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GEAR PUMPS IN THE PAST AND PRESENT

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Abstract: *Pumps represent the "heart" of every hydraulic system, regardless to their use. Gear pumps, especially thanks to their basic characteristics, have an important use in solving various fluid power systems. Due to these reasons, a lot of interest and attention are focused to the continuous improvement of their basic parameters. PPT-Hydraulic AD has manufactured them since 1958 in significant quantities, sometimes much more, but in recent years into respectable amounts. But, it should remember that only the quality products will have the ability for placement which implies a reasonable price. These are the basic prerequisites to survive and stay in the competitive market. Due to these reasons, the basic structural parameters will be analyzed in the first part of the work with presentation of manufacturing capabilities in the production of the same. Analysis of structural solutions will show that our plant is not far behind, in any sense, for competition. Test results of gear pump nowadays and comparisons to the devices manufactured in the 80's of last century will be used as a support for this. The special significance is the hundred percent testing of finished devices and placement without complaint, as well as testing and control at all stages of manufacturing. Test results show that PPT-Hydraulic AD is capable for manufacturing the gear pumps for pressures over 300 bars.*

Keywords: *gear pump with external gearing, actual flow, volumetric efficiency level, testing.*

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1. INTRODUCTION

Pump is a device without which one cannot imagine any single hydraulic system, and all thanks to the possibility of converting the mechanical energy into compressive energy of working fluid. Due to their considerable advantages (low production cost, safe operation in service, high volumetric efficiency), compared to the other, the gear pumps with external involute gearing and equal number of teeth of both gears are commonly used nowadays.

Due to the specificity of such structures, in terms of operating conditions, the devices must be precisely defined, calculated, implemented and tested, in order to guarantee high level of reliability the required performances in service. Regarding to the structural components of the pump, such as for example a housing, a special attention must be paid to the selection of its geometry, material and weight distribution, in order to meet the resistance criteria (satisfactory rigidity, desired dynamic behavior, permissible stresses), savings in material (weight reduction), reduction of noise level (always present request in hydraulic and pneumatic devices), etc. Certainly, the product price must be taken into account; therefore the performances of device, however, are achieved as a compromise based on geometrical, material and economic criteria.

Gear pumps, unlike other types of pumps, thanks to the constructive solutions allow relatively high numbers of revolutions, but it is not possible to perform the flow control as it greatly limits their field of application. But that is solved by the possibility of speed control the electrical drive and hence the servo requirements of the same, Fig. 1 [1].

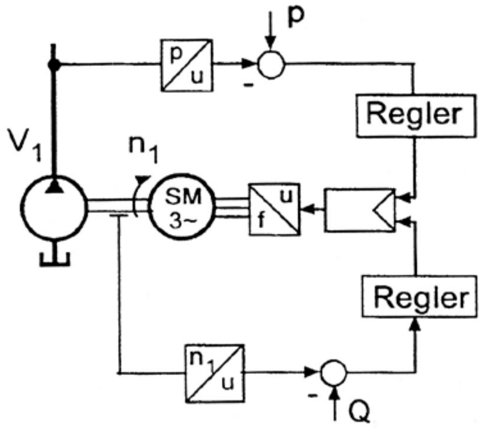


Figure 1: An example of possible regulation the fixed flow by changing the drive speed

The basic problem that needs to be solved in its development and manufacturing is to determine the technical-economic characteristics of the pump. Any variant solution is characterized by a set of positive properties (high degree of efficiency, high reliability in operation, low specific gravity, etc.) and a set of negative properties (increased noise, increasing in size, high price, etc.). The main task of designer consists in choosing the solution which enables to minimize the negative characteristics of structure and to increase the desired ones.

The principle of their operation is based on the volume change of working chambers, allowing suction, separation and suppression of fluid into pressure line. In the phase of volume increase the working chamber, the pressure is achieved under and the chamber is filled, i.e. the suction phase is achieved. When the action of operating element reduces the volume in chambers, the pressure phase occurs, i.e. compression. The value of working fluid pressure depends on the value of applied torque and it is not determined by the structural characteristics of the pump, but it is in a function of internal and external resistances in the system. The principle of operation and its component parts can be seen in Fig. 2 [2].

Gear pumps in the area of lower pressures are used as lubricating pumps for the main and auxiliary devices as well as the fuel pumps. In the area of high pressures, they are used for the source of hydraulic power in the open hydraulic systems in which the external loads are constant allowing different areas of application.

The actual flow of gear pumps is lower than the theoretical for a part of working fluid that flows from the area of high pressure in the area of lower pressure. The flow occurs as a consequence of the structural clearance between the surface of gear forehead and housing. This work presents the main directions of structural development of the same (problems and solutions), and the most significant parameters are shown in the example of pump from serial production. By comparison with characteristics of the same from earlier periods, it can be concluded that there are significant improvements in all matters. It is also shown by the results given in tables for the pump that is manufactured in serial production.

2. DEFINITION THE THEORETICAL AND ACTUAL PUMP FLOW WITH EXTERNAL GEARING

The operating element of these pumps, as it is mentioned above, is a coupled pair of gears installed in housing, Fig. 2 [1]. Gears are usually performed with flat involute gearing, and the standard sizes of these pumps have operating characteristics while Fig. 2 shows its common structural view [1-6]:.

- specific working volume: 0.25 to 266.66 cm^3/o (for special purposes and higher),
- operating pressure: 20 to 200 bars, now 270 bars (300 bars max),
- rotational speed of the pump drive shaft pump: 500 - 5.000 min^{-1} (all depending on nominal size and place of installation),
- total efficiency coefficient: 0.90 to 0.99,
- •noise level ≤ 87 dB.

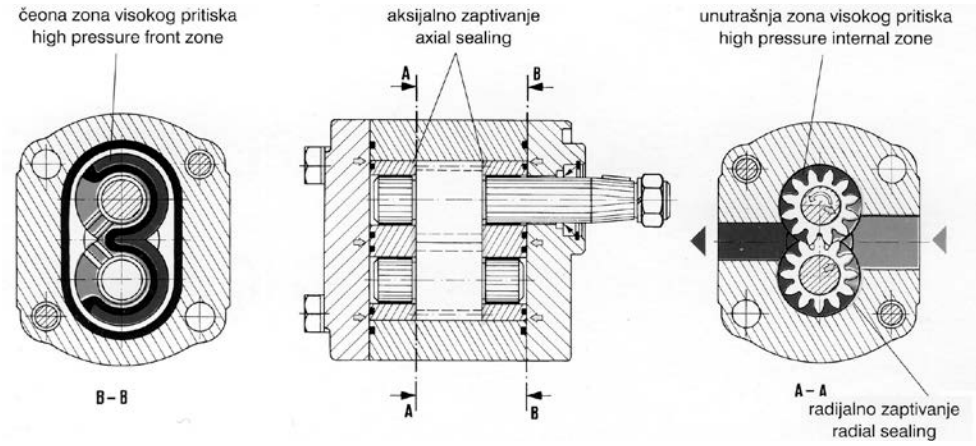


Figure 2: Cross-section of gear pump with external gearing (family 3115.**.**)

Theoretically flow of gear pumps is equal to the value (basic structural characteristics of the pump) of specific flow and rotation speed of drive gear, the expression (1), [6]:

$Q_T = V_p \cdot n \cdot 10^{-3} = 2\pi \cdot D_0 \cdot m \cdot b \cdot n \cdot 10^{-3}$ [l/min] **(1)**

where : Q_T – theoretical pump flow,

V_p[cm^3/ o] − specific pump flow that matches the displaced volume when the shaft rotates by one turn,

n [s^{-1}] – revolution number of the pump drive shaft,

D_0 [cm] − diameter of pitch circle of gear,

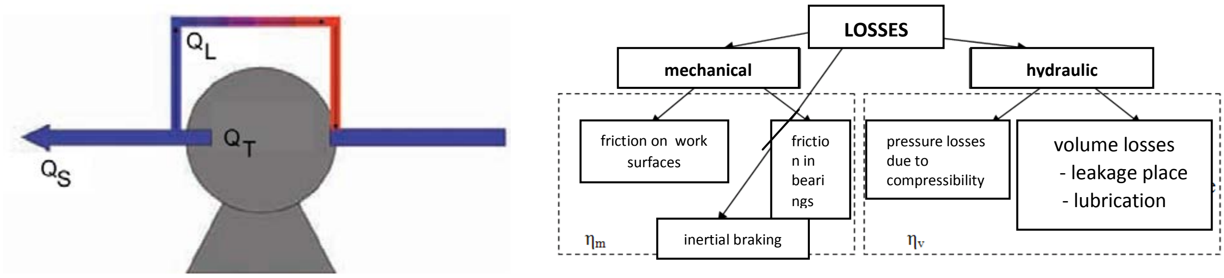
M [cm] − gear module,

b [cm] − gear width.

For the approximate flow calculations of gear pumps with the same gears, there are several empirical formulae and they can be found in the technical literature. For the pumps with a number of teeth z = 6 ÷ 12 (the most represented in PPT-Hydraulic AD), the volume of hollow between teeth has higher volume value of teeth; the value of π in the expression (1) is replaced with 3.5. Thus the expression is obtained that with sufficient accuracy determines the theoretical flow value of gear pumps, the expression (2) [6]:

$Q_T = 7 \cdot D_0 \cdot m \cdot b \cdot n \cdot 10^{-3}$ [l/min] **(2)**

The actual pump flow is obtained if the theoretical pump flow is reduced by flow losses, the expression (3), and it is shown in Fig.3.



a) **b)**

Figure 3: View of the actual flow and flow losses of the gear pump

what is seen from tables hereinafter [4, 5].

$$\eta_v = \frac{Q_s}{Q_T} = \frac{Q_T - Q_L}{Q_T} = 1 - \frac{Q_L}{Q_T} \quad \textbf{(3)}$$

Hydraulic compensation of axial frontal clearance is performed in the practice to the account of displacements the front sides of gear support ,what is seen from tables hereinafter [4,5].

$$Q_S = Q_T - Q_L \quad \textbf{(4)}$$

where: Q_S – actual flow, l/min, $\mathbf{Q_T}$ – theoretical flow, l/min, $\mathbf{Q_L}$- flow losses, l/min.

For all hydraulic devices, clearance is the basic conceptual element and the presence of flow losses is normal in their work. Losses of flow occur as the result of liquid flow from the region of higher pressure into the region of lower pressure through the structural clearances between the front surfaces of teeth and housing, sides of teeth and housing, as well as in the area of teeth contact. Flow losses practically do not depend on the revolution number, but on the operating pressure and clearance, the expression 4. Leakage of working fluid through the radial clearance occurs between the arch surface of body and the outer cylindrical surface of gear, as well as the frontal (axial) clearance between the side walls of bearing bushing and front surfaces of gear. In damaged profile of teeth in contact or inaccurate manufacturing of involute, a loss of flow is also possible on their contact line of teeth in contact.

Place of the largest leakage of gear pumps, related to the uncompensated frontal clearance, is exactly this clearance. Leakage through it is (75 ÷ 80) % of all its losses. Due to these reasons, its elimination is done and it is maintained in the required limits by testing [3,4]. This limit, in addition to the other characteristics, significantly raises the bearing bushing to the front sides of the last bushing (Figs. 2 and 4), that is faced to a cover. The connection is established by channel k, which is in connection with the pressure line, so that the oil under pressure acts on the bushing surface between the seals (A). It is sized in such a way, that the force (F), which pushes the bushing towards gear, is slightly greater than the force (F_1), which separates the bushing from gear. The ratio of these forces should be so chosen that separation of bushing and gear could not occur as well as seizing on the sliding surface of bushing.

According to Fig. 4, the installed seal in the form of kidney separates the high-pressure zone (pressure part of the pump A_1) and low-pressure zone (suction part of the pump A), provided that $A > A_1$, and also prevents external leakage. Surface for compensation is performed on both covers, but the compensation of frontal clearance is performed only over one surface – the one that is larger over the communication channel "**k**".

PPT-Hydraulics also uses the solution seals that restrict compensation surface housed in the bearing bushing, Fig. 5 [3,4]. The advantage of this solution is a multiple because the engraving of cover is avoided, what is enabled by material selection of better mechanical properties, so it is possible to achieve higher pressures. Much less dimensions are possible to be achieved with bedding in the cover and to get more stable operation of the pump, and therefore the system, Fig. 6.

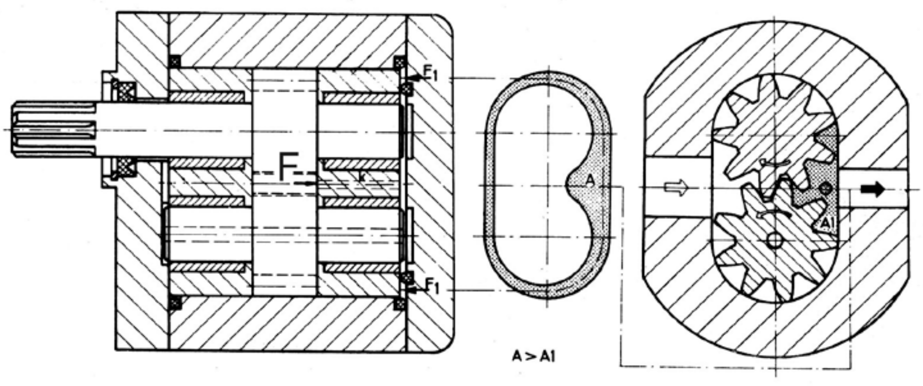


Figure 4: View of the pump with axial clearance compensation

Installation of roller bearings allows all of this and it is possible to install them on mobile machines.

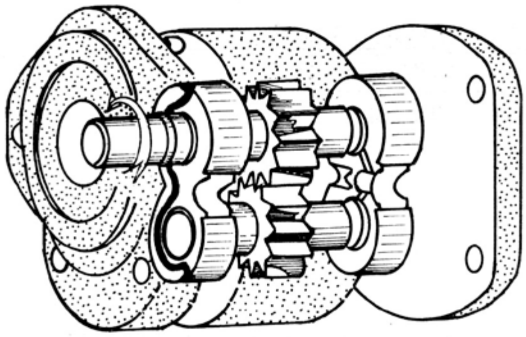


Figure 5: Example of compensation surface housed in housed in a bearing bushing

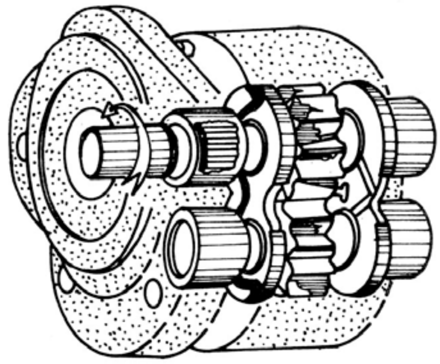


Figure 6: Example of compensation surface a bearing bushing and bedding in a cover

3. THE ACHIEVED LEVEL OF DEVELOPMENT AND NEW STRUCTURAL SOLUTIONS IN PPT-HYDRAULIC AD

The basic prerequisite for more intensive development of these devices refers to the following:

- Increasing the value of the basic technical parameters and their techno-economic optimization according to the conditions of application,
- Improving the overall efficiency level in order to achieve as much as better effects in terms of energy saving during operation,
- Decreasing the noise level as an important environmental factor,
- Decreasing the service life of device, etc.

The tendency of all manufacturers is constantly striving to raise the pressure level with simultaneously retaining at the same or higher level of other parameters such as noise, service life and overall efficiency level. Successes in these efforts largely depend on the level of technological development, in which every innovation in the field of construction must rely. This primarily refers to development the new and better quality materials for vital elements, the new processing procedures and advance in methods and measurement techniques. Many years of work to improve the overall efficiency level of gear pumps gave the visible results, so it is now assessed that further progress in this regard only for (1 ÷ 2%) would be possible only with disproportionately large investments [3]. Gear pumps with external gearing, thanks to the simplicity of construction, have a chance to retain the primacy as the cheapest pump despite the structural-technological requirements. This primarily relates to raising the pressure at level that is normal for piston pumps and thereby the field of application would be expanded. Today, the success is quite obvious that, in this regard, the leading manufacturers of these pumps have, because the level of nominal pressure was raised of 250 to 300 bars with tendency of further raise up to 400 bars. Certainly, the noise problem with this tendency became even more acute and has narrowed the field of application of these pumps in the fields where the power, not the noise, is the primary factor. This is primarily an area of severe service conditions such as encountered in hydro systems on mobile machines.

High pressure gear pumps are manufactured for more than 60 years in PPT-Hydraulic AD, and Fig.7 shows the historical start of manufacturing the same. The last fifteen years of intensive development of these pumps has resulted into development a new family of gear pumps, which are marked with ZPB (Figures 2 and 8) [3].

Figure 7: Thus the manufacturing of gear pumps has begun

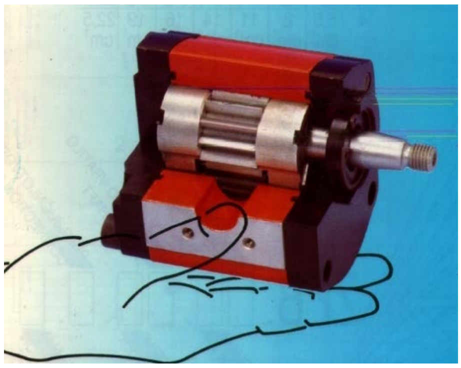


Figure 8: View of a new family of gear pumps from the group ZPB. **.**

This solution has a number of advantages over the standard family 3115. Among others, the level of nominal and highest pressures was significantly increased, the volume level of efficiency was increased, the service life of pump was extended and the noise is reduced as well as pulsation of flow and pressure. The improvement of all these parameters was performed using the new structural and technological measures in almost all vital parts of the pump.

These families of gear pumps allow use in hydraulic systems which require pressures up to 300 bars. These pressures of "piston pumps" were achieved by adequate conception of housing and covers. Housing material is extruded aluminum with high deformation degree (extruder). This material achieves significantly higher permanent strength than in aluminum die-casting, and thus higher reliability is obtained both for the pump and device of pump installation. Hydraulic casting with E-module of $(14 \div 16)10^7$ N/m^2 is used for cover.

Opposite to the aluminum covers with E-module $(7 \div 9)10^7$ N/m^2, this concept, due to higher E-module, is important, so that the sealing is reliable at high pressures. Furthermore, the use of hydraulic casting is also favorable for the screws of threads for fixing, which results in the structure compactness. In the cover (rear) of hydraulic casting, the valves can be fitted such as flow control valves or pressure limiting valves (significant in the pumps with control installation). It is well known that the number of gear teeth has the greatest influence on the flow pulsation. In this family of pumps, the gears with 12 teeth are adopted so that pulsations of flow and pressure are reduced. For comparison, the flow pulsations will be shown with different number of teeth [3]:

- 9 teeth, pulsation is 22%,
- 10 teeth, pulsation is 18%,
- 11 teeth, pulsation is 16%,
- 12 teeth, pulsation is 14%.

As pulsation has a decisive effect on noise, this gives a major contribution to the reduction of noise. The bearing journals of gears are specified with maximum roughness below 1 μm what results into optimal performances in sliding bearings coated with Teflon (DU bearings). The uniform surface hardness of gears is achieved by quality heat treatment, what in the end results in high resistance to wear of sleeve, bearings and gearing. The technique with DU bearing was applied for gear positioning because it guarantee the optimal exploitation. DU bearing is a bronze bearing coated with Teflon with steel support. This technique of positioning has significant advantages [3]: **low friction coefficient, good sliding properties, good capability of installing, slight wear, high loading, higher temperature range, moisture resistance, long service life.**

High efficiency of the pump is achieved by optimal defining the compensation area. Sealing elements are made of specially developed rubber compound based on perbunan with low rest of deformation from pressure and function of specially adapted hardness. To increase the service life, the seals are additionally supported with protective Teflon rings resistant to high temperatures. Axial forces of compensation are constant throughout the whole number of revolutions, what means that the compaction force is proportional to the pressure in pump.

It has already been pointed out that in this generation of gear pumps the pulsations of pressure and flow are reduced, what results into reduced noise. The solution of bearing bushings with an optimal redirecting of pressure contributes to this with appropriate design of drainage the "squashed" oil on pressure side. Therefore, a significant improvement is achieved regarding to the technical solutions, which have a drain of "squashed" oil toward the suction side. Characteristic of bearing bushings in these pumps is partially rebutted edge on the side of gear, resulting in controlled increase of pressure in a hollow between teeth of gear. A new generation of gear pumps (ZPB) has anti-cavitation characteristics [3]:

- Easy formation of pressure in the chambers of teeth; sensitivity is reduced to the effect of air;
- High hardness of bushings prevents formation of erosion in the area of teeth contact, and thus results in decreased sensitivity to dirt;
- Specially shaped distribution edges on bearing bushings, which results in the "opening" chambers of teeth at the beginning, and this means premature filling to avoid cavitations at high rpm.

Within the Development of PPT - Hydraulic AD, there are efforts to implement the new solutions of gear pumps with housing of NL (Fig. 10). Unlike the ZPB solution, in which the floating bearing is applied, this family of gear pump uses the concept of fixed DU bearings in the box and back cover, [3]. Compensation of axial clearance is carried out through the sliding bronze plates containing high pressure seal, which allows high volumetric and mechanical efficiency. In this way, the radial forces of gears do not affect compensation of axial clearance. Some of the advantages include: reduced dimensions (bearings in covers), more stable system, pumps have longer service life.

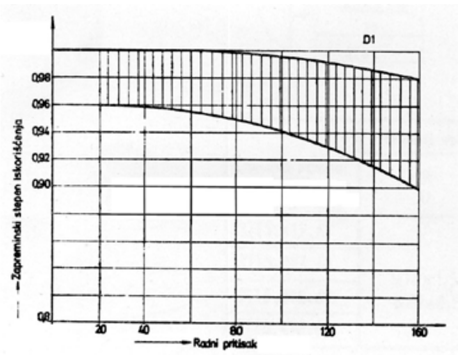


Figure 9: Typical diagrams of pumps from the group 3115.***.**

Figure 10: View of gear pump with housing of NL (dismantled with the basic parts)

They are designed for hydraulic systems on mobile machines and in general for the work in the hardest conditions. The results obtained on test stands for testing the functions and service life, as well as from the field while working in the exploitation conditions, are quite satisfactory. We can expect that further development of gear pumps will flow in the direction of increasing pressure with retaining high level of volumetric efficiency level ($\eta_v > 0.95$), further reducing the pulsations of pressure and flow and increasing service life. These performances can be achieved working on [3]:

- modification of gearing,
- improving the construction of bearing bushings,
- introduction the new technological processes,
- application the new materials.

4. AN EXAMPLE OF QUALITY MANUFACTURING THE GEAR PUMPS

Market demands as well as increasingly present competition have initiated the development of gear pump, nominal size V= 28 cm^3/r and test results will be given hereinafter in this work. Test results for five pumps are provided for different values of axial clearance (110÷160) µm. The same should demonstrate its optimal value with the aim of increasing the volume efficiency level [3].

Pump No. 1 – axial clearance of 110µm

p[bar]	0	50	100	150	210	250	270	
Q_S[l/min]	31.9	31.4	31.1	31.2	31.5	31.6	31.5	n = 1150 min^{-1}
η_v	0.99	0.975	0.966	0.969	0.98	0.981	0.98	t = 50^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1150[min^{-1}] = 32.2 [l/min]								
Q_S[l/min]	52.5	52.7	52.5	52.6	52.8	52.7	52.6	n = 1900 min^{-1}
η_v	0.987	0.99	0.991	0.99	0.99	0.99	0.99	t = 50^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1900[min^{-1}] = 53.2 [l/min]								

Pump No. 2 – axial clearance of 130µm

p[bar]	0	50	100	150	210	250	270	
Q_S[l/min]	32.0	31.4	30.9	30.9	31.3	31.7	31.8	n = 1150 min^{-1}
η_v	0.994	0.975	0.96	0.96	0.972	0.984	0.988	t = 50^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1150[min^{-1}] = 32.2 [l/min]								
Q_S[l/min]	53.0	52.6	52.2	52.1	52.6	52.7	52.6	n = 1900 min^{-1}
η_v	0.996	0.99	0.98	0.98	0.99	0.99	0.99	t = 50^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1900[min^{-1}] = 53.2 [l/min]								

Pump No. 3 – axial clearance of 140µm

p[bar]	0	50	100	150	210	250	270	
Q_S[l/min]	32.0	31.0	30.4	30.3	31.0	31.4	31.4	n = 1150 min^{-1}
η_v	0.994	0.963	0.944	0.94	0.963	0.975	0.975	t = 52^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1150[min^{-1}] = 32.2 [l/min]								
Q_S[l/min]	52.8	52.3	51.6	51.6	52.0	52.3	52.0	n = 1900 min^{-1}
η_v	0.992	0.983	0.97	0.97	0.98	0.983	0.98	t = 52^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1900[min^{-1}] = 53.2 [l/min]								

Pump No. 4 – axial clearance of 160µm

p[bar]	0	50	100	150	210	250	270	
Q_S[l/min]	31.9	31.2	30.6	30.7	31.2	31.5	31.5	n = 1150 min^{-1}
η_v	0.99	0.99	0.95	0.953	0.99	0.99	0.99	t = 50^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1150[min^{-1}] = 32.2 [l/min]								
Q_S[l/min]	52.8	52.2	51.8	51.8	52.3	52.0	52.1	n = 1900 min^{-1}
η_v	0.994	0.98	0.974	0.974	0.983	0.978	0.98	t = 50^0C
Theoretical pump flow Q_T = 28 [cm^3/o]·1900[min^{-1}] = 53.2 [l/min]								

For calculating the efficiency level dependence with pressure increase, using the expression 4, the values are calculated in given tables.

5. CONCLUSION

PPT - Hydraulic AD follows the global trends in development of these devices from which the development of the new structural families has resulted that have already confirmed their high level of quality both in domestic and international markets. Development of gear pumps in these directions leads to a slight improvement of all its parameters and significant reduction in noise and, as such, it is highly suitable for evaluation the achieved technical level of gear pump as a whole, as well as for evaluation the operating condition of its individual parts. The general condition can be described as follows:

- The realized quality, in every respect, the testing results of four pumps with different values of axial clearance have shown. As it is also stated in the text, it has the highest effect on the loss of flow, expressed in volumetric efficiency level.
- Comparison with the given diagram in Fig. 9 can be used as a contribution to this, where it can be seen how the present solution is better in every way.
- Testing devices have a big role in all of this and without which all of that could not be checked and verified by test reports, Fig. 11.
- Also, the weight reduction is more than 30% for the new solution [3,5].

Figure 11: View of universal test stands for testing of hydraulic devices

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