Cylinder Seals in Water and Oil Hydraulics

Franc MAJDIČ, Mitjan KALIN, Alen LJOKI

Abstract: The frictional forces associated with hydraulic seals are an important part of designing hydraulic cylinders. For this reason, we decided to carry out detailed research on the influence of different seal types on a variety of hydraulic fluids. The research was divided into three parts: experimental work on a hydraulic test rig, experimental work on a tribological test rig and a numerical study. For the hydraulic part we made a new test rig in order to determine the frictional forces on different types of seals in water and oil hydraulics. The paper explains the hydraulic seals' properties and the theoretical background for determining the frictional force. The measurements were preformed on the test rig at two different operating pressures in a hydraulic cylinder, at two different speeds of the piston and for two different hydraulic fluids: water and oil. The work includes additional experimental results, which are later analysed in detail. Finally, there are numerical analyses of the seal friction for different operating pressures in the hydraulic cylinder.

Keywords: Seal friction, hydraulic cylinders, oil hydraulics, water hydraulics, tribological testing

1 Introduction

Seals are mechanical elements that prevent the flow of fluids or gases from one chamber to another, that separate chambers with different pressures, or that prevent the passage of harmful solid particles into a chamber, where we have a medium that must be isolated from external influences.

Roughly speaking, seals are divided into static seals and dynamic seals, where the seal moves relative to the element with which it is in contact.

Dynamic seals are mostly used in hydraulic cylinders, and for that reason we decided to focus only on those types of seals. The primary task of the seal is to ensure a sufficient sealing force, wherein it is also important to the frictional force that occurs as a result of the sealing force. An appropriate sealing force is difficult to achieve, the problem being a balance between the sealing force and the frictional force: the sealing force must be just large enough, while the frictional force must be as small as possible. In individual cases, the frictional force is from 2 to 10% of the total workforce, which can be performed using a hydraulic cylinder [1].

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The aim of this work was to investigate the influence of the most commonly used shape and material seal on the piston rod of the hydraulic cylinder on the frictional force. The selected seal was an O-ring.

For the selected gasket we performed tribological tests to determine the coefficient of friction. Later, we also made a numerical cal-

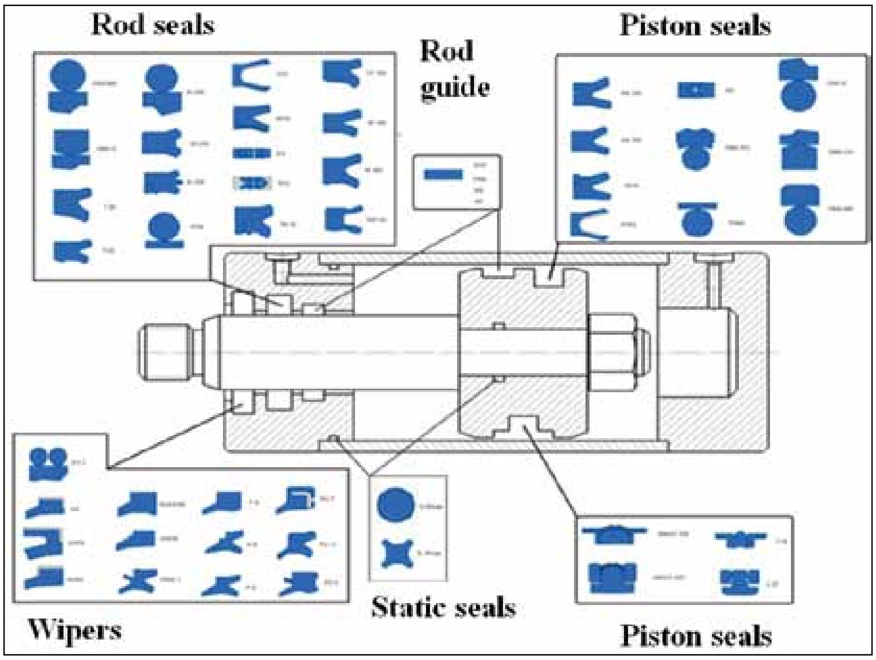

Figure 1. *Various seals for use within hydraulic cylinders [2]*

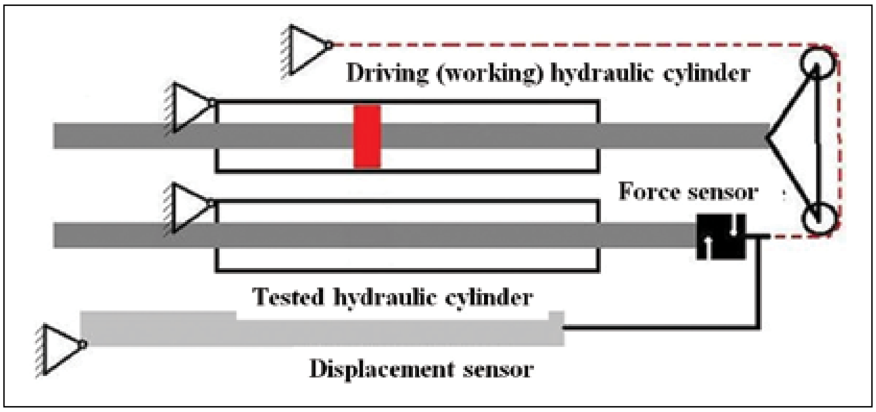

Figure 2. *Schematic view of the selected test rig*

culation and determined the force of friction in relation to the results obtained using tribological tests.

There are several types of seals in hydraulic cylinders. They differ in terms of form and material, depending on the method of installation, the temperature range, the used hydraulic fluid, the pressure, and the speed of movement. Hydraulic seals are important for minimizing the loss of liquid in hydraulic parts, and therefore have a major impact on the efficiency of hydraulic systems. Some types of seals and other elements, which are today used within a hydraulic cylinder, are shown in *Figure 1* [2].

2 Experimental setup

2.1 Hydraulic test rig

During the design of the hydraulic test rig we developed a few different concepts, from among which the schematic test rig presented in *Fig. 2* was chosen. By using the hoists, which can be moved using a hydraulic cylinder, through the cable, the shaft can be pulled. The speed can be controlled easily, because the speed of the piston rod is exactly twice as much as the speed of the movement of the driving hydraulic cylinder.

The test rig consists of a driving hydraulic cylinder, which is operated by a control device, a Poclain NTS-3-O, and the tested hydraulic cylinder, which was moved through pulleys. The control unit regulated the oil flow through the control valve to adjust the speed of the driving cylinder.

The individual measurements were carried out according to the following steps:

- First, it was necessary to empty and dismantle the hydraulic cylinder, so it could be cleaned and prepared for the measurements,
- When we changed the hydraulic liquid in the tested hydraulic cylinder (oil-water), it was necessary to thoroughly clean the cylinder with compressed air, to clean all the connections and at the end, with degreasing fluid, clean the remaining hydraulic oil from the surfaces,
- The filling of the test cylinder with hydraulic fluid was only done through one connector and the other end we left open, so that the cylinder could be ventilated by removing all the air bubbles out of the system,
- The pressure in the tested hydraulic cylinder was increased to 50 bar, for the seal to adjust and so the seals could create a lubricating film,
- Later we relieved the pressure in the cylinder at 0 bar and started with the measurements,
- Each measurement with certain parameters was repeated three times. The average value of the three measurements was analysed.
- The measurements were started at 0 bar and then the pressure was increased in steps of 50 bar to 150 bar,
- After completing all the measurements at the chosen speed, the throttle was adjusted for another speed. The tests were repeated with the steps mentioned above,
- When we completed all the measurements, it was necessary to replace the test liquid and then repeat the whole process, as previously described.

The measured data were acquired using LabView software. The displacement of the piston rod, the cylinder pressure and the frictional force were measured. The speed was calculated from the measurement results.

Figures 4 and *5* show the results of the measurements on the hydraulic test rig.

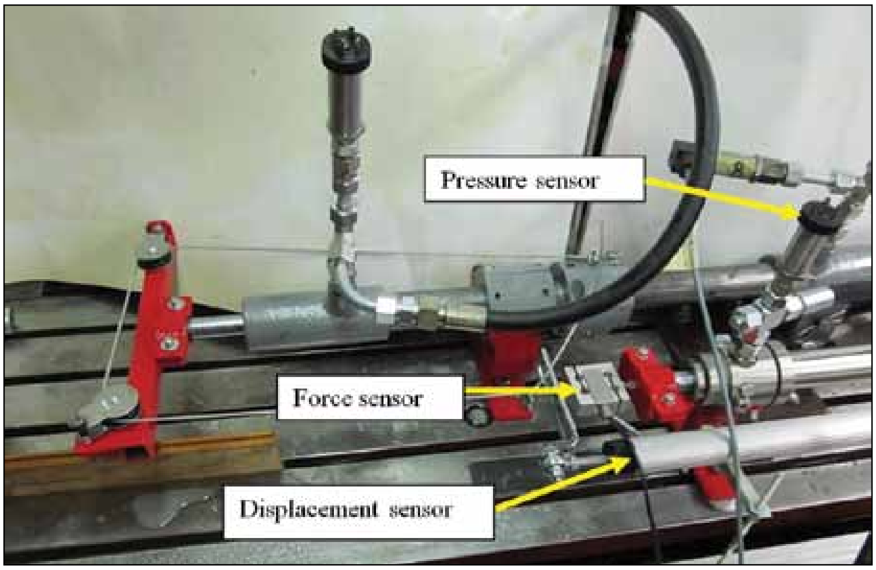

Figure 3. *Hydraulic test rig used for the measurements*

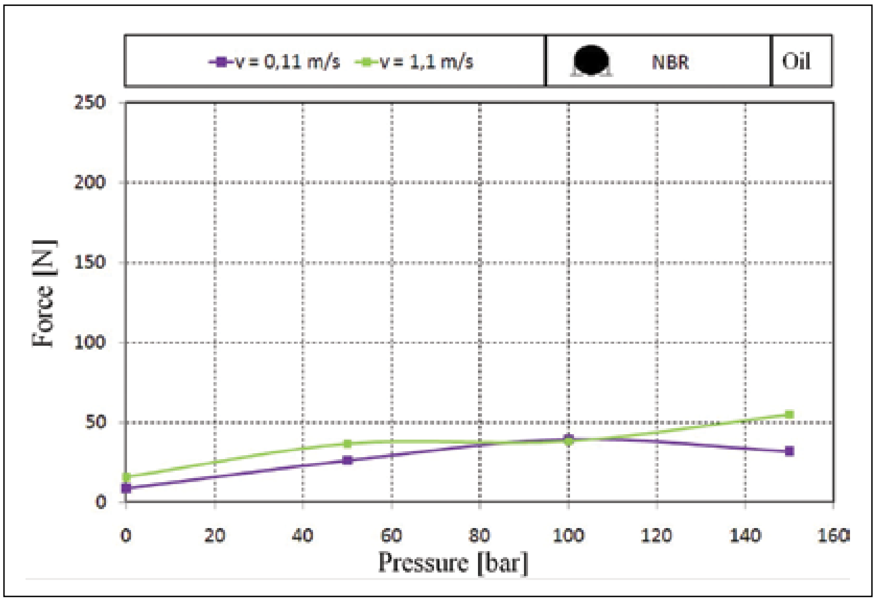

Figure 4. *The results of the measurements with O-ring seals piston rod - hydraulic oil*

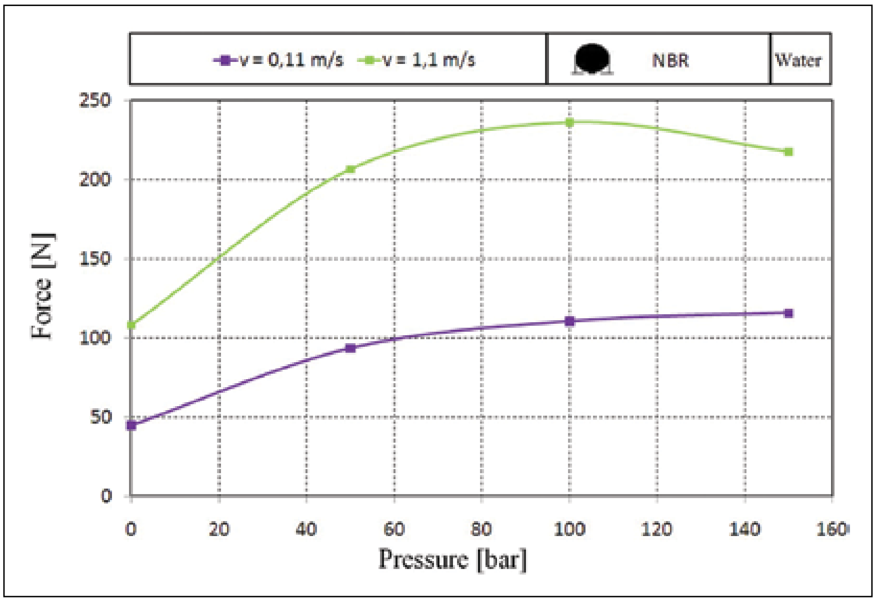

Figure 5. *The results of the measurements with O-ring seals piston rod – water 2*

2.2 Tribological test rig

The tribological measurements were performed on a Cameron-Plint TE77 *(Fig. 6)*. For the measurements of the tribological parameters we used a reciprocal movement. This was achieved by using an eccentric mechanism, which allows the adjustment of the speed and the length of the displacement, while the displacement was inversely proportional to the speed.

The measurements were carried out at two levels of compression force. Initially, it was necessary to reduce the force with the help of numerical simulations. The contact pressure during the tests should be the same as the pressure in actual use. Therefore, we performed a series of numerical simulations, where we simulated the effect of the operating pressure on the entire seal and the influence of the compression force on the shank with a cut-off seal.

For 50 bar of working pressure we obtained sufficient contact pressure. The tension force during the testing was from 120 to 150 N. If, during the measurements, deformation or wear of the seals were to occur, those measurements would be invalid.

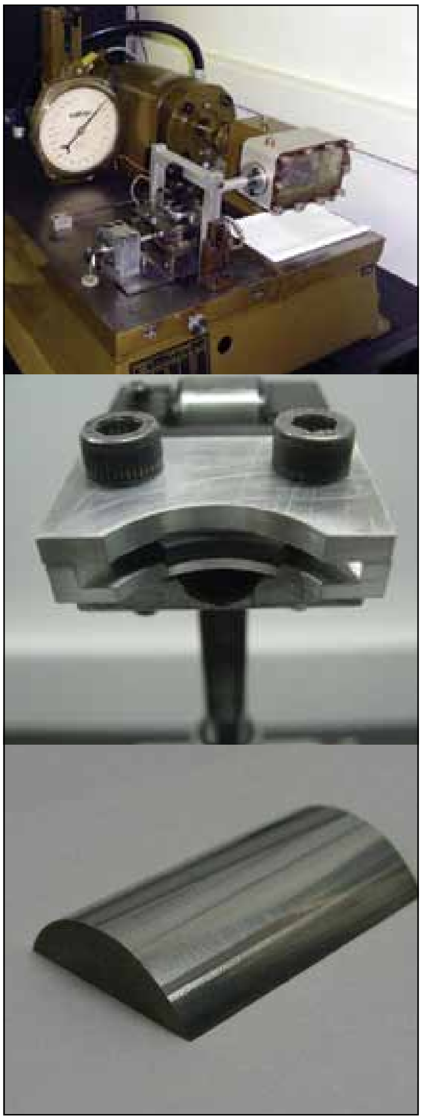

Figure 6. *Tribological test rig with measurement accessories*

Therefore, the measurements were made on two forces, i.e., 20 and 50 N, see *Table 1*.

Table 1. *Comparison of the results of measurements for friction coefficient at two compression forces and two different fluids*

O-ring	Friction coefficient [/]	
	Water *Average*	Oil *Average*
Force 20N	0.165	0.113
Force 50 N	0.133	0.062

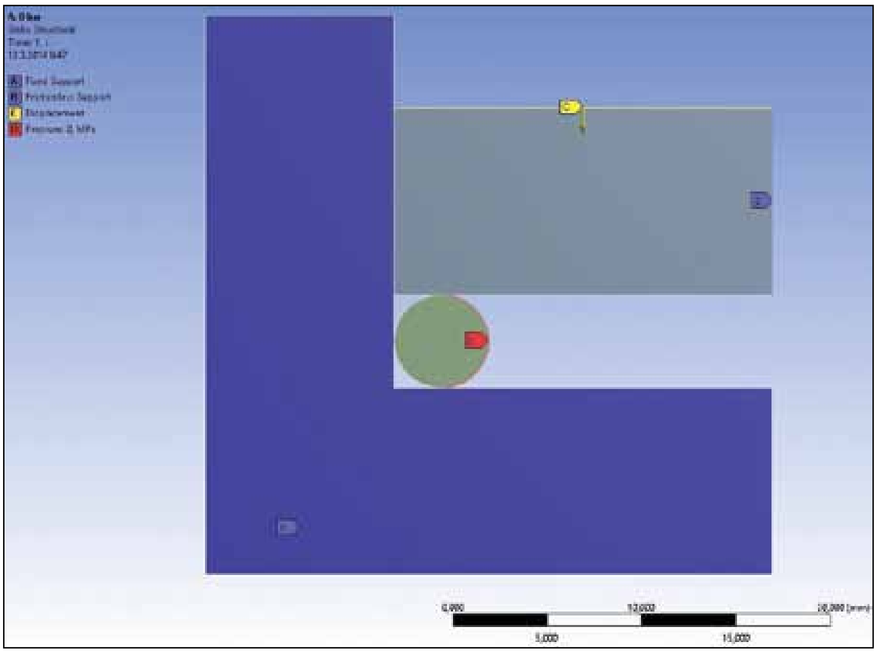

Figure 7. *2D model for the FEM analysis*

3. Numerical part

During the research a numerical analysis of the contact pressure on the force was made. From the simulation results we calculated the frictional force.

Since it is an axially symmetrical problem, we replaced the 3D model for the analysis with a 2D model. The numerical model is shown in *Fig. 7* [3 – 5].

In the analysis, we observed deformation in the radial direction. At the beginning of the simulation the upper part pressed the seal into the deformed state. Later, we applied pressure on the seal.

Figure 8 shows the results of four numerical analyses performed at pressures of 0 bar, 50 bar, 100 bar and 150 bar. The figure shows the stress state at different operating pressures in the hydraulic cylinder. The largest local tension (15 MPa) occurred at a pressure of 150 bar.

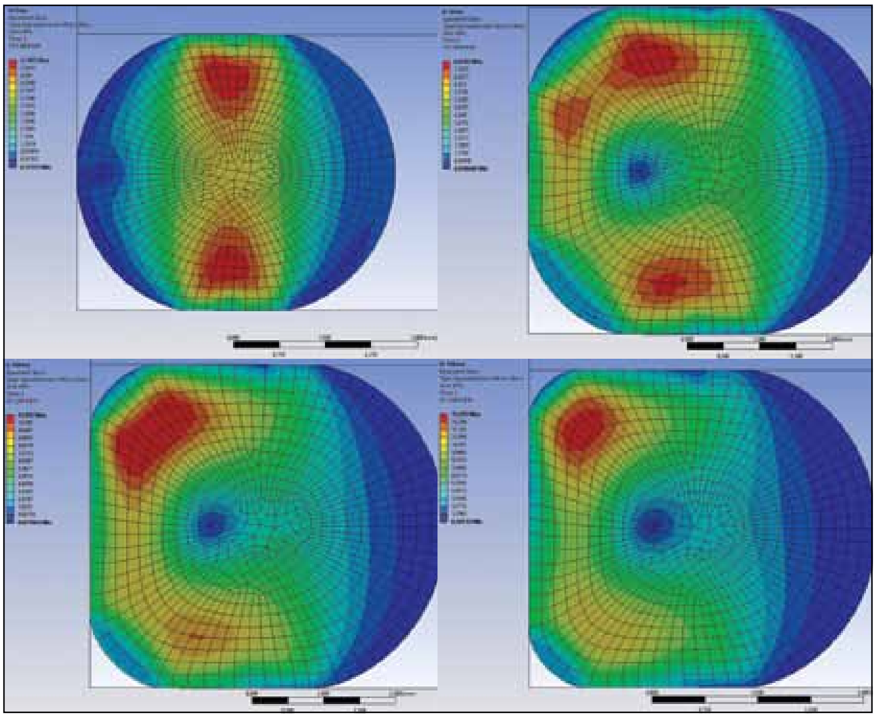

Figure 8. *Deformed seal at different pressures: 0, 50, 100 and 150 bar*

4 Results and Discussion

We compared the numerical with the measurement results at a rod speed of 0.11 m/s. A comparison was made for different hydraulic fluids and at four different pressures. The results are shown in *Table 2*.

Based on the results of the numerical analysis, the values are relatively good, because it should be noted that the calculated frictional force is calculated only based on the coefficient of friction and the normal force does not take account of the mechanics of the contact and the impactoflubricantsinthecontact.Comparing the measured force in the oil shows a slightly larger deviation.

5 Conclusions

The aim of this research was to investigate the scope of the friction seals within the hydraulic cylinder, especially in terms of comparing the force of the friction seals in two different hydraulic liquids. The first hydraulic fluid was mineral hydraulic oil and the second was water without additives. Even though there have been great developments in the field of water hydraulics in recent times, it is still not often used in practise. Users of hydraulic systems are often, for various reasons, reluctant to use water as a hydraulic liquid. One of the reasons for their reluctance is also the friction seals inside the water hydraulic cylinders [6]. The aim of this study was to demonstrate that the friction seals are not a major limitation in the development and use of water as a hydraulic liquid.

In previous studies, the frictional force of the water seal within the hydraulic cylinder was usually assessed by measuring the pressure difference between the ends of the observed hydraulic cylinder. However, such a method is not pre-

Table 2. *Comparison of the numerical results with the measured values of the friction forces tested in different hydraulic fluids*

	Pressure	Calculated [N]	Measured [N]
Oil	0 bar	12	4
	50 bar	17	13
	100 bar	27	19,5
	150 bar	31	15,5
Water	0 bar	26	22
	50 bar	37	46,5
	100 bar	59	55
	150 bar	69	57,5

cise enough, especially in the case where we want to determine the frictional force for the moving hydraulic cylinder.

In this work, a new experimental approach to determining the friction forces of seals is presented. For this purpose, a new hydraulic test rig was made, which allows separate measurements of the force of friction piston rod seals.

The result of the comparative analysis of the use of water and oil indicates that the water may be used as a hydraulic liquid, with appropriate selection of the hydraulic seal, and be comparable with oil.

The maximum friction force during the testing with hydraulic oil was 19.5 N and for water it was 57.5 N. This means that for a hydraulic cylinder that can produce a force of 8042 N, the friction force for oil represents 0.24 % of the total force. In contrast, for water the friction force presents 0.72 % of the total force. The difference in the frictional forces is in favour of the oil hydraulic cylinder. While the comparison of the results at a lower speed for the piston rod shows better efficiency in favour of the water hydraulics.

In the future we are planning to test different shapes of seals and also seals made out of different materials.

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Tesnila hidravličnega valja za vodno in oljno hidravliko

Razširjeni povzetek

Poznavanje sile trenja v povezavi s hidravličnimi tesnili je pomemben del konstruiranja hidravličnih valjev. V ta namen smo se odločili detajlno raziskati vpliv različnih tipov hidravličnih tesnil glede na uporabljeno hidravlično kapljevino. Raziskava je bila razdeljena na tri dele: eksperimentalno delo na hidravličnem preizkuševališču, eksperimentalno delo na tribološkem preizkuševališču in na numerične izračune z analizo rezultatov. Za hidravlični del smo izdelali novo preizkuševališče za merjenje sile trenja pri različnih tipih tesnil v sistemih z vodno in oljno hidravliko. Prispevek govori o lastnostih hidravličnih tesnil in rezultatih teoretičnega izračuna sile trenja ter rezultatih meritev teh sil. Meritve so bile izvedene na preizkuševališču pri štirih različnih tlakih sistema, dveh hitrostih batnice in dveh različnih hidravličnih kapljevinah. To sta mineralno hidravlično olje in voda. Delo zajema dodatne eksperimentalne rezultate, ki so v nadaljevanju analizirani. Na koncu so predstavljeni rezultati numeričnih izračunov in rezultati meritev ob štirih različnih tlakih in obeh uporabljenih kapljevinah *(Tabela 2)*.

Ločimo statična in dinamična tesnila. Pri dinamičnih tesnilo opravlja relativni pomik glede na element v kontaktu. V hidravličnih valjih se uporabljajo oboja tesnila, vendar so dinamična v delovanju bolj problematična, zato jih bomo detajlno obravnavali. Osnovna naloga tesnila je zagotavljanje primerne tesnilne sile med elementoma, posledica pa je sila trenja, ki je v rangu od 2 % do 10 % celotne »delovne« sile. Obstajajo različni tipi tesnil, ki se razlikujejo po obliki in materialu, po načinu vgradnje, temperaturni odpornosti, vrsti uporabljene

kapljevine, delovnem tlaku in hitrosti drsenja. Nekaj tipov tesnil, ki se trenutno vgrajujejo v hidravlične valje, je prikazanih na *sliki 1*. V pričujoči raziskavi smo se osredotočili na najbolj pogosto obliko in material tesnila – izbrali smo O-tesnilo iz poliuretana (NBR).

V postopku konstruiranja hidravličnega preizkuševališča smo izdelali nekaj shematskih konceptov in na koncu izbrali koncept, ki je predstavljen na *sliki 2*. S škripčevjem lahko preprosto prilagajamo hitrost pomika batnice, katere hitrost je natanko dvakrat večja od hitrosti pogonskega hidravličnega valja. Na *sliki 3* je sestavljeno in opisano hidravlično preizkuševališče z vsemi sestavinami. Meritve so potekale po vnaprej določenih korakih. Določevali so velikost testnih tlakov in pretokov ter ukrepe in načine pri menjavi hidravlične kapljevine. Zajemanje podatkov o pomiku batnice, višini tlaka v hidravličnem valju in velikosti sile trenja je potekalo s programom NI LabView. Rezultati meritev, pridobljenih na hidravličnem preizkuševališču za mineralno olje in vodo, so prikazani na *slikah 4* in *5*.

Tribološke meritve so bile izvedene na napravi Cameron-Plint TE77, ki je prikazana na *sliki 6*. Za meritev triboloških parametrov smo uporabili vzajemno gibanje. To je bilo doseženo z uporabo ekscentričnega mehanizma, ki omogoča prilagajanje hitrosti in dolžino pomika, pri čemer je pomik obratno sorazmeren hitrosti. Pri tlaku 50 bar smo zagotovili zadosten kontaktni tlak. Izmerjena sila trenja se je gibala med 120 N in 150 N. Ker je prišlo do deformacij in obrabe tesnil, smo merili pri dveh različnih silah trenja. V *tabeli 1* so prikazani koeficienti trenja pri dveh različnih silah in obeh hidravličnih kapljevinah.

Analizirani model je simetričen, zato smo problem obravnavali »v ravnini«. Na *sliki 7* je predstavljen numerični model, na katerem smo izvedli simulacije. Pri simulaciji smo opazovali deformacije tesnila. Na začetku smo z zgornjim izrezom batnice pritisnili na tesnilo, da smo ga deformirali, nato pa smo dodali delovni tlak. Deformacijo smo merili pri tlakih 0 bar, 50 bar, 100 bar in 150 bar. Silo trenja smo izračunani na podlagi rezultatov simulacije. Natančnejši rezultati simulacij so razvidni iz *slike 8*.

Rezultati meritev in numerične analize sil trenja so primerjani pri tlakih 0 bar, 50 bar, 100 bar in 150 bar. *Tabela 2* vsebuje rezultate za vodo in mineralno olje. Iz primerjave vidimo, da je odstopanje med rezultati meritev in rezultati numeričnih izračunov sile trenja majhno, tj. v rangu med 4 N in 15 N. Pri analizi rezultatov je treba upoštevati, da pri numeričnem izračunu nista bila upoštevana kontaktna mehanika in udar kapljevine.

Zaključek: *Namen pričujočega dela je bil raziskati področje tesnil, uporabljenih v hidravličnih valjih. Uporabljeni kapljevini sta bili mineralno hidravlično olje in voda brez aditivov – pitna voda. Bistvo prispevka je pokazati, da tesnjenje ni omejitev za uporabo vode kot hidravlične kapljevine. Z raziskavo je bil predstavljen nov eksperimentalni postopek ugotavljanja sile trenja na tesnilnih elementih. Razvito je bilo novo preizkuševališče, na katerem je možno ločeno meriti silo trenja na batnici.*

Ključne besede: trenje tesnil, hidravlični valj, oljna hidravlika, vodna hidravlika, tribološki testi