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RESEARCH

Experimental Research for Measuring Friction Forces from Piston Sealing at the Hydraulic Cylinders

C. Cristescu[a], C. Dumitrescu[a], R. Radoi[a], L. Dumitrescu[a]

[a] *Hydraulics and Pneumatics Research Institute, Romania.*

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Corresponding author:

Corneliu Cristescu
Hydraulics and Pneumatics Research Institute, Romania.
E-mail: corneliu_cristescu@yahoo.com

A B S T R A C T

The article presents some aspects of developing, within INOE 2000-IHP, of an experimental research on the determination of frictional forces that occur in the mobile sealings of the pistons, between the piston sealings and the inner liner of hydraulic cylinders. In the first part of the paper, are presented some specific elements of the experimental device and of the testing stand which have been developed, while in the second part are presented some graphical results obtained in experimental research, as well as some comments on them. This developed experimental research marks the continuing of a major action on the tribological behavior of mobile hydraulic seals, which are frequently used in the construction of hydraulic cylinders.

1. INTRODUCTION

Hydraulic cylinders are basic components of hydraulic control and actuation of mechano-hydraulic systems. The hydraulic cylinders convert the hydrostatic energy into mechanical energy, by achieving, within a certain time, a certain force, with a certain speed in a straight stroke.

The continuous development of the field of hydraulic acting systems, their penetration in the most unexpected industrial applications, caused that each component to be investigated very carefully, in terms of ensuring the technical performance claimed. A special attention was given to the tribological behavior.

The mobile/dynamic translation sealings are specific to the hydraulic cylinders, Fig. 1, and there could be for sealing of the cylinders rod, [1-3], or for sealing of the cylinders piston [4-5].

Fig. 1. The Rexroth hydraulic cylinder.

In Fig. 2 is presented a piston sealing, where they realize the sealing on the piston with diameter d, being in reciprocating translation motion on the stroke, in a fluid medium with the constant viscosity η and under the pressure p., S being the piston stroke, v and v_r being the velocities of the cylinder piston, in both directions.

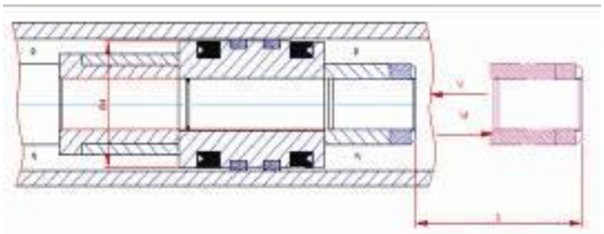

Fig. 2. The sealing of the cylinder piston.

Dynamic behavior of the hydraulic cylinders from hydraulic driving installations of the machines and technological equipments is strongly influenced by the performance of their sealing systems. That is why, in recent times, it pays special attention to sealing systems used in the construction of hydraulic cylinders.

The mobile/dynamic translational sealing of the hydraulic cylinders, which realize the sealing of the rods or of the pistons, are in alternative translation motion on the working stroke. The process of mobile sealing of the hydraulic cylinder piston is realized in conditions of friction-fluid and lubrication, when between the surfaces with relative motion with speed v (the sealing sleeve and cylinder piston), is provided continuously portent lubrication.

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 modeling and computer simulation, but must to be determined, also, by experimental methods.

The research of the tribological behavior of sealing systems of the hydraulic cylinder seals was made both by theoretical mathematical modeling and numerical simulation and, also, experimentally.

This paper presents the experimental device and testing stand and, also, some experimental results regarding the measuring and the evolution of the friction forces from the piston sealing of a hydraulic cylinder.

2. OVERVIEW OVER THE TESTING STAND

For experimental determination of frictional forces, occurring between the piston seals and inner liner hydraulic cylinder, was designed and developed an experimental device and a testing stand, Fig. 3, a) and b), equipped with modern "on-line" system for acquisition and measuring the evolution of the tribological parameters of interest [5].

The acquisition and measurement system is based on the use of high performance sensors and transducers and a computerized data processing system [6].

(a) Overview of the test stand

(b) Creating pressure with the hand Pump

Fig. 3. The stand for experimental determination of frictional forces.

The main unit of the testing stand is the experimental device, which contains the investigated sealing and is mounted on the framework of the drive system, Fig. 4, where it can be seen the rod of piston with the dual sealing system, the pressure and temperature transducer for oil between the gaskets, Fig. 5, as well as the force transducer, Fig. 6.

Fig. 4. The experimental device mounted on stand.

Fig. 5. The pressure and temperature transducer.

Fig. 6. The force transducer.

The drive system has, at the bottom of the framework, a stroke transducer, shown in Fig. 7, which allows measurement of the stroke, on the one hand, including measuring the actual speed of displacement of the rod through the gaskets seals, obtained by derivation of the stroke. The ambient temperature, at which the research is conducted, is measured by a digital environment thermometer, shown in Fig. 8, which by its contact rod, directly indicates the instantaneous temperature of the stand. Pressure of working oil, sealed by the two gaskets tested, is created by using a hand pump, shown in Fig. 9, which has a pressure gauge to indicate directly the working pressure and, also, a local display pressure transducer that allows pressure digital reading and sending signal for storage to the computer.

Fig. 7. The stroke transducer

Fig. 8. The ambiental thermometer

Fig. 9. The hand oil pump

By means of special electric cables, all signals provided by transducers reach the acquisition board installed on the computer, and this one, based on specialized software, allows the capture, storage and processing of data. Processed data are supplied in numerical form, as tables of variation of parameters of interest, or in graphical form.

Presentation in graphical form of the obtained results allows detailed analysis, by comparison, at every moment, of the evolution of each parameter, as well as the interdependence and influence of each one during a full working cycle.

3. CONDUCTING EXPERIMENTAL MEASUREMENTS

With the availability of the experimental stand developed and presented, have been proposed various testing scenarios that lead to measuring and recording of the variation of frictional forces between the piston seals and inner liner of hydraulic cylinder rods, as well as other parameters of interest.

3.1 Material and type of tested seals

According to the technical solution for the achievement of the experimental device it has been agreed that experiments should be started by testing seals based on two ***U***-shaped gaskets, Fig. 10, mounted face to face, on the special piston, Fig. 11. In Figure 12, are presented the main components of the experimental device.

The material, from which the gaskets were made, was a rubber of hardness Shore 85.

Fig. 10. U-shaped gaskets.

Fig. 11. The piston with gaskets

Fig. 12. The main components

3.2 Testing pressures adopted

Since the working pressures in usual hydraulic installations of mobile devices 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. Creating pressure of working fluid between the two seals tested is achieved through a hand pump (Fig. 9), which is connected to the space between gaskets, through an axial hole made in the piston rod and a radial hole made in piston body (Fig. 12).

Through the other radial hole made in the piston rod, is connected a pressure and temperature transducer (Fig. 5), enabling the “on-line” measurement of oil pressure and temperature, even in the space between the two seals tested.

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 amounts 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.

3.3 Testing speeds adopted

The hydraulic system for operating the experimental stand is equipped with an axial piston pump which can deliver a oil flow of around 50 l/min, which corresponds to a theoretical speed, at the tested seal, of about 125 mm/s.

In this context, were regarded as sufficient a speed levels at the experimental device for measuring the frictional force, but in the future we will continue for different levels for speed.

3.4 Parameters measured

Experimental determinations were mainly aimed at measuring and recording the evolution of frictional forces that occur in the piston seals of hydraulic cylinder. Since the experimental device and the measurement system developed for the determination of frictional forces provide broader measurement opportunities, including measurement of some functional parameters, graphic and tabular variations were obtained simultaneously for several parameters, namely:

1. variation of frictional forces within the piston seals of hydraulic cylinder;
2. variation, within reasonable limits, of pressure in tested seal;
3. variation of relative stroke of special piston with tested seal;
4. variation of relative velocity between the special piston with tested seals and the liner of hydraulic cylinder;
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 variation of the 4-5 parameters, mentioned above.

These data gathered form a real experimental database, on the variation of frictional forces within the rod seals of hydraulic cylinder, which represents an important contribution of the authors in this field.

3.5 Experimental determination procedure

Experimental determination of frictional forces was carried out using a procedure established taking into account the objective and the testing possibilities offered by the developed stand.

First it proceeded to the proper installation of the experimental device for determining frictional forces within the piston seals of hydraulic cylinder, in accordance with the corresponding technical documentation. Then, it performed the connection/linking of the device, through transmitting cables, with the electronic and computer system for capturing, recording, processing and storing data on computer, for which specialized software has been developed.

To conduct the experimental determinations rigorously, in order to ensure accurate measurements, with guaranteed repeatability, steps were taken as follows:

- during the first stage of tests, the pump was adjusted for necessary test flow, respectively for established test speed at the experimental device (125 mm/s);
- there were established pressure steps/levels for which experimental measurements were performed (steps of 50 bar) in the pressure range of interest of 0-250 bar;
- it has been agreed that for each pressure step, 3 independent determinations should be performed;
- at every determination, were captured 3 full working cycles (lifting-lowering);
- the necessary pressure at the double piston sealing has been achieved with the hand pump (Fig. 9);
- numerical tables were obtained on computer, as well as graphs with variations of the above mentioned parameters, for each pressure step, in the pressure range 0 ÷ 250 bar.

4. SOME EXPERIMENTAL RESULTS

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 consecutive working cycles. in total, were 54 experimental determinations. the average values of frictional forces for the two piston seals, for significant pressure steps, are shown in the table below, namely: Table 1- the friction forces values for two piston seals.

After analyzing these experimental results, some conclusions have been drawn both on variation of frictional forces, in terms of quantity and quality, and also some issues concerning conduct of experimental research, and even to improve constructively the experimental device.

Table 1. The friction forces values for two piston seals.

Nr. crt	Pressure step [bar]		Friction force [N]				Velocity [m/s]			
			Stroke				Stroke			
			Downward		Upward		Downward		Upward	
	Value	Variant	Max.	Rem.	Max.	Rem.	Max.	Min.	Max	Min.
1	10	a	39	3	-44	-28	1295	100	-140	-105
		b	30	5	-54	-35	133	123	-129	-106
		c	29	6	-52	-33	134	123	-123	-105
2	50	a	144	90	-185	-162	129	123	-130	-102
		b	163	124	-204	-128	130	100	-130	-105
		c	170	116	-225	-145	130	102	-138	-102
3	100	a	292	205	-336	-187	128	111	-128	-105
		b	275	177	-369	-158	130	116	-137	-105
		c	291	210	-348	-190	130	110	-135	-108
4	150	a	408	290	-397	-228	128	100	-131	-105
		b	392	277	-386	-225	130	108	-135	-107
		c	409	295	-416	-226	128	107	-138	-106
5	200	a	555	369	-517	-256	124	109	-133	-105
		b	515	353	-531	-275	126	107	-131	-109
		c	494	355	-505	-266	125	106	-136	-106
6	250	a	538	368	-600	-321	127	108	-131	-105
		b	555	390	-573	-315	127	109	-138	-110
		c	535	394	-544	-520	127	109	-135	-109

To concretize the above mentioned, below, will show an example of complex graphs obtained for certain pressure and speed steps, mentioned above, which will reveal some interesting and instructive points.

Thus, in Fig. 13, are represented the complex graphics of parameters variation for pressure step values of 250 bar (variant b) and high speed, elected for this stage for theoretical value of speed about 125 mm/s). The Fig. 14 represents the same graphics seen on the computer screen.

If it is analyzed the evolution of frictional force for the pressure step of 250 bar, shown in Fig. 13, and, also, the graphics from the Fig. 15, where are represented the variations for all steps pressure , we will get the following:

- The frictional forces from the 3 working cycles are revealed and for each cycle 2 alternations can be noted, first alternation gives the progress of frictional force in downward stroke (positive) and the second alternation gives frictional force in upward stroke (negative).
- It is noted that, in upward stroke, the values are slightly larger, in absolute value, than in downward stroke, when values are always lower.
- This difference is explained by the fact that in downward stroke, there is a process of natural alignment of the rod of special piston with double seals and the liner of cylinder, and therefore no additional blocking, jamming, or kneeling forces appear, while in upward stroke, there are additional blocking/jamming forces. Therefore, in upward stroke, the frictional forces are always larger and, usually, they have a peak of friction forces.
- At the beginning of each alternation, there occurs a peak, which is even higher as the break of movement (up or down) was longer, as shown by the stroke chart, which looks like a trapezoid. If this trapezoid becomes a triangle, that is the break is almost zero, then these peaks do not occur. The occurrence of these peaks is explained by the tendency of adhesion of the piston seals to the inner of liner, if movement stops for a longer period. When restarting, by peeling of the seal, the force increases sharply and an increasing peak of the frictional force occurs, similar to the phenomenon of "*stick-slip*".

In conclusion, the frictional forces measured on the downward stroke are the true ones, because they contain no additional forces, and they will be considered valid.

Fig. 13. The complex characteristic graphs for pressure step values of 250 bar.

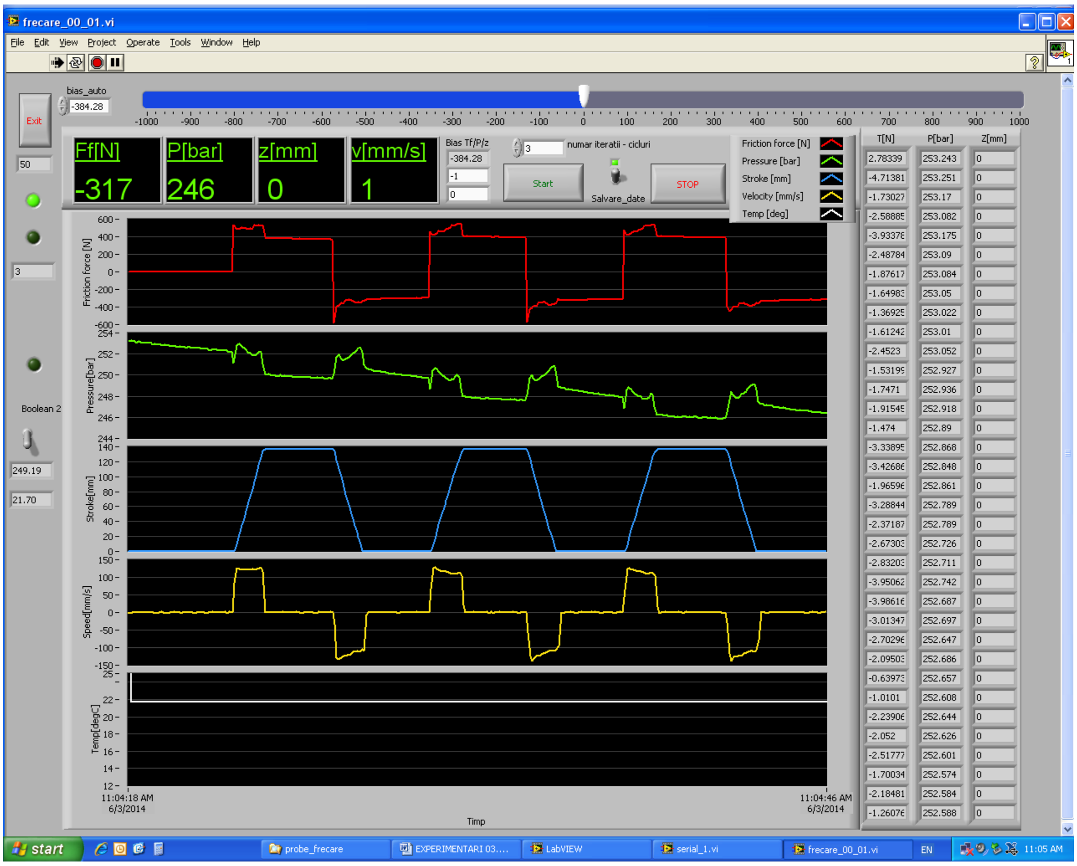

Fig. 14. The screen of the computer for 250 bar.

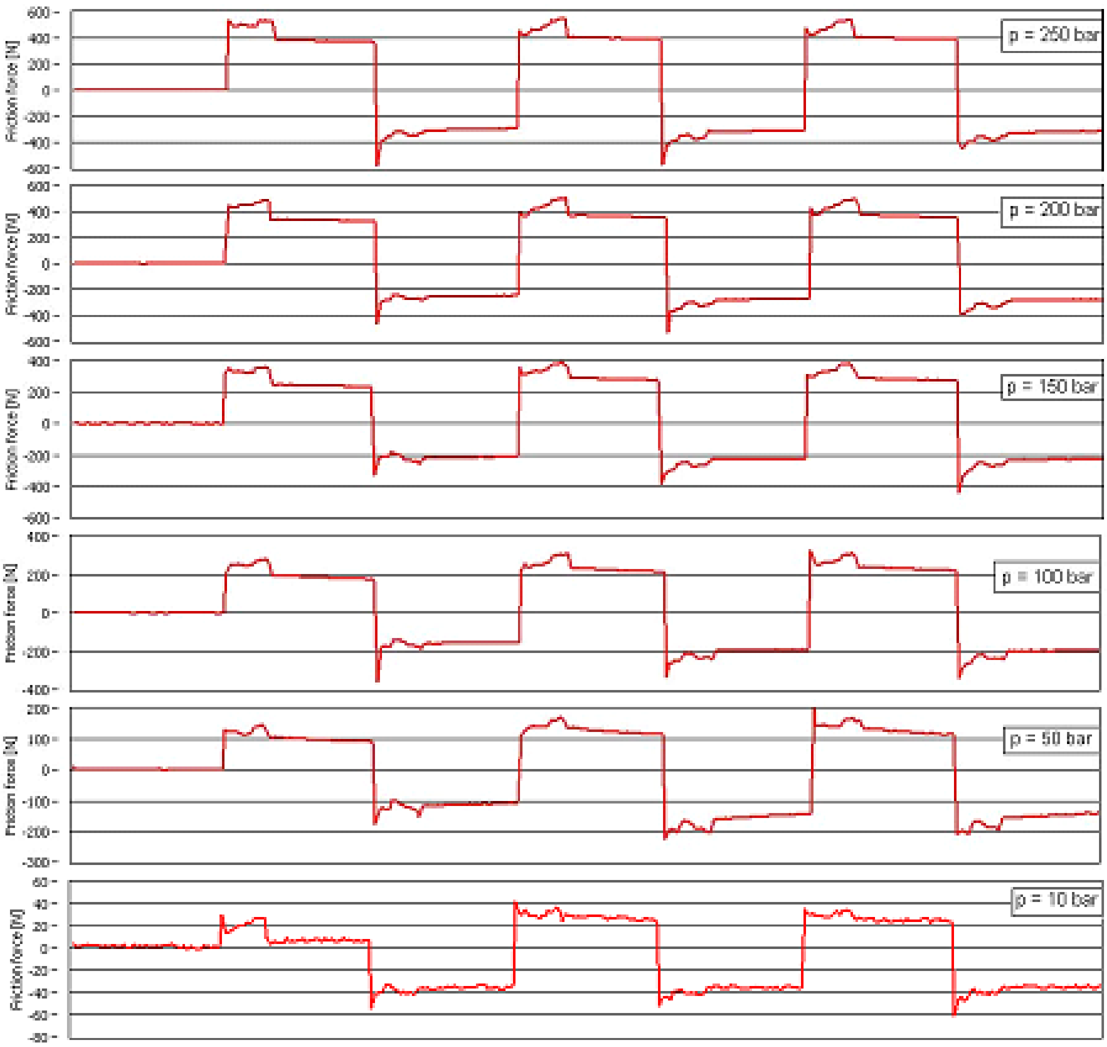

Fig. 15. The variations of the friction forces for all pressure steps

Schematic diagrams in Fig. 15 show the variation of frictional forces between the piston seals and liner of hydraulic cylinder for pressure steps of 10 bar, 50 bar, 100 bar, 150 bar, 200 bar and 250 bar. The variations of all frictional forces shown in Fig. 15, creates a complete picture of the variation of frictional forces with increasing pressure. From the comparative analysis of the charts of variation of frictional forces, shown in Figs. 14 and 15, one can notice that the values of frictional forces increase with increasing pressure, but it seems that, at high values of pressure, increasing of frictional forces is slightly smaller. This it can see in the Fig. 16, where is represented the variation of the friction forces versus the oil pressure existing between the two gaskets of the piston seal.

Close analysis of the graph of variation of pressure between the two seals, reveals a very interesting evolution that we did not found in previous research, case when the pressure drop was about 10 %.

In this stage, through introducing a isolation valve of hand pump (Fig. 9), the pressure drop between gaskets was reduced to about 5 %. As a result, the curve of pressure variation is not quasi-linear, but now it has a specific profile, which highlights, in detail, the phenomenon of detachment of gaskets from the liner and, respectively, their bonding/pasting on the cylinder liners and, also, the residual/remanent pressure/ force on gaskets.

The graph highlights the process of pushing the gasket, which is bonded on cylinder liners, when produces an increase in pressure, and in detachment of gaskets, there is a decreasing of pressure, inclusively, a loss of fluid. During the stay, between upward race and downward race, there is a pressure drop. At the beginning of the race upward, again is produced an increase in pressure, but in the mirror from the down stroke. In this manner, is possible to describe much better the sealing process for the seals which have a reciprocating / alternative movement.

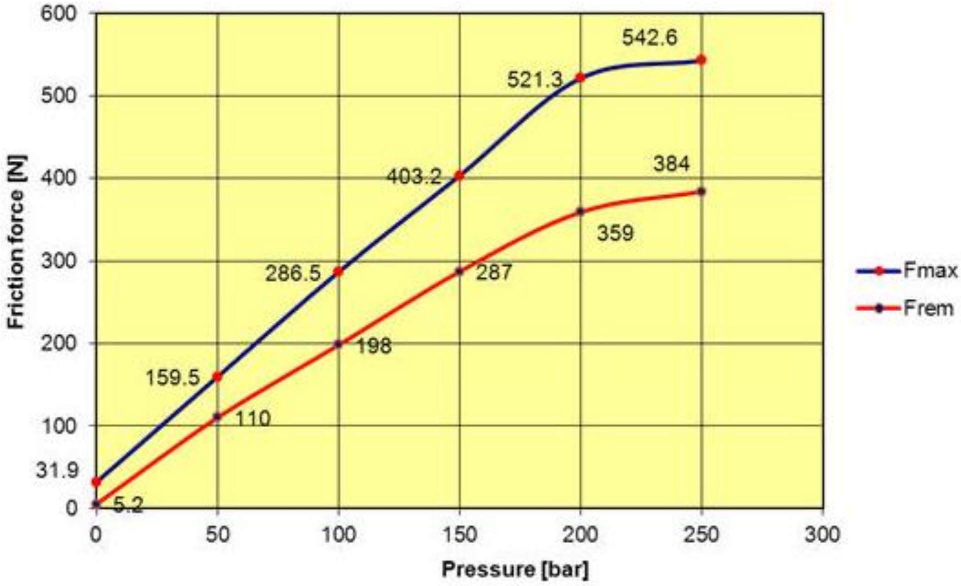

Fig. 16. The variation of the friction forces versus the pressure.

It is, also, noteworthy that in all the charts above, after the cessation of movement, there remains a residual/remanent force, slightly smaller than the frictional force during movement. This residual force is explained by the fact that seals, which during movement suffer elastic distortion, developing furthers the elastic force, pulling, as genuine springs, the piston rod, respectively, the force transducer, which measures it and transmits it to the data acquisition system. The three cycles of the same measurement are almost identical, which shows already the character of repeatability of the measurement process, which is emphasized, also, by independent measurements performed on each step of pressure.

5. CONCLUSIONS

The paper presents the measurement experimental device and the testing stand for measuring frictional forces in piston seals of hydraulic cylinders and there are shown graphic examples of their variation.

Valid measurements of frictional forces are obtained in downward stroke, due to the phenomenon of natural alignment of the piston rod and the liner of cylinder that eliminates the occurrence of additional jamming forces.

It is shown that the two graphs for three consecutive cycles, which are almost identical, and the 3 consecutive measurements, for the same pressure step, demonstrate *repeatability* of the process of measuring the frictional forces in piston seals of hydraulic cylinders.

The values of frictional forces increase with increasing pressure, but it seems that, at high values of pressure, increasing of frictional forces is slightly smaller.

The variation of pressure between the two seals reveals a very interesting evolution, which allows describing much better the sealing process for the seals which have a reciprocating movement.

The measurement system, based on advanced transducers and, also, electronic and computerized data processing, guarantees the accuracy of measurements performed on the stand.

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