Serbian Tribology Society

SERBIATRIB '15

14th International Conference on Tribology

University of Belgrade, Faculty of Mechanical Engineering

Belgrade, Serbia, 13 – 15 May 2015

EXPERIMENTAL RESEARCH ON THE DETERMINATION OF THE FRICTION FORCES FROM DYNAMIC SEALS OF THE HYDRAULIC CYLINDERS

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Abstract: *The article presents a synthesis of experimental research conducted by the authors, in order to determine the frictional forces that occur during operation, in dynamic seals of the hydraulic cylinders, used in hydrostatic driving/actuating of the technological equipments. There are presented, briefly, the experimental devices and stands, as and some experimental graphical results, which have been obtained for the variation of the main parameters of interest from the operation of hydraulic cylinders: friction forces, pressures of work, working stroke and working speeds and, also, oil temperature. It make some remarks on the allure of the variation graphs of the friction forces and, also, some considerations on the frictional losses occurring in the operation of hydraulic cylinders. Finally, some conclusions with scientific and practical value are issued, from which can be extracted some constructive optimization measures and for increasing of energy efficiency of the hydraulic cylinders.*

Keywords: *tribology, seals, frictional forces, hydraulic cylinders, testing stand.*

1. INTRODUCTION

The sealings represent assemblies of machine elements which close hermetically a space containing a medium under pressure, the separation of two or more spaces with mediums under different pressures, respectively the tight protection of some spaces containing lubricants, against leakages or the intrusion of foreign bodies [1].

The sealings may be fixed or mobile**,** and the mobile ones, may be with rotation or translation motion, the last ones being the subject of the present article. The mobile or dynamic translation sealings are specific to the hydraulic cylinders, Fig. 1 where realize the sealing on the rod with diameter *d*, and the piston with diameter *D*.

Performing optimum dynamic sealing represents a key factor for providing the reliability of the hydraulic drive systems [2].

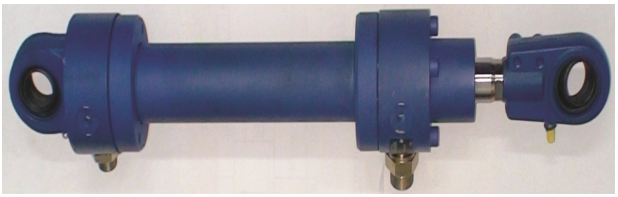


Figure 1. Hydraulic cylinder type REXROTH

The process of dynamic seal of the hydraulic cylinder piston and rod is realized in conditions of fluid friction, when between the surfaces with relative motion with certain speed, the cylinder body and the rod and the piston are provided continuous lubrication with fluid lubricant which adheres to the component parts in motion [3].

The seal process and, also, the tribological process are influenced, by a lot of factors,

besides the phenomena from the seal interstice, by the shape and the material of the seal type, the mechanical characteristic of the parts which are being in contact [4].

The fluid lubricant adheres to the component parts in motion. The variation of the tangential force, which appears between the surfaces with relative motion, represents the real friction force, which can be calculated by mathematical modelling and computer simulation, but must to be determined, also, by experimental methods [5].

Within the equipment and systems where they are include, hydraulic cylinders must ensure the parameters required by the system and have a proper dynamic behaviour. An important role in ensuring the dynamic behaviour of hydraulic cylinders is played by the forces occurring in the system. Frictional forces that occur between cylinder rods and between cylinder and piston seal, their seals play an important part and influence the dynamic behaviour of hydraulic cylinders [1].

In this regard, their institute has developed an extensive research to determine, by experiments, the frictional forces within the seals of hydraulic cylinders. Some specific issues, related to conducting such research, have already been communicated, [6-8].

2. THE CONDUCTING OF EXPERIMENTAL DETERMINATIONS

In order to know and to determine, on experimentally way, the evolution of the friction forces in the hydraulic cylinder seals, the research was developed in two directions, namely:

- In the first stage have been developed theoretical and experimental research to determine the frictional forces in the dynamic seals of the rods of the hydraulic cylinders, and
- In the second stage, experimental investigations have been developed for determining the friction forces in the dynamic seal of the pistons of the hydraulic cylinders, using a special experimental device.

For experimental determination of frictional forces, occurring in the seals of the hydraulic cylinders, was designed and developed two different experimental devices, one for rod seals, and another for piston seals, also, a testing stand, presented in Figure 2.

Figure 2. Overview of the testing stand

To conduct the experimental research, were developed research programs and procedures, which established working mode, respectively, the results to be obtained. Also, have been settled the basic parameters of the research, presented in the following.

2.1 Type, shape and material of tested seals

To achieve the experimental researches for measuring of the friction forces which appear in the seals of the hydraulic cylinders, was chosen the gaskets with U shape, made from rubber of hardness Shore 85, Fig. 3a and b. The experimental devices were conceived that the two used gaskets, have to be mounted face to face, on special parts [6,8].

(a) (b)

Figure 3. U shape and rubber for gaskets

2.2 The pressures adopted for testing

Since the working pressures in usual mobile hydraulic installations are usually of max. 160

bar, and seldom of 210 bar, it has been agreed that the maximum testing pressure should be of 250 bar. To have a convincing experimental database, it has been considered as appropriate to carry out experimental measurements for different values of working pressure. There were selected, as pressure levels, the significant steps at every 50 bar, in the range of 0 to 250 bar, in each experimental measurement being performed 3 working cycles of the hydraulic cylinder and, for each value of working pressure, were realized 3 determinations. The creating of the pressure steps is made with a hand pump by the operator, Fig. 4.

Figure 4. Creating pressure with hand pump

2.3 Testing speeds adopted

To achieve the experimental researches for measuring of the friction forces, were regarded as sufficient two theoretical speed levels at the experimental devices, namely: 50 mm/s and 100 mm/s, but, practically, the speed varies around of these values.

2.4 The experimental procedure and measured parameters

For experimental determination of frictional forces, was necessary to elaborate of one experimental procedure, which has been presented in previous papers [6,8]. With taking into account of the research objective and of the testing possibilities offered by the developed testing stand.

Experimental determinations were mainly aimed at measuring and recording the evolution of frictional forces that occur in the seals of the hydraulic cylinder. Since the experimental devices and the measurement system developed for the determination of frictional forces provide broader measurement opportunities, including the measurement of the some functional parameters, the graphic variations were obtained simultaneously for several parameters, namely: 1 – variation of frictional forces within the seals of hydraulic cylinders; 2 – variation, within reasonable limits, of the pressure in the tested seals; 3 – variation of working stroke of the special tested seal; 4 – variation of working velocity at the seals; 5 – variation of temperature between the two gaskets during testing.

Thus, following the experimental measurements, a number of complex graphics were obtained, each one showing the variation of the 4-5 parameters, mentioned above.

These data gathered form a real experimental database, regarding the variation of the frictional forces which appear on seals on rods and on pistons of the hydraulic cylinders, which represents an important contribution of the authors in this field.

3. THE ECPERIMENTAL DETERMINATIONS OF THE FRICTION FORCES

3.1 The friction forces in the piston seal

In the Figure 5, is presented a rod seal, where realize the sealing on the rod with diameter d, being in reciprocating translation motion on the stroke *S*, in the fluid with the constant viscosity η and under pressure *p*, *v* and *vr* are the velocities, in the both senses, and Q represents the leakages from the seal.

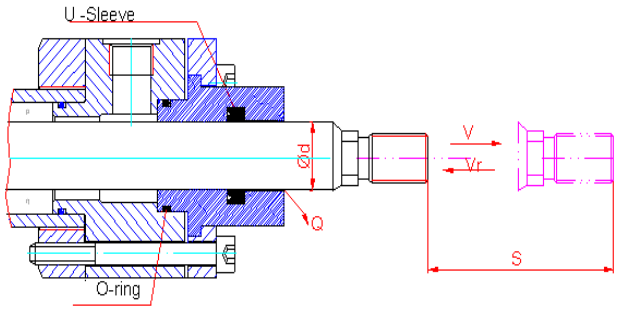
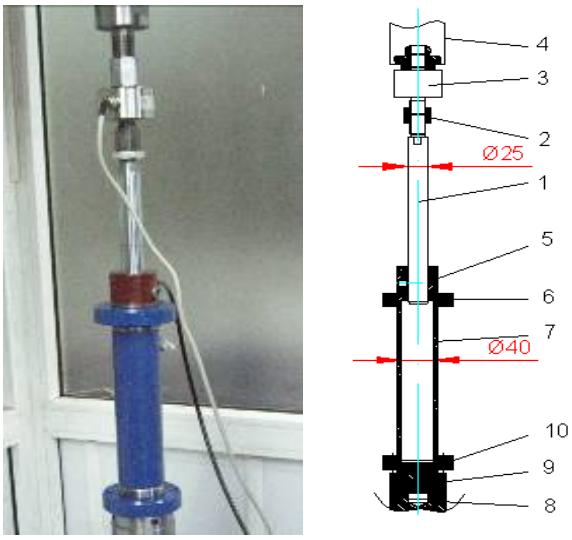


Figure 5. The rod seal of the hydraulic cylinder

In order to evaluate the friction forces from the rod sealing of the hydraulic cylinders, was designed and developed an experimental device, presented in Figure 6a, which was mounted on the stand which assured the vertical stroke [2].



(a) (b)

Figure 6. Experimental device for rod seal

In the schematic representation from Figure 6b, it can see the fixed rod (1), a threaded bush (2), the force transducer (3), the up catching stationary head (4) of the existing stand. Downside, the rod crosses the double sealed bush (5) assembled by means of a nut (6), from the used cylinder, by its liner (7), which is mobile one. Downside, the cylinder liner is connected to the mobile rod (8) of one the other hydraulic cylinder, of the existing stand where is mounted, by means of a connection part (9) and of a nut (10).

In the first series of measuring, it was tested one type of seal, named *U sleeve*, for one kind of material and only for the sealing of the rod, with the diameter to 25 mm.

There are obtained a lot of complex graphs obtained for different pressures (50 bar pressure steps) and certain speed step (100 mm/s), One experimental result is given in Figure 7, where are represented the complex characteristic graphs for pressure step values of 200 bar and high speed (theoretic about 100 mm/s).

These graphs were presented and analyzed in detail, and have been drawn some particularly and interesting conclusions [6].

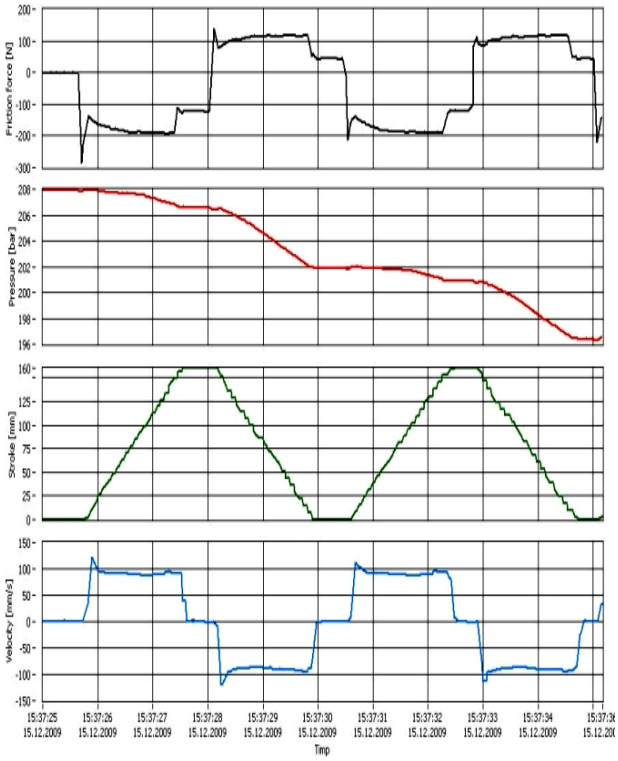


Figure 7. Graphics for pressure step of 200 bar

3.2 The friction forces in the piston seal

In the Figure 8 is presented a piston seal, where realize the sealing on the piston with diameter *D*, being in reciprocating translation motion on the stroke *S*, in the fluid with the constant viscosity η and under pressure *p*, *v* and *vr* are the velocities, in the both senses [7].

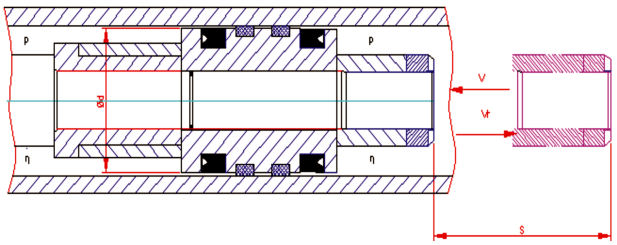


Figure 8. The piston seal of the hydraulic cylinder

In order to evaluate the friction forces, from the piston sealing of the hydraulic cylinders, was projected and realized an original experimental device, presented in Figure 9, which, also, was mounted on a test stand. The components are similar, but the conception is other. It can see the existing of a fixed hydraulic cylinder “body” on the force transducer and a mobile red rod ,actuated up and down, by the test stand.

Figure 9. Experimental device for piston seal

Following the developed experimental research, it was obtained a complete set of experimental results, for 6 steps of pressure, with 3 determinations for each step, each measurement having 3 working cycles. In total, were 54 experimental determinations. One example is presented in Figure 10.

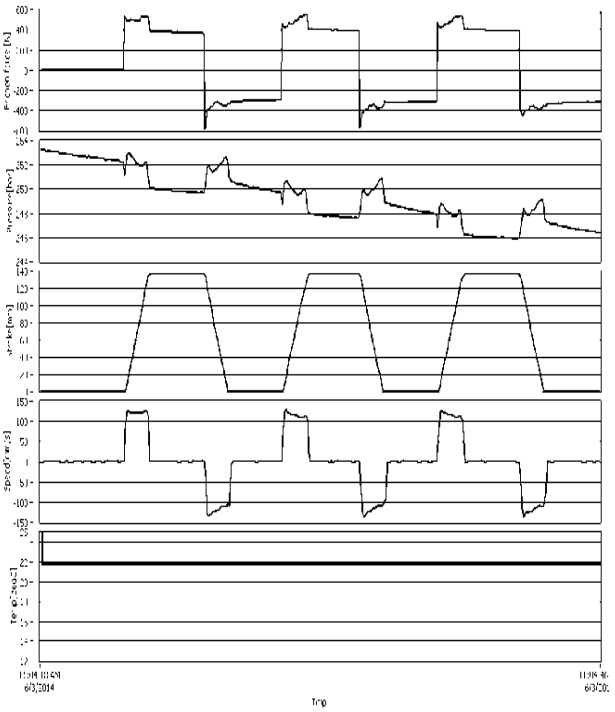


Figure 10. Complex graphs for pressure of 250 bar

These graphs were presented and analyzed in detail, and have been drawn some particularly and interesting conclusions [8].

4. ANALYSIS OF THE FRICTION LOSSES ON SEALS OF THE HYDRAULIC CYLINDERS

To this end, has been selected a range of values of the friction force F_f, from the seals investigated, and three consecutive measurements were averaged for the same level of pressure. Each of these values are valid for the two seals of the experimental device, but the half of each values is valid for a single seal. Finally, has been calculated the pressure force F_p, for each pressure step, and then has been calculated the report/ratio of friction force F_f versus active pressure force F_p, as the ratio R, decimal or percentage.

4.1 Analysis of the friction losses on sealing of the rod

For the friction forces of seals for rods of the hydraulic cylinders, have been obtained the data contained in Table 1, below.

Table 1. The friction forces on the rod sealing

No crt	Press. steps [bar]		Rod friction forces F_{fr} [N]		Calcu-lated press. forces F_{pt} [daN]	Forces report $Rt = F_f/F_p$ [-]
	Val.	Var	Med. value	No. seal 2 / 1		
1	10	a	9.4	12.6 / 6.3	76.5	0.0082
		b	13			
		c	15.5			
2	50	a	47.5	43.2 / 21.6	382.5	0.0056
		b	40.5			
		c	41.5			
3	100	a	75	74.6 / 37.3	765	0.0048
		b	75			
		c	74			
4	150	a	93.5	94.2 / 47.1	1147	0.0041
		b	93.5			
		c	95.5			
5	200	a	113	104. / 52.2	1530	0.0034
		b	96.5			
		c	103			
6	250	a	118	108. / 54.2	1912	0.0028
		b	101			
		c	105			

On the basis of data, were calculated the report/ratio *Rt* between the frictional forces and the pressure forces on the lower face of the piston of one equivalent hydraulic cylinder.

The report/ratio *Rt* is the expression of losses of active force F_p, due the friction forces which appear on the seals of rod and piston of one hydraulic cylinder.

4.2 Analysis of the friction losses on sealing of the piston

Data on the frictional forces inside of seals of the piston of hydraulic cylinder analyzed, are summarized in Table 2, where, de asemnea, were has been calculated the values of the pressure forces on the great face of the piston, for each pressure step, and, also, was calculated the ratio *R*.

Table 2. The friction forces on the piston sealing

Nr. crt	Pressure steps [bar]		Piston friction forces F_{fr} [N]		Calculated press. forces F_{pp} [daN]	Forces report $Rp = F_f/F_{pp}$ [-]
	val.	var	val. med.	Nr seal 2 / 1		
1	10	a	39	32.6 / 16.3	125.6	0.0129
		b	30			
		c	29			
2	50	a	144	159 / 79.5	628.3	0.0126
		b	163			
		c	170			
3	100	a	292	286 / 143	1256	0.0114
		b	275			
		c	291			
4	150	a	408	403 / 201	1885	0.0107
		b	392			
		c	409			
5	200	a	355	521 / 260	2513	0.0104
		b	515			
		c	494			
6	250	a	538	542 / 271	3142	0.0086
		b	555			
		c	535			

The forces of friction of piston seals which are contained in Table 2 are produced, effectively, in the expansion stroke of the rod of the hydraulic cylinders, not in withdraw stroke of the rod.

4.3 Analysis of the friction losses on seals, at the withdraw stroke of the rod of the hydraulic cylinders

On the withdraw/return stroke of the rod of hydraulic cylinders, participate both sealing of the piston and sealing of the rod, therefore, at this stage, can cumulate the two friction forces which cumulate their effects.

Table 3. The frictional forces on the withdraw stroke of the rod

Nr. crt	Press. [bar]	Friction forces one seal F_{fr} [N]			Calculated press. forces F_p [daN]	Forces report $Rtp = F_f/F_p$ [-]
	Val.	Piston seal	Rod seal	$F_t + F_p$		
1	10	16.3	6.3	22.6	76.5	0.0295
2	50	79.5	21.6	101	382.5	0.0264
3	100	143	37.3	180	765	0.0235
4	150	201	47.1	248	1147	0.0216
5	200	260	52.2	312	1530	0.0204
6	250	271	54.2	325	1912	0.017

In return/withdraw stroke of the piston rod of the hydraulic cylinders, the friction losses from sealing system are almost double, in comparison with the friction losses in the piston rod extension phase, they significantly reducing the active force of pressure, which is less so.

In this way, the friction losses in the hydraulic cylinder sealing systems, are important and should be taken into account to analyze the dynamic behaviour of the hydraulic cylinders.

4.4 Graphs variation of the friction forces from the seals of the rods and pistons of the hydraulic cylinders

Based on data contained in the three tables above, were traced curves of variation of pressure forces, Fig. 11, the variation of the friction forces on seals, Fig. 12, and the variation of the forces reports, Fig. 13.

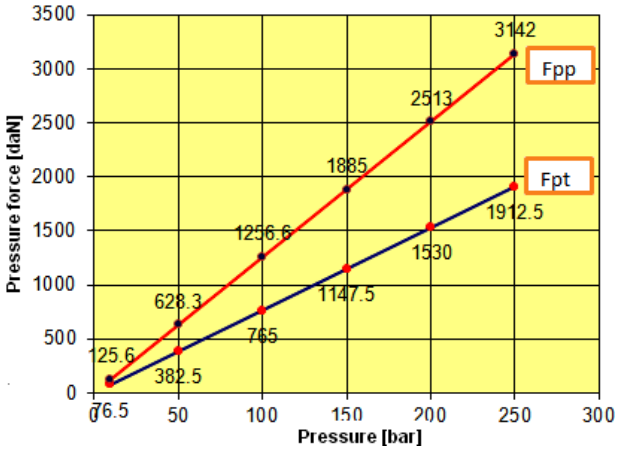


Figure 11. The variation of pressure forces

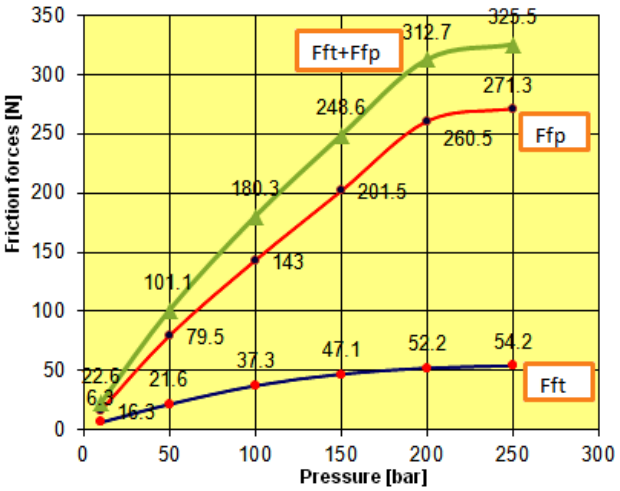


Figure12. The variation of the friction

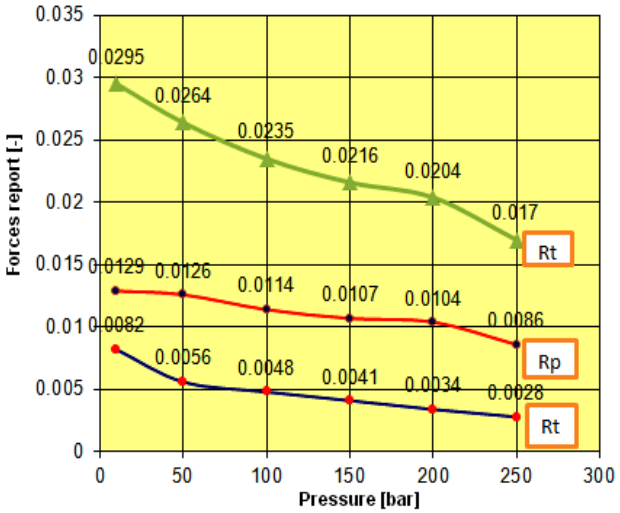


Figure 13. Forces report variation

5. CONCLUSIONS

The article presents a synthesis of experimental research developed by the authors, in order to determine the frictional forces that occur in dynamic seals of the hydraulic cylinders.

There are presented, in brief, the experimental devices and some graphical and numerical results.

Finally, has been made a analysis of frictional losses and has been drawn the curve of variation of pressure forces, variation of the friction forces on seals and variation of forces reports in order to quantify the losses through the friction forces versus the pressure e forces.

The friction forces are increasing with increasing of pressure, but, at the high values, the increasing is diminished.

The finally conclusion is that the friction losses in the sealing systems of the hydraulic cylinder, are important and should be taken into account to analyze the dynamic behaviour of the hydraulic cylinders.

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