

IMPROVING THE FLOW VARIATION OF EXTERNAL GEAR HYDRAULIC PUMP

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Abstract: *The paper concerns with the theoretical aspects regarding the improvements on the flow ripple for the external hydraulic gear pumps. During the last decades, there are many research activities for increasing the efficiency by using the hydraulic pumps as suppliers for system with variable or constant loads. A better solution could be the external hydraulic gear pump, whether the flow has a continuous variation, so that it could be controlled by the rotational speed of the electric motor.*

Keywords: *Hydraulic system, external gear pump, control, constant flow.*

1. Introduction

Nowadays, there are many concerns regarding the new solutions for designing hydraulic system with lower level consumption of energy. The hydraulic systems work with very high power, so these issues now assumes even greater importance than before. The choosing of the hydraulic supplier system has to be done very carefully based on a technical and economic analysis.

It is very well known that the life cycle cost of the technical system has the following structure:

- 5 – 20 % for investments;
- 80 – 90 % for maintenances, especially for implementation, service, for training, for taxes, assurance, energy.

Regarding the hydraulic actuation systems, where there are higher power levels, the cost of energy is the mainspring of this aspect.

Almost all the hydraulic systems have hydraulic pumps with constant flow as supplier elements of their structure. The constant hydraulic flow of the pump is an useful feature even for the hydraulic systems where we have to accomplish the load variation of the motor. This has to be done because of the lower price of these pumps comparing with the variable flow pumps. More often, the hydraulic system for flow variation implying the variation of the working load has a valve placed before or after the motor. Even though the solution is very simple, the efficiency is very low finally.

The functioning of the volumetric pump is based on the continuous variation of the volume of some internal chambers due to the relative motion of a piston, blade or slider relative to the grounded part. Some technical clearances have to be designed in order to provide the movements. Due to this reason, there are some leaks from the chambers with high pressure to the chambers with low pressure, so the viscous friction forces are working. Meantime, on these parts there are acting pressure forces implying kinetic frictions. A well designed hydraulic pump means a compromise between minimum loss of flow and minimum values of friction.

So, we may conclude we have to choose the hydraulic supplier based on a very carefully analysis made from technical and economical point of view.

The gear hydraulic pump is one of the most used pumps for the systems working with medium power, because of its technical simplicity, the lower price and easily maintenance. We have to specify it is a constant flow pump.

These pumps have the following parts (Fig. 1):

- Cylindrical external gear made of the wheels 1 and 2, most often with teeth's involute profile;

- The main part comprising the central body 3, and two plates placed on the extremities 4 and 5. Inside the main body, where the minimal clearance was designed around the gear, there are two holes A and R directly tied to the two rooms for flow aspiration and expulsion.
- The rod 6 fastened to one of gear wheel;

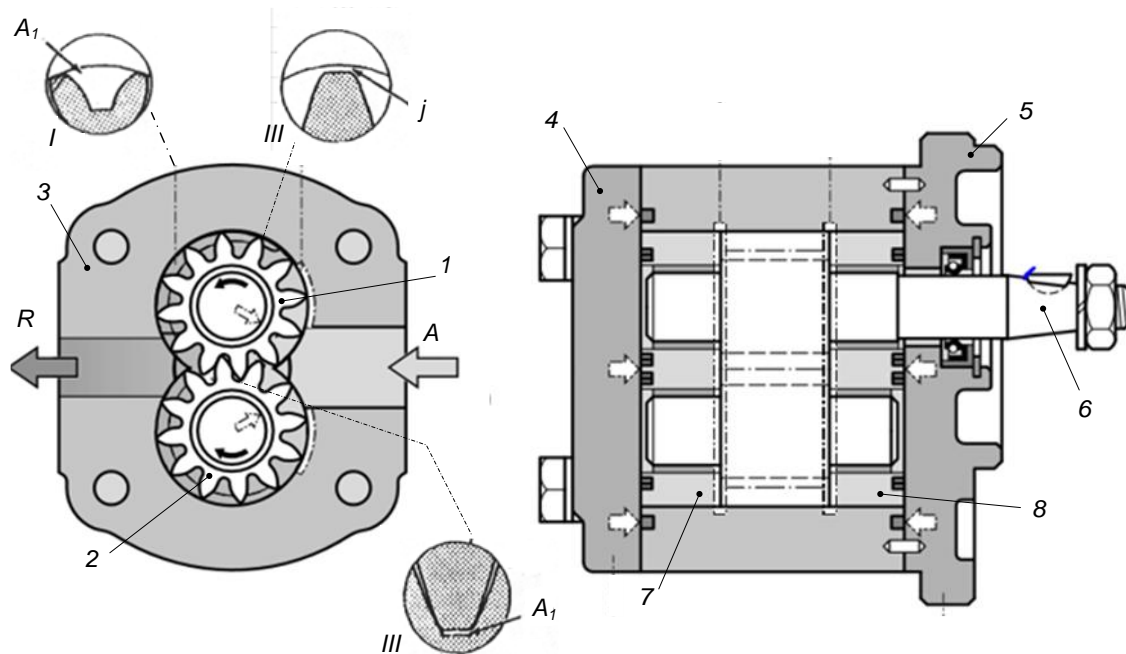


Fig. 1. The main parts of the hydraulic gear pump.

- Two bearings numbered 7 and 8.

When the gear wheels are rotating around the gear axis following the clockwise and counter-clockwise arrows (Fig. 1) the teeth placed nearby the suction chamber are sorting out from the gear space, so that a supplementary room may be functional. Inside this room it is a low level pressure, so the flow coming from the supplier will be filled in. The well-known volume of oil, named "trapped volume" is closed between two consecutive teeth pairs in contact, so it is carried out through the expulsion.

There are two unwished phenomena during the working process: loss of flow and the action of asymmetric forces having higher values whether the pressure increases. The flow is lost between the pump body and external peak of the teeth, the external surfaces of the gear and the parts numbered 7 and 8 (Fig. 1). There are some solutions for reducing these leaks by designing an internal pipe for bringing the expulsion pressure on the external surfaces of the parts 7 and 8, so that there are pushed toward the gear.

The paper [1] presents an improved formulation of the pressure evolution of the external gear pump, highlighting the phenomena such as axial flow, the accurate description of the trapped volume and its connection with input and output chambers. There are pointed out some genuine ideas regarding the simulation for force and torque based on the numerically description of flow areas inside the complex groove designed.

The paper [2] describes the work, which has been done by using HYGESim (Hydraulic Gear Simulation) tool, for modelling the external gear pump functioning with non-Newtonian fluids, like plastics, polymers, paints. The main concern was the modelling of flow through orifices. The results were discussed with respect to the angular position of the gear starting from the suction to the delivery zone, showing the progression of the tooth space. The geometry model can give an idea of how areas of different orifice connections vary with angle.

The work presented in paper [3] is about the 3D numerical simulation of an external gear pump performed for more realistic prediction of pump performance and internal flow phenomena by

considering leakage in the lateral gap. The research was focused on the effects of the designed parameters on the flow rate and flow characteristics. The result validation was done for a pump with high rotational speed.

The paper aims to propose a method for improving the flow variation of an external gear hydraulic pump, by controlling the speed of the electrical motor. The solution is useful and could be used for the systems with constant or variable load.

2. The flow variation for the external gear pump

The external gear pumps used for the hydraulic systems provide the well-known advantages such as higher efficiency, compactness and safety. There are internal and external gear pumps depending on the meshing shape inside the gear, but the latter ones are preferred for high pressures. Due to its working principle, meaning the fluid is passing periodically from inlet port to outlet port there are some disadvantages comprising the flow and pressure ripples as well as the attention we have to pay to the pressure level. The pressure value has to be inside a well-known range, because of malfunction avoidance. If it is lower, we may expect the cavity phenomenon inside and if it is higher, the gear is over-loaded, so the mechanical assembly will be affected by losses, vibration and noise.

The meshing flow that provides the trapped volume is influenced by the tooth profile and it has to be designed very carefully. The entrance shape of this volume is generated by the circle; it is followed by the teeth lateral surface governed by the involute and finally another surface having the circle as generative curve. Because of making the understanding process of the phenomena a little bit easier, we may assume that the instantaneous points along the line of action separate the high pressure from the low pressure at each value of the angular position described by β .

In order to compute the flow variation, we may start from the equality between the hydraulic power and the mechanical power given by the electrical motor:

$$P \cdot dq = M \cdot d\beta \quad (1)$$

P - hydraulic power; dq – elementary flow variation; M – mechanical torque; $d\beta$ – elementary rotational movement due to the electrical motor actuation.

The mechanical torque is given by the equation [4]:

$$M = F_1 \cdot \frac{r_a}{2} - F_2 \cdot \frac{\rho_1}{2} + F_3 \cdot \frac{r_a}{2} - F_4 \cdot \frac{\rho_2}{2} = p \cdot \frac{b}{2} \cdot (2 \cdot r_a^2 - \rho_1^2 - \rho_2^2) \quad (2)$$

As it is shown in Fig. 3, there are the following meanings for the notations: F_1 , F_2 , F_3 and F_4 – pressure forces acting on the lateral teeth surface having the thickness b and p – the pressure value; r_a – value of addendum radius of the gear; ρ_1 and ρ_2 – the radii of points along the tooth profile.

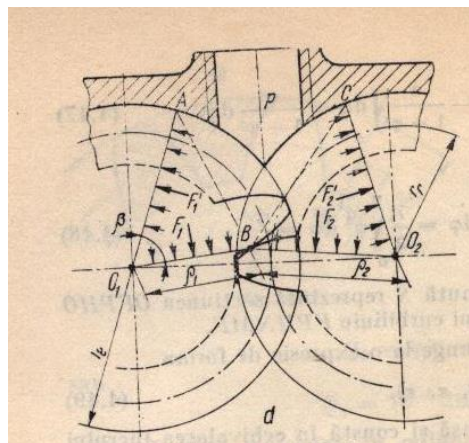


Fig. 2. The geometrical elements of the gear.

Taking into account that:

$$\rho_1^2 + \rho_2^2 = 2 \cdot (r_r^2 + x^2) \quad (3)$$

We may compute the external gear pump torque:

$$M = p \cdot b \cdot (r_a^2 - r_r^2 - x^2) \quad (4)$$

where x – the position of contact point along the line of action.

Finally, as we have started from equation (1) we may find the relationship between the displacement of contact point along the gear line during the process and the rotational movement of driving gear:

$$\frac{dq}{d\beta} = b \cdot (r_a^2 - r_r^2 - x^2) \quad (5)$$

$$\frac{dx}{dt} = r_r \cdot \frac{d\beta}{dt} \quad (6)$$

We use the mathematical equation characterising the geometrical dimensions of the involute gears, so we may assume that: $b = \psi \cdot m$ [mm] the face width of the gear, where m – modulus and ψ – the thickness coefficient; $r_b = \frac{m \cdot z \cdot \cos(\alpha_0)}{2}$ the base circle radius; r_r – the radius of rolling circle; z – the number of teeth for the involute gear and $\alpha_0 = 20^\circ$ the gear angle.

Taking into account all the mathematical relations presented above, we have computed the flow variation depending on time and rotational speed of the motor by using MATLAB for solving the following first order differential equation system:

$$\begin{cases} \frac{dq}{dt} = \frac{4 \cdot \psi \cdot (r_a^2 - r_r^2 - x^2)}{z \cdot \cos(\alpha_0)} \cdot \left(-2 \cdot x \cdot \frac{dx}{dt} \right) \\ \frac{dx}{dt} = r_r \cdot \omega_m \end{cases} \quad \text{if} \quad 0 \leq x < p_b - l/2 \quad (7)$$

$$\begin{cases} \frac{dq}{dt} = \frac{2 \cdot \psi \cdot (r_a^2 - r_r^2 - x^2)}{z \cdot \cos(\alpha_0)} \cdot \left(-2 \cdot x \cdot \frac{dx}{dt} \right) \\ \frac{dx}{dt} = r_r \cdot \omega_m \end{cases} \quad \text{if} \quad p_b - l/2 \leq x < l \quad (8)$$

Where ω_m – the electrical motor rotational speed; p_b – the gear pitch along the base circle; l – the length of line of action.

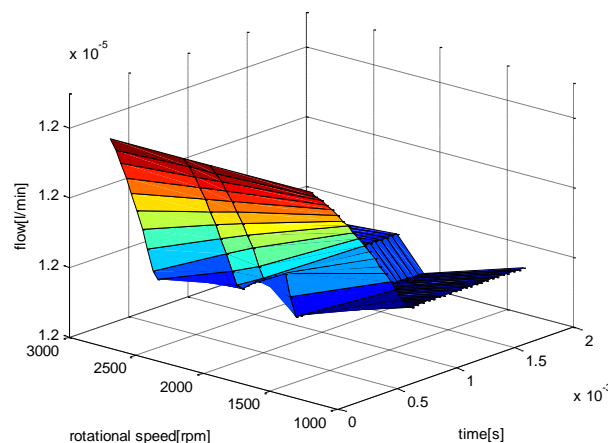


Fig. 3. The computed results.

We have solved this first order differential system by using Runge-Kutta method and imposing the condition for the solutions nearby starting point of time. The numerical set-up was done with the values reported below: $m = 1.5$ [mm]; $z = 13$; $r_a = 23.4$ [mm]; $r_r = 9.749$ [mm]; for the electrical motor we have taking into account the following values: $(n_m)_1 = 2700$ [rot/min]; $(n_m)_2 = 2150$ [rot/min]; $(n_m)_3 = 1950$ [rot/min]; $(n_m)_4 = 1200$ [rot/min].

The results are presented in Fig. 3 for the flow variation over time and rotational speed of the AC motor, so that we may infer the shape of this dependence and proportionality. As we have expected, the main conclusion is that we may control the flow law variation by controlling the rotational speed of AC motor.

3. Conclusions

The paper aims to point out the main advantages of using the external gear pump for the hydraulic systems with variable or constant flow, as a better solution for improving the efficiency. The choosing of the hydraulic supplier system has to be done very carefully based on a technical and economic analysis. There are two unwished phenomena during the working process: loss of flow and the action of asymmetric forces having higher values whether the pressure increases. The flow variation may appear due to the leaks through the clearance, for instance. The presented theoretical method could be used in order to control the flow according to the electrical motor rotational speed.

References

- [1] Mucchi, E., G. Dalpaz, and A. Fernandez del Ricon. "Elasto-dynamic analysis of a gear-pump Part IV: Improvement in the pressure distribution modeling." *Mechanical Systems and Signal processing*, no. 50-51 (2015): 193-213.
- [2] Rituraj, Fnu, and Andrea Vacca. "External gear pumps operating with non-Newtonian fluids: Modeling and experimental validation." *Mechanical Systems and Signal processing*, no. 106 (2018): 284-302.
- [3] Yoon, Yonghan, Byung-Ho Park, Jaesool Shim, Yong-Oun Han, Byeong-Joo Hong, and Song-Hyun Yun. "Numerical Simulation of three-dimensional external gear pump using immersed solid method." *Applied Thermal Engineering*, no. 118 (2017): 539-550.
- [4] Oprean, Aurel. *Hydraulics for Tools/Hidraulica masinilor unelte*. Bucharest, Technical Publishing House, 1983.
- [5] Devendran, R.S., and Andrea Vacca. "Theoretical analysis for variable delivery flow external gear machines based on asymmetric gears." *Mechanism and Machine Theory Journal*, no. 108, (2017): 123 – 141.