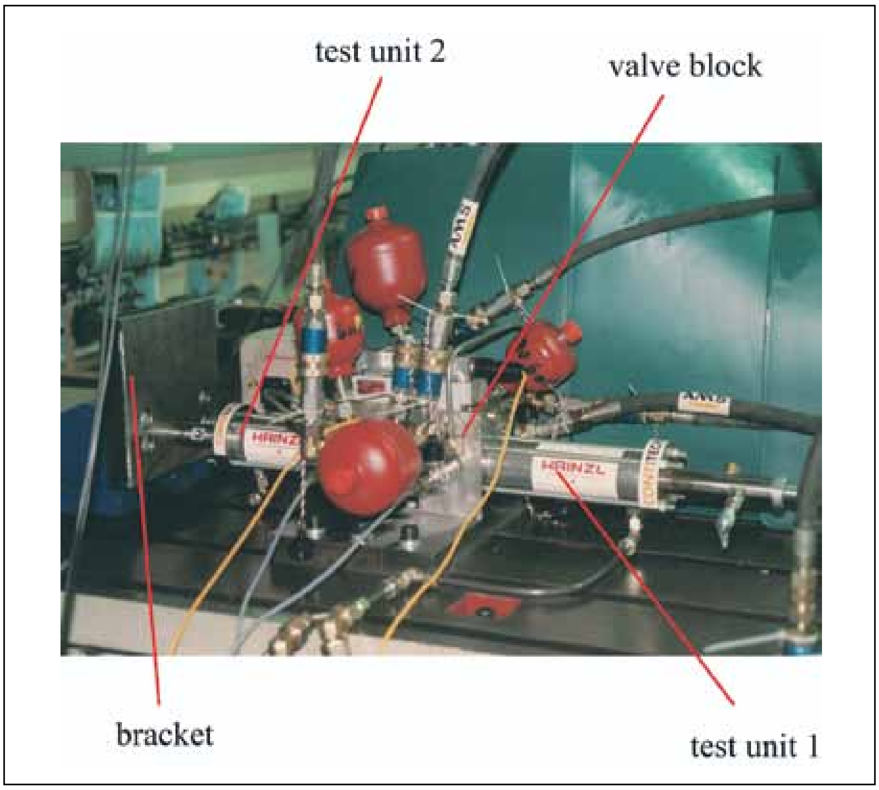

Figure 6. *Test-rig*

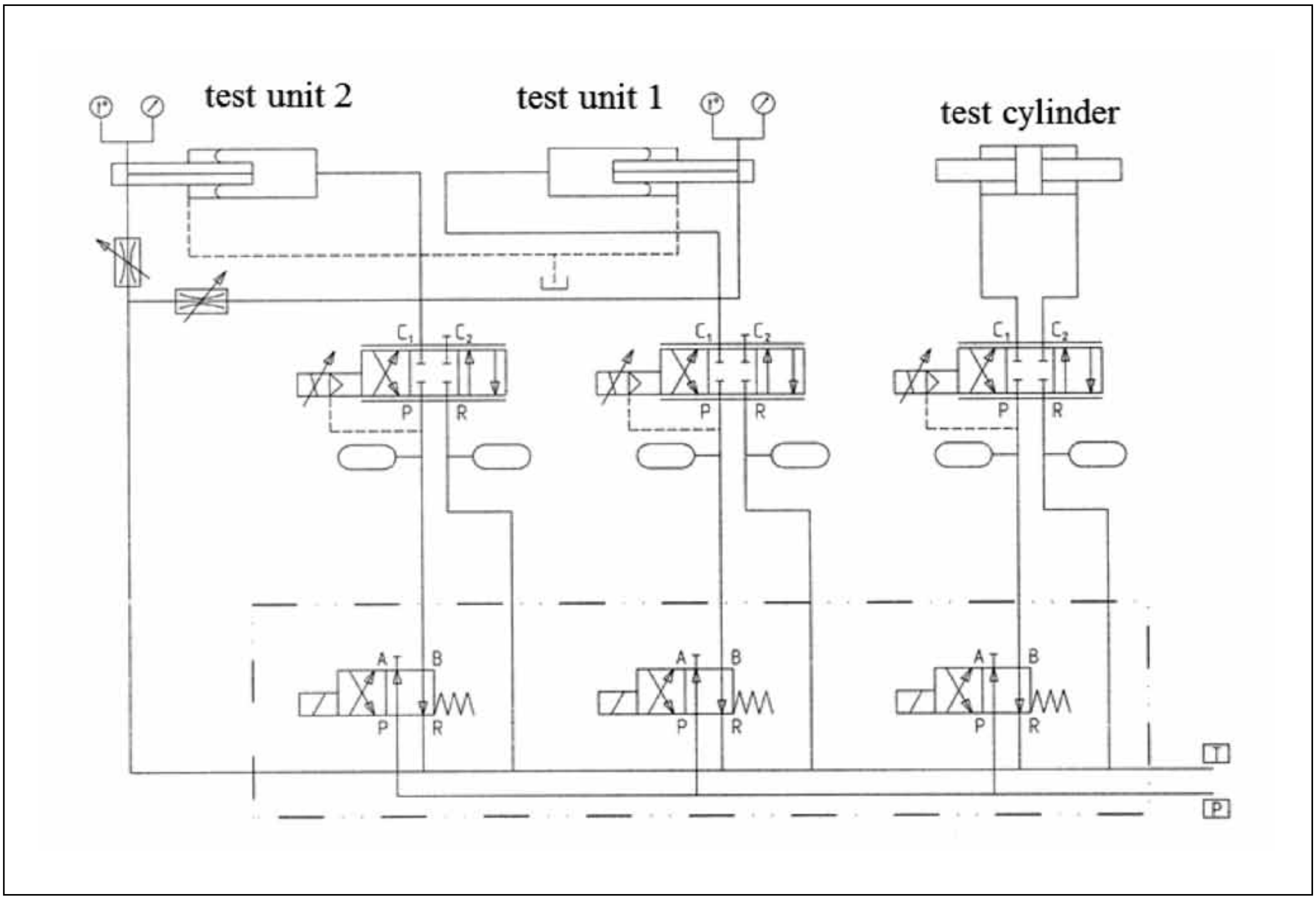

Figure 7. *Hydraulic diagram*

Table 2. *Burst pressure*

	producer burst pressure [bar]	determined burst pressure [bar]
test 1	225	190
test 2	225	190
test 3	225	192

Then the maximum load was reduced from trial to trial. The results of the individual experiments are summarized in a diagram (Wöhler curve, *Figures 9* and *10*).

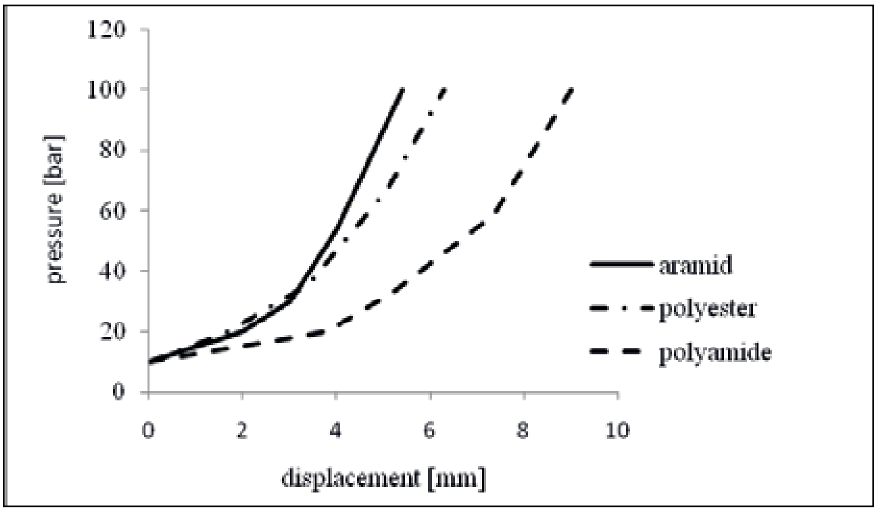

Figure 8. *Spring rate*

In cooperation with HAINZL industrial systems, it was agreed that an achievable number of two million load cycles would be sufficient to determine a test as positive. If this limit was reached before the bellows failure, the test would be aborted. The frequency of the applied load was higher than would occur in practice under normal operating conditions. The reason was due to the reduced trial period.

The experiments with test unit 1 resulted in a maximum load of 50 bar in order to achieve the predetermined limit of two million cycles (Table 3). By increasing the load, the tolerable number of cycles fell dramatically (Figure 9 and 10). The experiments with zero stroke (test unit 2) resulted in a maximum pressure of 60 bar (*Table 4*).

4.3.1 Test unit 1

The experiments with test unit 1 were performed at a frequency of 3 Hz and a stroke of 16 mm. This ensured that a point of the bellows-

Table 3. *Summary of experiments with test unit 1*

	load cycle		
p_{max} [bar]	polyamide	aramid	polyester
50	2000000	-	-
55	1700000	-	-
60	284000	382000	1648000
66	135000 168000	-	-
100	1626 8055 9500 10478 11376 14500	-	18000 21000
120	1460 2100 2640	-	-
140	1180 1210 1240	-	-

Table 4. *Summary of experiments with test unit 2*

	load cycles			
p_{min}/p_{max} [bar]	1 Hz	2.5 Hz	5 Hz	10 Hz
6/66	-	-	2000000	-
6/76	-	-	408000	-
6/86	-	-	32500	-
6/100	-	-	4260 8500 9500 12600	4100
6/140	350	300 1070 1100	990 1240 1500	1100

surface rolls from the support tube up to the piston rod.

4.3.2 Test unit 2

The experiments with test unit two were conducted at frequencies of 1, 2.5, 5 and 10 Hz.

4.3.3 Failure causes

The failure causes were on the bellows in both experiments, respectively. The bellows were leaking because of the high-load. The reason for this leakage was not the failure of the fabric layers, but the failure of the rubber layer [3].

5 Conclusion

The two million load cycles could not be achieved with the available manufacturing technology for bellows. A change of the fabric-layer material did not significantly improve the life-time of the bellows.

New bellows with four fabric layer are made to prevent the pressing of the rubber layer through the fabric layer. Whether this modification could increase the life time should show up in new tests.

References

[1] Tammisto Jyrki, Mattila Jouni, Irving Mike, Siuko Mikko, Vile-

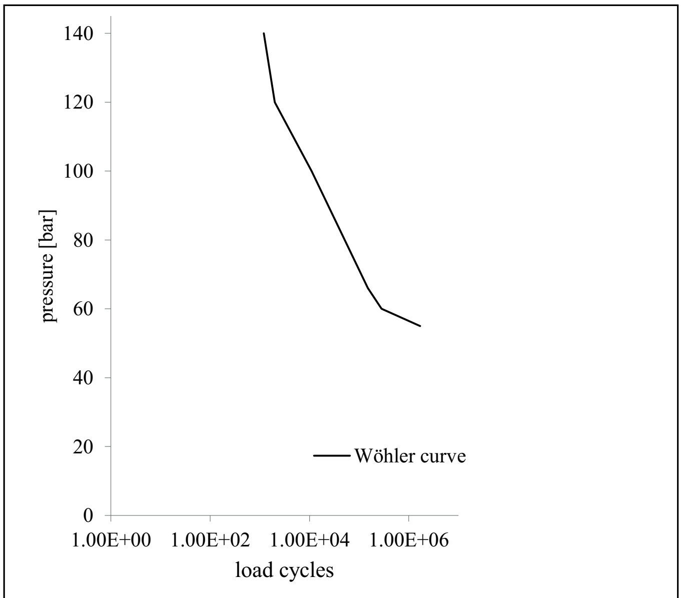

Figure 9. *Wöhler curve*

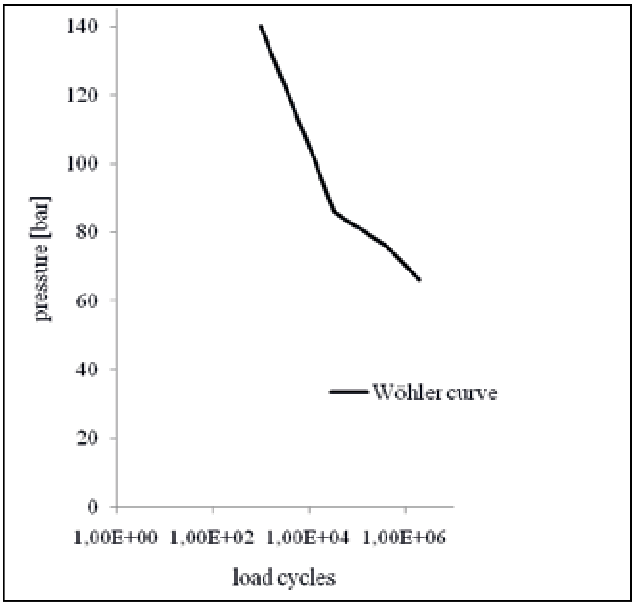

Figure 10. *Wöhler curve (zero-stroke)*

nius Matti. Radiation effects on friction and leakage properties of water hydraulic seals. *Scandinavian International Conference on Fluid Power*, 10: 229-238, 2007.

[2] S. Wetzel, E. Bock. Tap water hydraulics, a challenge for seal technology. *Eureka-Factory--Projekt, Wasserhydraulische Antriebssysteme – HYDRA*, 36-54, 2000.

[3] H. Hochleitner, J. Edler. Construction and testing of a hydraulic cylinder for water hydraulics. *Fluid Power 2011*, Maribor, 93-102, 2011.

Nova zasnova hidravličnega valja za vodno hidravliko

Razširjeni povzetek

Na nekaterih področjih industrije se kot tekočina v hidravličnih sistemih uporablja voda. Takšni področji sta na primer živilska industrija, kjer vodo kot tekočino uporabljajo zaradi okoljskih predpisov, ali pa rudarstvo zaradi varnostnih predpisov. Voda kot medij pa postavlja posebne zahteve glede načrtovanja hidravličnih komponent. Tako je potrebno za vsak sestavni del komponente, ki je v stiku z vodo, uporabiti materiale, odporne na korozijo. Dodatno pozornost je potrebno nameniti dinamičnim tesnilom. Zaradi pomanjkljivega mazalnega učinka vode se življenjska doba dinamičnih tesnil drastično skrajša.

V prispevku je predstavljena alternativna zasnova hidravličnega valja, ki omenjene pomanjkljivosti vsaj delno odpravlja. Delovni prostor predlagane izvedbe omejuje valjast meh, ki v stiku z vodo ne kaže nobenih negativnih posledic. Za vodenje batnice se uporabljajo vodilni obročki, zato dinamična tesnila niso več potrebna. Tako zasnovan valj je bil testiran na namenskem preskuševališču. Z določitvijo porušitvenega tlaka je bila določena največja dovoljena obremenitev valja. Poleg tega je bil valj preskušan tudi s trajnostnimi testi, z različno velikimi tlaki, da se določi njegova življenjska doba. Tako je mogoče opraviti primerjave med novo zasnovanim valjem in običajnimi valji, ki se uporabljajo na področju vodne hidravlike.

Ključne besede: hidravlika, vodna hidravlika, hidravlični valj, načrtovanje