THE ANALYSIS OF FLOW LOSSES THROUGH DYNAMIC SEALS OF HYDRAULIC CYLINDERS

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Abstract: *To hydraulic actuators most commonly known as cylinders a feature seen in terms of performance is the product availability depending on dynamic seals. This paper intends to clarify the issue of losses through mobile sealing elements of parts in relative linear motion piston – cylinder liner and rod – piston guide. In the second part of the paper there is presented a comparison of these losses to those of other hydraulic equipment.*

Keywords*: hydraulic cylinders, piston seals, flow losses.*

1. Introduction

As it is known, hydraulic cylinders also known as actuators or linear hydraulic motors convert the pressure energy of oil supplied by a pump into mechanical energy capable of providing an active energy of translational motion and thus mechanical work, [1]. From a constructive point of view there is a variety of such hydraulic devices, in figure 1 being shown a double acting and unilateral rod cylinder mounting with front flange.

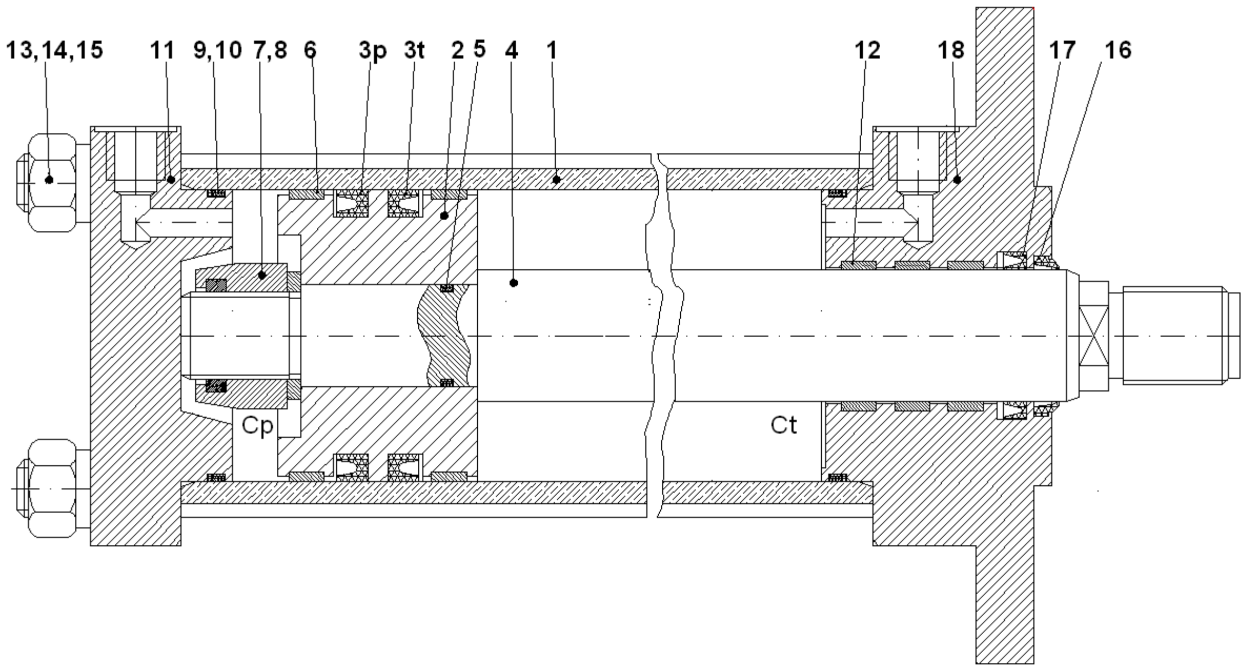

Figure1. The components of a hydraulic cylinder
1 - cylinder liner, 2- piston, 3t - piston socket mounted near the rod, 3p - piston socket mounted near the piston end, 4 - cylinder rod, 5 - fixed rod seal, 6 - piston guide ring, 7- nut, 8 - washer,10- O ring, fixed lid seal, 11- lid, 12 - rod guide ring, 13 - tie bar, 14 - nut, 15 - washer, 16 - scraper, 17- rod socket, 18 - mounting lid.

When using hydraulic motors, components that wear out are sockets 3p, 3t, 17, guide rings 6,12, rod 4 and scraper 16 as a result of friction towards the fixed parts. Elements that first wear are the sockets and the negative effect materializes through loss of flow inside and outside of the product. Size of these losses determines the acceptability criteria for mobile sealing gaskets and thus their life span. The variety of sealing elements for rod and piston correlated to the criteria of the cylinder working speed, maximum working pressure and dimensions determined the manufacturers to avoid stipulating in booklets the acceptable flow loss amounts over the lifetime of these products and thus the time for their replacing.

2. Sealing process

As it is known, until now, there has not been developed a general theory of sealing explaining all aspects of this process. Seals are machine parts assemblies aimed at closing as tight as possible a space containing a hydraulic environment under pressure. Sealing system, in the case of hydraulic cylinders, must maintain pressure and avoid loss of fluid to the low pressure side, both inside the cylinders, by isolating chambers Cp and Ct,- figure1- and outside the rod during its movement outwards. In the case of hydraulic cylinders sealing is achieved due to pressing when mounting against the contact surface and also due to the radial force resulting from the pressure of the sealed environment itself. This way to achieve the pressing force from within the hydraulic system is called the "self sealing".

In Figures 2 and 3 are shown elements with self sealing (O ring and socket), [2]

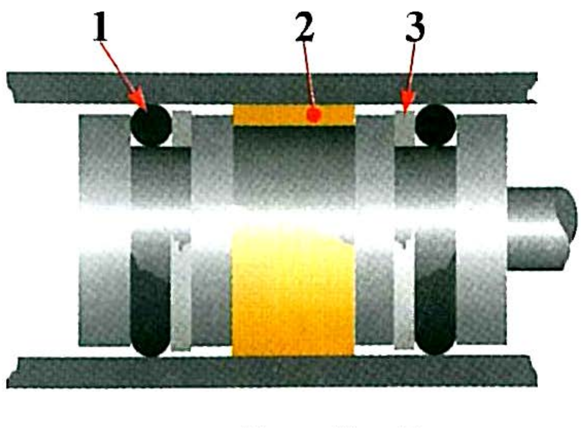

Figure 2
Mobile sealing of the piston with O rings:
1- O ring, 2- guide ring, 3- anti-extrusion ring

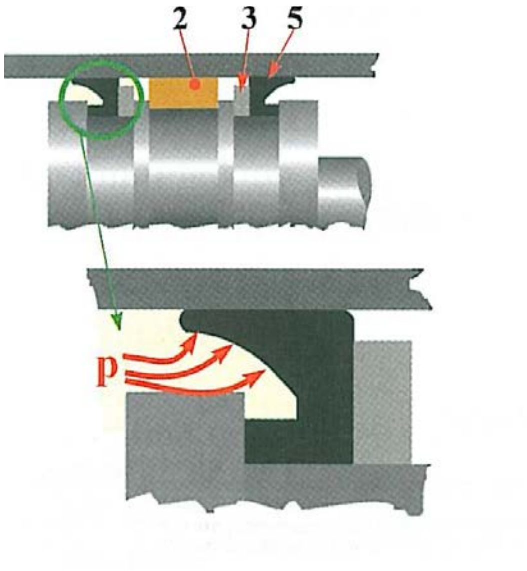

Figure 3
Mobile sealing of the piston with sockets
2-guide ring, 3- anti-extrusion ring,
5- sealing socket.

By installing the seal into its place with an elastic deformation by compression, there is created locally an initial sealing pressing. When there occurs pressure of the sealed environment automatically increases the force by which the cylinder socket presses against the cylinder liner. As one can see, the initial pressing, when assembling, has less weight compared to pressing resulting from hydraulic environment pressure. Uniformly distributed radial force [3] for sealing the piston is calculated using the formula:

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$F = \pi D p l$

D – piston diameter;

p – pressure within the piston;

l – sealing length

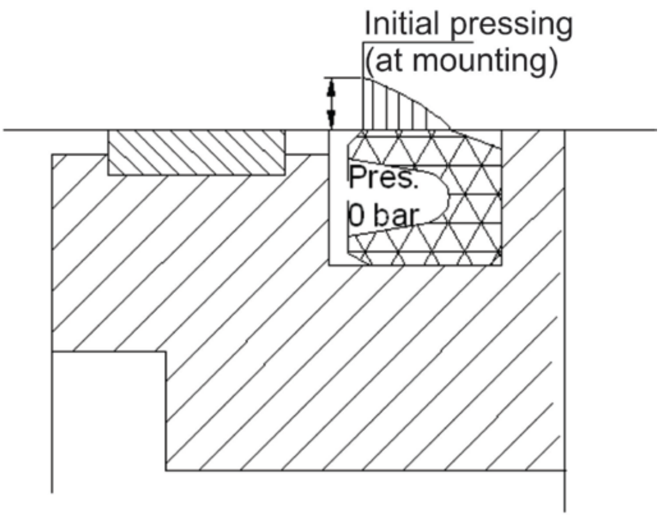

Figure 4
1-initial pressing, at mounting, of the socket in the absence of pressure

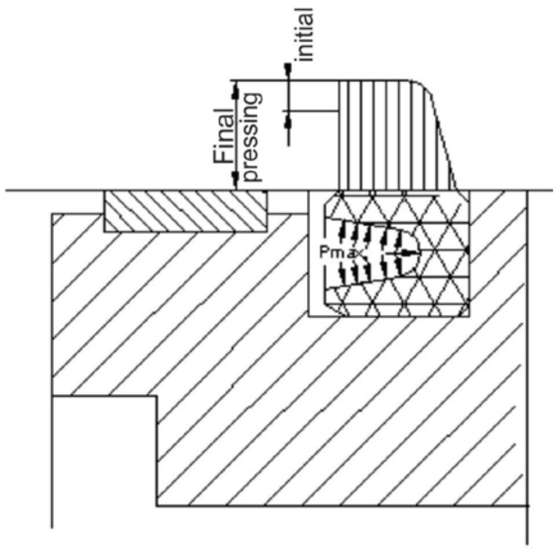

Figure 5
1- final pressing of the socket in the presence of static pressure

Fluid losses during displacement of rod and piston are in fact leakages through the clearance existing between the sealing and surrounding parts. In the specialty literature they are also known as losses in flow of the cylinder as this amount of oil reaches the tank circuit.

Flow loss consists of the amount of oil which during the input stroke of the rod in the cylinder no longer returns to the area under pressure. Size of these losses depends on several parameters: oil viscosity, roughness, deviations in shape of the part that the socket is in contact with, materials, state of wear of the seal, constructive solution, size etc. The sealing through contact process is related to the presence of a clearance needing to be closed, characterized by the pressure gradient **dp/dl**, parameter which determines the pressure **p** curve shape along the length **l** of the socket.

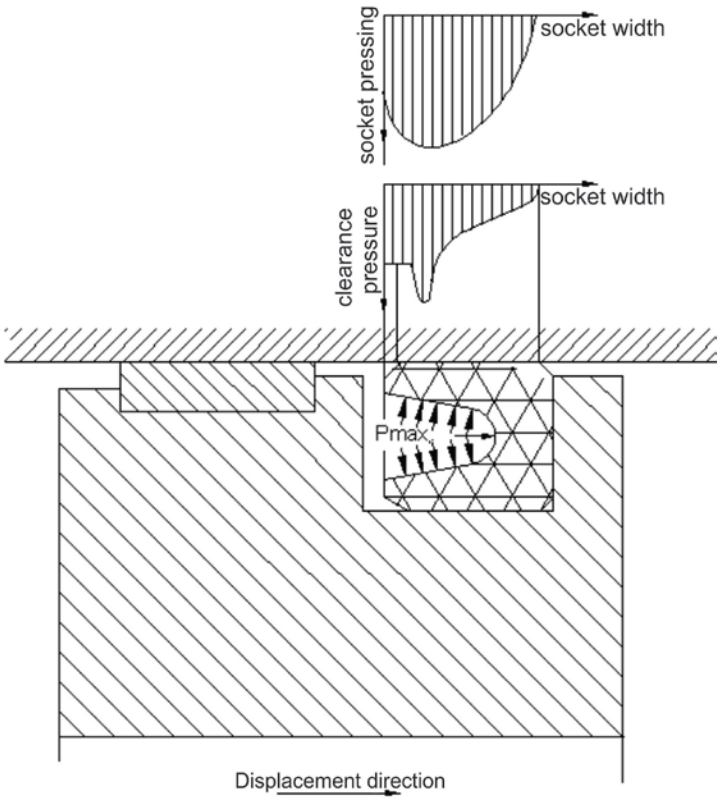

Figure 6
Variation of hydrodynamic pressure within the sealing clearance of the socket

At piston displacement the socket is deformed during the hydrodynamic process of occurrence of a clearance. During displacement the initial pressing from the seal mounting does not change. Socket deformation is minor compared with the average size of the clearance, the graphic of hydrodynamic pressure variation within the clearance along the sealing length of the piston socket looking, hypothetically, as shown in Figure 6, [4].

When switching from non-operative mode to reciprocating motion mode in the presence of viscous oil the two areas are completely separate, hydraulic film whose thickness changes will result in increased oil loss. Fluid film thickness on the work surface should be as small, but sufficient to produce lubrication of seal.

3. Quantifying flow losses (leakage) at hydraulic cylinders

Measurement of fluid loss in hydraulic cylinders is performed to assess the functional status of the seal after installation but also after certain periods of working, at endurance test for determining the lifetime of the product. This check is also performed periodically within the program of hydraulic system maintenance and compulsorily after repairing of cylinders.

3.1. Quantifying flow losses at rod socket

In accordance to the provisions of STAS 8535-83, measurements are performed at a pressure of 1.25...1.5 rP (rP – rated pressure) after performing five double strokes - the testing diagram is shown in Figure 7.

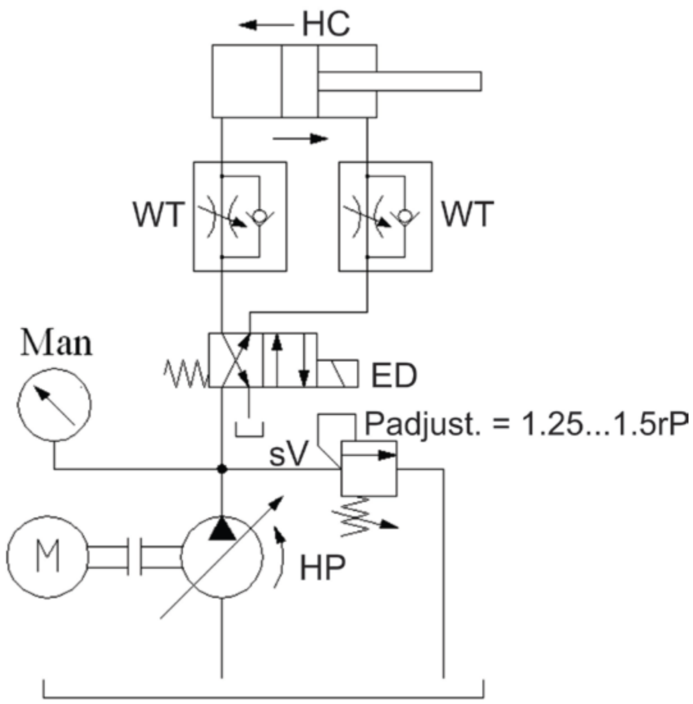

Figure 7
HC – hydraulic cylinder to be tested, HP- hydraulic pump, sV- safety valve, M-manometer, ED-electrically actuated distribuitor, WT – way throttel

The safety valve sV is adjusted at the pressure of 1.25 ... 1.5 rP, and then there are performed a minimum of five double strokes by switching on and switching off the electromagnet of distributor ED. Way throttle valves WT are adjusted so as to achieve the load opposite to cylinder displacement. This operation aims to achieve a maximum thickness of oil film on the surfaces moving relative to the stationary ones (piston - liner, rod – guide).

Measurement of losses at the rod is performed during the external tightness check on a certain amount of time, permissible values being specified in manufacturer standards and very rarely in supplier catalogues. Measurements are usually performed at an oil viscosity of 33±3 mm^2/sec, corresponding to a temperature of 50±5ºC.

Measurement diagram of flow losses to the rod is shown in Figure 8.

After pulling back the piston in position in Figure 8, pressure adjusted by the stand valve is maintained constant over a certain period of time 10...15 min.

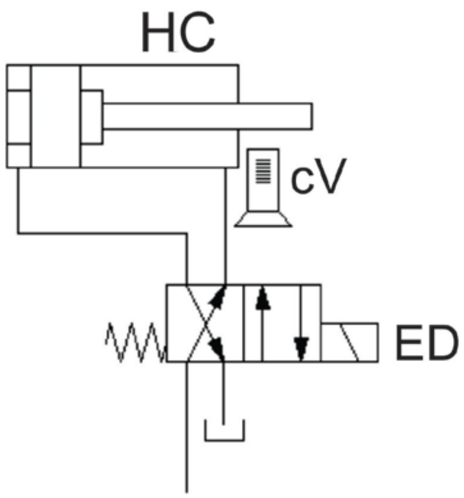

Figure 8
HC – hydraulic cylinder in drawn back position, ED-electrically actuated distribuitor, cV - calibrated vessel

Losses of fluid through the piston sealing area reach the tank via distributor DE, while losses through the rod sealing clearance, which are of interest for these checks will be collected in calibrated vessel cV. Regarding fluid loss amounts there are diverse opinions. According to some authors, on the rod is allowed forming of a film of oil without forming droplets. Another opinion is that the volume of the film which is formed should not exceed a volume of 0.5 cm^3 to 50 double strokes, a double stroke having a length of 0.5m at the maximum working pressure. There is promulgated an even more tolerant amount of fluid loss at a 30mm diameter rod: up to 5 drops / min (0..25 cm^3/min) at the pressure of 110 bar. This value is too large and should not be taken into account.

On the other hand, the notion of admissible fluid loss is still insufficiently clarified. For example, in the specialized literature they speak of zero losses, although these losses can mean a few cm ^{3}/h, without the occurrence of drops. An acceptable amount of flow losses to rod, measured as illustrated in Figure 8, is up to 6.5 mg/min to seal in new condition. During operation of the cylinder losses get larger and time when the product must be replaced is chosen by the user.

In conclusion, rod seal of a cylinder is chosen depending on the purpose, requirements and safety that it must comply with inside the hydraulic system, e.g. at the cylinder rod from aircraft outside losses are not allowed. An indicator of a seal performance is the number of kilometers covered with a certain pressure not exceeding the amount of loss provided in manufacturer standards.

3.2. Quantifying flow losses at piston sockets

Internal flow losses through the piston sealed clearance are an important parameter which is measured during type tests, on a regular basis but also during predictive maintenance program. Checking, according to the standard in force, is performed in five fixed, intermediate, equally spaced positions of the cylinder stroke at a pressure of 1.25...1.5 rP after performing minimum five strokes on a stand, Figure 7. Measurement of internal flow losses is performed according to the diagrams in Figures 8 and 9.

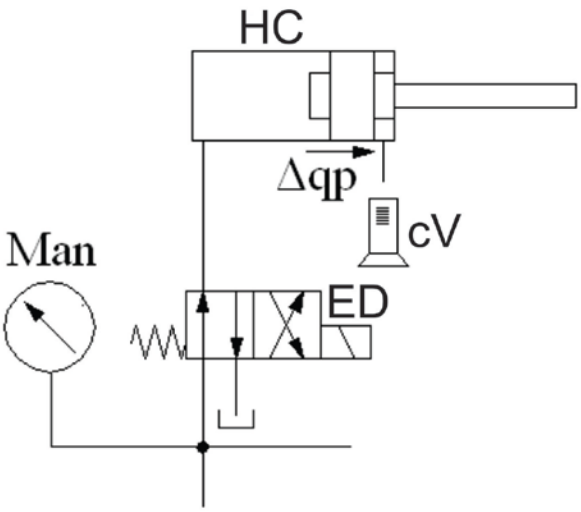

Figure 9
HC – hydraulic cylinder in advanced head stroke position, ED- electrically actuated distribuitor, cV - calibrated vessel, Man-manometer

The amount of liquid that is collected in the calibrated vessel cV relates to a minute, but for more accurate measurement duration should be about 10 ... 15 min. Usually this check is performed at both ends of the stroke - Figures 9 and 10.

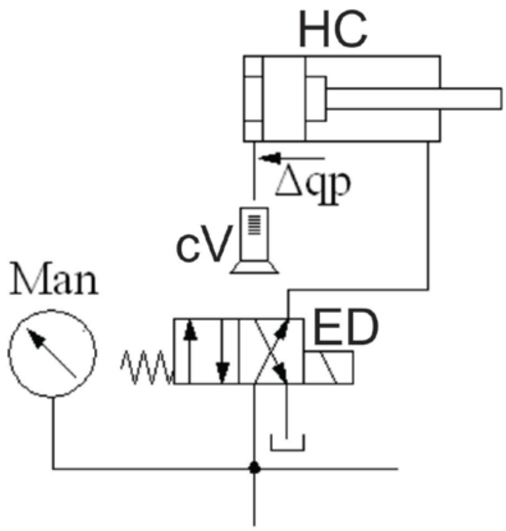

Figure 10

Measurement of internal losses in the other three fixed points of the rod complicates the stand structure, for this reason the check is performed only at the end of the stroke. Currently, most manufacturers of cylinders buy pipe for cylinder liner from specialized manufacturers, so that there are guaranteed deviations from cylindricity, roundness, straightness and material. During the experiments, due to the high safety coefficient, 3.5, no residual deformities were observed as convex or concave shape. Moreover, in calculation formula of cylinder liner thickness the liner length is not taken into consideration and thus checking in intermediate positions is not justified.

Measurement of internal losses in several points is performed, usually, at cylinders on mining machinery which have undergone hydraulic shocks and whose liner was deformed as a result of massive rock fall.

In terms of internal losses, in this area also technical information are few and elusive, not being indicated the sampling parameters: pressure, socket diameter, material, oil temperature, etc.

In figure 11 is shown a diagram of the internal losses depending on piston diameter at hydraulic cylinders of 160 bar used in machinery – tools, [5]. Permissible values are higher compared to those of rods, their growth is not visible outside the hydraulic system, and the negative effect is quantified by lowering rod speed compared to initial adjustment. Mean value recommended by the manufacturers of hydraulic cylinders, measured under the above conditions, is 6 mg/min in the case of a socket in new condition.

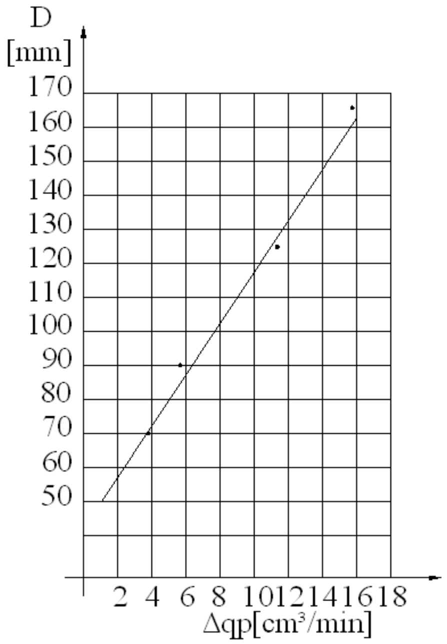

Figure 11
Variation of flow losses depending on the outside diameter of sockets to a pressure of approximately 160 bar

It can be seen that the losses increase proportionally with socket circumference and they have the lower limit value 1 cm ³/min which is still a high value. Flow losses diminish the more dynamic viscosity is higher, it being inversely proportional to them. Theoretically, the variation of viscosity is dependent on oil temperature and actually it materializes in the amount of leakage. Determination of fluid loss is based primarily on the results of experimental tests, even more as the friction regime of sealing surfaces is most commonly semi-fluid and exceptionally fluid.

4. Internal losses at other hydraulic devices

Permissible values of fluid losses at hydraulic cylinders are much smaller than at other devices. For instance, in Figure 12 are shown permissible losses to hydraulic slide valve manifolds at a pressure of 160 bar. Values are high because their operation is conditioned by the existence of radial clearances, unlike mobile sealing elements where there is a pressing force at mounting which increases in the presence of pressure inside the cylinder. Variation of losses on the levels of dimensional parameters rD6, rD10, rD20, rD32 depends on hydraulic diagrams of manifolds and the overlap between the slide valve and the body. For a cylinder that has a piston diameter of 90 mm and moves at 0.020 m / s is required a flow rate of 800 l / min, corresponding to a manifold rD 32. Comparing the graphs in Figures 11 and 12 it can be noted that permissible losses at the mobile piston seal are of 6 cm³/min, while at the manifold they are of 600 cm^3/min – that is 100 times higher.

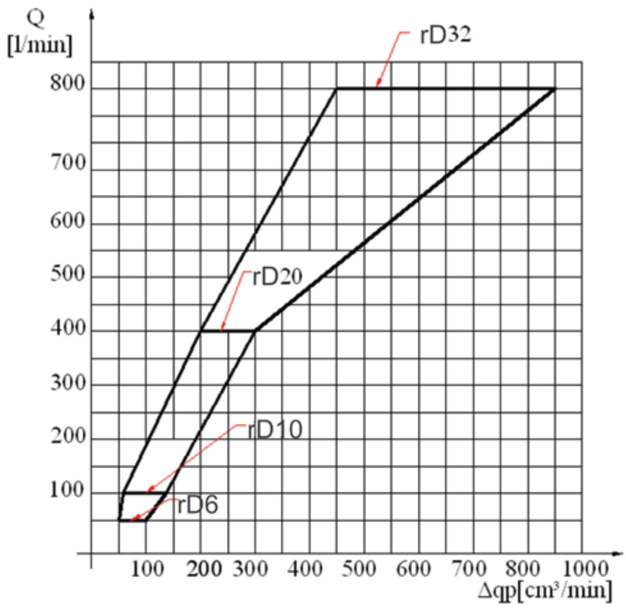

Figure 12
Flow losses at 160 bar at slide valve manifolds

At axial piston pumps permissible flow losses are caused by leakage through diametrical and frontal clearances. In Figure 13 is presented the variation of flow losses related to flow. These values increase during operation, the user choosing the moment when he/she considers the pump should be replaced [6].

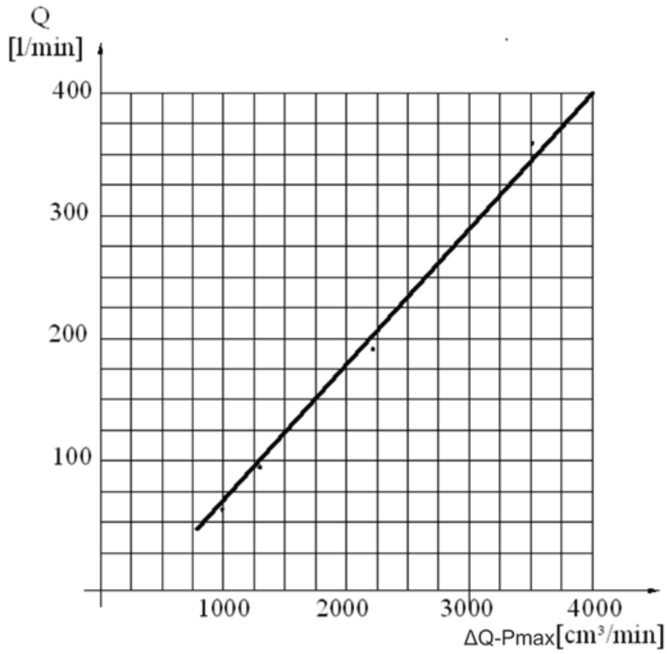

Figure 13
Flow losses at 160 bar at axial piston pumps

5. Conclusions

Evaluation of flow losses in hydraulic equipment as accurate as possible is required for efficient sizing of hydraulic electric pumps. Pump flow that is taken into account is the useful flow of hydraulic system to which are added flow losses of the equipment, and in this sense, we can calculate the volumetric efficiency of the hydraulic system. Also, increasing over time of oil losses due to wear is an important parameter in determining the lifetime of hydraulic equipment, of sealing elements and in establishing the maintenance program.

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