EMBEDDED RESEARCHES ON ADAPTIVE PARAMETRIC MODELING OF HYDRAULIC GEAR PUMPS

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Abstract: *This paper presents some of the research results on a fundamental and applicative procedures regarding the integrated intelligent conception of a Romanian series of hydraulic gear pumps. Following the analysis of the pump series in the manufacturing process, the requirement for a modernized parametric design of this product has been identified. Thus, we observed the beneficiaries' requirement for certain flows that are currently not provided by the current range of pumps. The parametric design of the pump leads to an easy and adaptive modification of the supplied flows, resulting in an innovative methodology which is very useful for the design and process engineers. The methodology is based on a computer-aided 3D modeling, specific pressure, drive torque, flow rate, etc. Each of these parameters leads to the intelligent modification of the certain geometric and functional features of the pump series designed to be adaptable to the dynamic demands of a modern economy.*

Keywords: GEAR PUMP, CAD MODEL, PARAMETERIZATION, PRESSURE, GEOMETRIC VOLUME

1. Introduction

Hydraulic gear pumps, due to their constructional simplicity, reduced number of components, high performance and reliability, low manufacturing cost and operational safety, are widely used to drive hydraulic fluids (for increasingly various industrial applications, from automotive to medical) in complex installations of different types and sizes.

Generally, these pumps contain two meshed gear wheels (spur or helical gears). The driving gear (driven by a motor or by an induced magnetic field) rotates in a certain direction and trains the driven gear in the opposite direction. Thus, by engaging the gears, the liquid between the teeth and closed by the pump elements (body, cover, bearing blocks) is transferred from the suction zone (inlet) to the discharge zone (outlet). The pumped liquid is trained around the two gears and not through the gears, thereby creating a pressure inside the pump [1, 2]. The liquid is transferred without flow pulse. Some pumps allow the fluid to be transferred in both directions, being called bidirectional pumps, which is one of the main advantages the user is looking for when selecting a pump.

Another important advantage of this type of pumps is given by the self-priming capability because at the moment of engagement/ meshing the air is discharged from the gaps between the teeth, pressure is created and the liquid is aspirated due to the formation of an instant vacuum, sufficient for priming [3].

The precise way the pump components are manufactured, especially the meshing gears and the suction and discharge chambers, allows the hydraulic pumps to reach high pressure values with a very good efficiency (75-85%). For this purpose, strict tolerance conditions [4] have to be observed/fulfilled, the wheels have corrected teeth profile and often asymmetrical flanks [5, 6].

The current research on hydraulic gear pumps is associated with the creation of functional models that allow operation at high and constant pressures, with high efficiency and low weight (certain pump components are made of composite polymeric materials or light metal alloys). Also, a current requirement is a low noise and vibration level [3, 7], but also the ability to quickly create customized pumps when the manufacturer's standard range does not meet a particular market demand.

In order to improve modern pumps, to simulate and implement them, a comprehensive computer-optimized design study, many calculations, numerical simulations and tests are required [8, 9, 10].

The latest researches in the field, carried out within an important Romanian pump company [11], highlighted concerns about reducing the size and weight of the pumps components, developing micro-pumps, and replacing their current materials (alloys of steel and aluminum) with polymeric composite materials, one of the stated goals being the costs reduction for production and maintenance [12].

2. Main steps in the conception and parametric design of hydraulic gear pumps

In this paper we did a research on conception and computer aided design for improved and new models of hydraulic gear pumps, their static and dynamic analysis, functional tests etc.

The studied pumps have an important applicability in the automotive field, operate at high speeds and have good volumetric efficiency. The constructive and functional parameters of the pumps are carefully considered. It is observed how modifications of certain component dimensions influence the flow range, their weight and of the pump assembly, the driving torque and the efficiency.

During the conception stage, we performed calculations, created several 3D pump models using the CATIA v5 product and, thus, many constructive variants were analyzed.

We considered the variations in the pressures of the hydraulic fluid, the speed and friction between the pump components, the type, shape and dimensions of the meshing gears. All these parameters developed the CAD models and, together with mathematical models, were useful and necessary tools in the stages of the dynamic evaluation of pumps behavior to reduce noise, vibration, friction, etc.

Thus, for each pump model, we considered the following steps: analysis of the functional role of the pump and its structure, identification of dimensions, tolerances and assembly conditions, technological possibilities of manufacturing certain components, 3D parametric design of the pump assembly [13, 14], establishing the connections between the dimensions of its components, FEM simulations of the gears behavior in conditions imposed by hydrostatic pressure [9, 10, 15].

In the 3D modeling steps, we performed a study of the fluid flow transmitted by the pump, a comparison between the data resulted from the numerical calculations and those obtained from the experiments. Thus, we observed a mathematically correct correlation on how the fluid flow increases with the rising of an important characteristic of the pump: the geometric volume.

The results of this analysis showed that the parametric 3D model of the pump based on the variation of this geometric volume can be particularly important for the design and development of the pump series, also allowing the determination of the minimum and maximum pressures (and their variation) in the gaps of the meshing teeth. This reduces the noise and vibrations during operation, but especially the mistakes/errors that can lead to failures in pump's priming, early wear or even tearing of the teeth after many hours of service.

We constantly paid attention to the importance of simulating the functioning of the parametric model pumps to determine their predictable behavior after manufacturing and installing in the hydraulic installations.

In the research, for the parametric 3D modeling, we also took into consideration the technologies of manufacturing the pump components, the control and assembly methodologies and the analysis of the running behavior.

3. Parametric conception of a series of pumps

By the parametric design, we generated the drawing and optimized the teeth profiles (Fig. 1), using involute equations, 3D creation of the spur gears and then of the pump assembly, using numerous relations and equations [16, 17] and a methodology presented in [10, 18, 19]. With this parametric approach applied on the gear profile, it is possible to change all these parameters easily, which leads to several pump variants and, consequently, to the change of the fluid flow transmitted by it.

The main data involved in the design and modeling of the pump are: geometric and operating parameters (Q_p – flow rate, V_g - geometric volume/displacement, pressure p_p, speed n_0, efficiency η, other conditions and constraints).

We considered some variants such as pumps with one, two or more rotors, number of teeth, module, gear width, pressure angle, etc. Generally, the pump is driven by a constant-speed electric motor, but we focused our attention towards the design and implementation of the magnetic actuator [20]. For this, however, certain pump components should be made of polymeric composite materials to reduce the pumps weight and the driving torque required to rotate the meshing gears [21].

Figure 1 presents the parametric profile of the pump teeth.

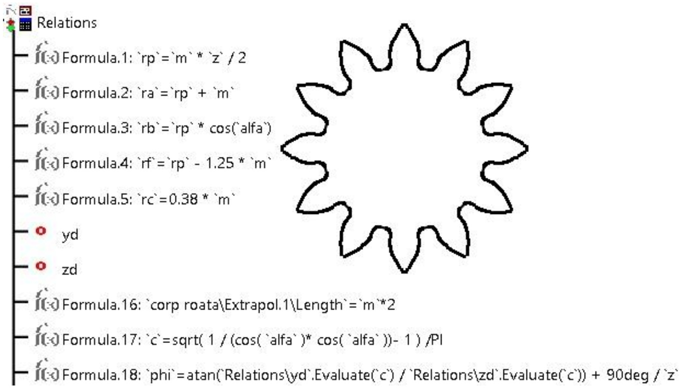


Fig. 1. *Parametric creation of the gears profile*

The parametric design of the gear pump assembly should be characterized by: constructive simplicity, compactness, operational safety and low noise [10].

The gaps between the gearing's teeth form conveyor cups for the hydraulic fluid. The cups volume is determined by the geometrical elements of the involute tooth gears [17] supported by the bearings blocks.

Both gears have the same number of teeth. As the gears rotate, they separate on the intake side of the pump, creating a vacuum and suction which is filled by the fluid. The driving gear z_1 rotates at a constant speed n_0 in one direction and the driven gear z_2 rotates in the opposite direction (Fig. 2).

The fluid is aspired through the Inlet aperture at the atmospheric pressure p_0 and is carried by the gears to the discharge (Outlet) aperture of the pump, where the meshing of the gears displaces the fluid (flow Q_p, l/min and pressure p_p, bar). The mechanical clearances are small, in the order of 10 μm. The tight clearances [4], along with the speed of rotation, effectively prevent the fluid from leaking backwards.

The Q_p and p_p values represent the basic characteristics of the pump [16], being particularly important for the user in selecting the pump and dimensioning the hydraulic system.

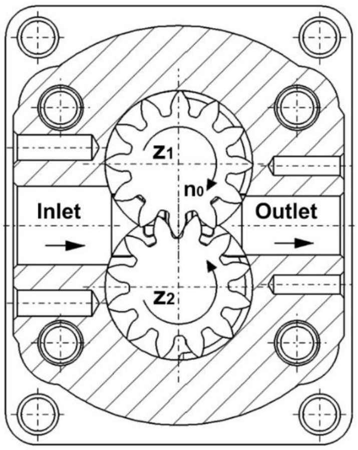


Fig. 2. *Section through the gear pump*

The 3D CAD model of the pump in Figure 3 was created based on the specific parameters: number of teeth $z_1 = z_2 = 12$, center distance A = 31.4 mm, module m = 2.54 mm (normal specific displacements x_n = 0.2 mm pinion z_1, x_n = 0.199 mm gear z_2 and frontal specific displacement x_f = 0.2 mm), gear width b = 18.3 mm, pitch circle diameter d_d = 30.48 mm, outside circle diameter d_a = 37.413 mm, rolling circle diameter d_r = 31.4 mm, base circle diameter d_b = 28.642 mm, pressure angle $\alpha = 20^0$, teeth height h = 6.205 mm, normal gear pitch p_n, normal arc of dividing the tooth/gap s_n/e_n, frontal contact ratio ε = 1.494, constant chord s_c = 3.85 mm.

The parameter values are based on the numerical methods [10, 17] and standards in the field [4, 11]. Analysis of these data shows that the involute teeth gear is corrected [22, 23].

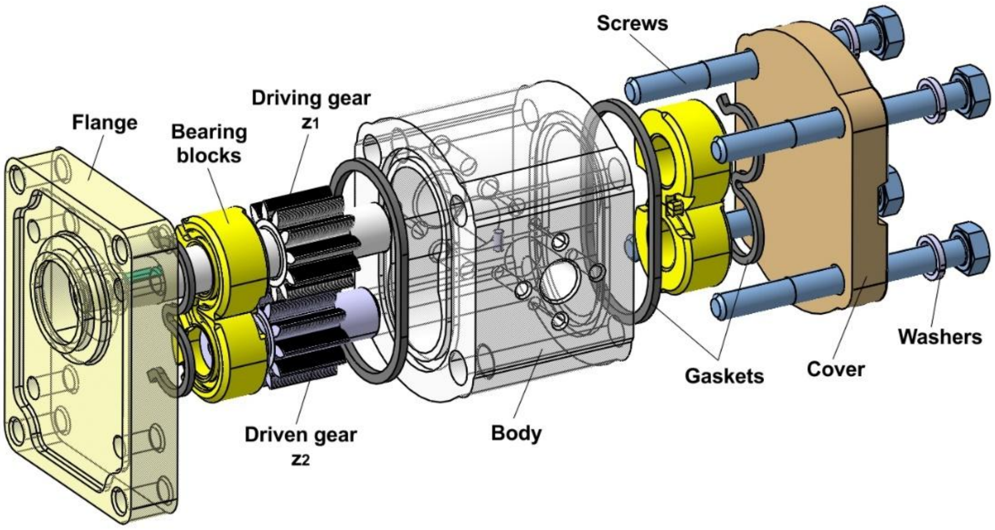


Fig. 3. *The 3D model of the gear pump*

Figure 4 contains a 3D detail of the gear, marked as a gap (cup) of/between two successive teeth, its volume is denoted as $V_{gt} = b{\cdot}A_p$, mm^3, where *b*, mm, is the gear width and A_p, mm^2, is the area of the cup profile.

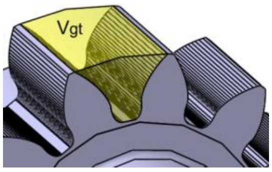


Fig. 4. *The cup volume between two successive teeth*

The geometric volume V_g of the pump is calculated by the formula (1), [16]:

$$V_g = 2 \cdot z \cdot V_{gt} \cdot 10^{-3}, \text{ [cm}^3\text{/rot]} \quad (1)$$

The pump flow Q_p results from the formula (2), [16, 17]:

$$Q_p = \frac{V_g \cdot n_0}{10^3} \cdot \eta_v, \text{ [l/min]} \quad (2)$$

where: n_0 is the driving speed (rot/min), *z* the number of teeth for each gear and η_v the volumetric efficiency (%).

High speeds, over 1500-2000 rot/min, lead to appearance of the cavitation process, which reduces the pump flow, efficiency and gas occurrence in the hydraulic fluid.

With the 3D CAD model of the pump created in CATIA v5 and knowing the influence of parameters on the pump's flow, we developed a program in Visual Basic Application (VBA) that directly modifies certain values based on a selection (Fig. 5) of the pump's geometric volume. For a certain value of the pump's geometric volume and the speed n_0 at which the pump operates (between the min and max limits imposed by the manufacturer), the pump will provide a certain flow, according to the formula (2).

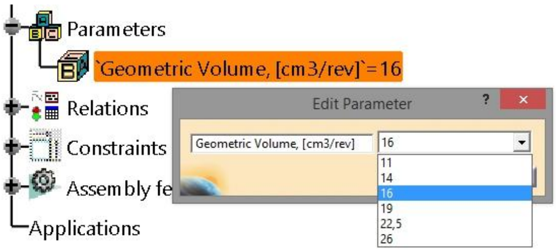
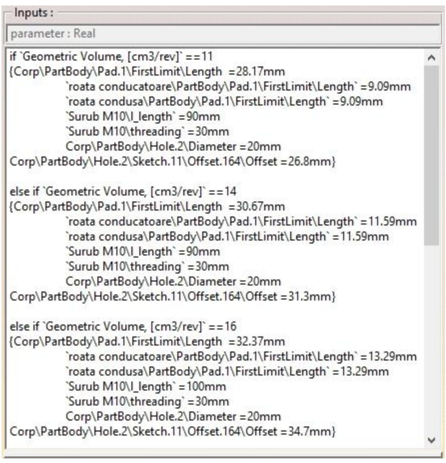


Fig. 5. *User selection of the geometric volume*

Figure 6 is a short sequence from the parametric modification of the pump assembly by the VBA code. The geometric volume selection paragraphs are observed, as shown in Figure 5, calculating and imposing certain values for dimensional parameters of many pump's components. We previously determined the values based on a numerical measurements and calculations [10, 18].



```
Inputs :
parameter : Real
if `Geometric Volume, [cm3/rev]` ==11
{Corp\PartBody\Pad.1\FirstLimit\Length  =28.17mm
        `roata conducatoare\PartBody\Pad.1\FirstLimit\Length` =9.09mm
        `roata condusa\PartBody\Pad.1\FirstLimit\Length` =9.09mm
        `Surub M10\l_length` =90mm
        `Surub M10\threading` =30mm
        Corp\PartBody\Hole.2\Diameter =20mm
Corp\PartBody\Hole.2\Sketch.11\Offset.164\Offset =26.8mm}

else if `Geometric Volume, [cm3/rev]` ==14
{Corp\PartBody\Pad.1\FirstLimit\Length  =30.67mm
        `roata conducatoare\PartBody\Pad.1\FirstLimit\Length` =11.59mm
        `roata condusa\PartBody\Pad.1\FirstLimit\Length` =11.59mm
        `Surub M10\l_length` =90mm
        `Surub M10\threading` =30mm
        Corp\PartBody\Hole.2\Diameter =20mm
Corp\PartBody\Hole.2\Sketch.11\Offset.164\Offset =31.3mm}

else if `Geometric Volume, [cm3/rev]` ==16
{Corp\PartBody\Pad.1\FirstLimit\Length  =32.37mm
        `roata conducatoare\PartBody\Pad.1\FirstLimit\Length` =13.29mm
        `roata condusa\PartBody\Pad.1\FirstLimit\Length` =13.29mm
        `Surub M10\l_length` =100mm
        `Surub M10\threading` =30mm
        Corp\PartBody\Hole.2\Diameter =20mm
Corp\PartBody\Hole.2\Sketch.11\Offset.164\Offset =34.7mm}
```

Fig. 6. *Visual Basic code sequence*

The dimensional modifications shown in Figures 7 and 8 applied to the pump assembly represent two extreme variants of the pump series [10, 17], according to the selection in Figure 5.

Each constructive design passed through the complex FEM simulation process to determine the forces and pressures generated in the real operating conditions [9, 19]. When the situation imposed it, certain components changed their dimensional parameters (behavioristic 3D modelling).

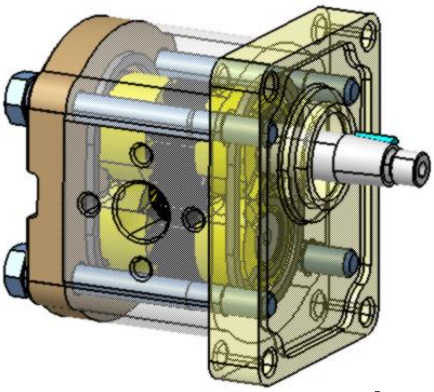


Fig. 7. *Pump assembly for V_g=11 cm^3/rev*

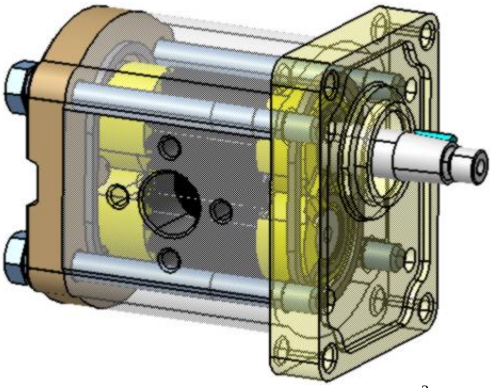


Fig. 8. *Pump assembly for V_g=26 cm^3/rev*

For the magnetic drive pump [24, 25] variant, we will replace the flange and re-design the pump body and the driving gear (pinion) from Figure 3 to fulfill the main condition of complete sealing of the hydraulic fluid from the external environment (this is one of the main imposed conditions for this type of pumps).

The gearing calculations and FEM simulations for the forces and pressures will be resumed in multiple iterations to reach the optimal solution. Calculations and tests will also be performed to design and optimize the choice of magnetic elements (stator and rotor) and their integration solution in the new pump assembly.

The goal is, of course, to convert the current pumps (Figure 9, as a test variant or another constructive variant) into a magnetically driven and highly leak-proof pump [26]. Some components will be made of composite polymeric materials [27].

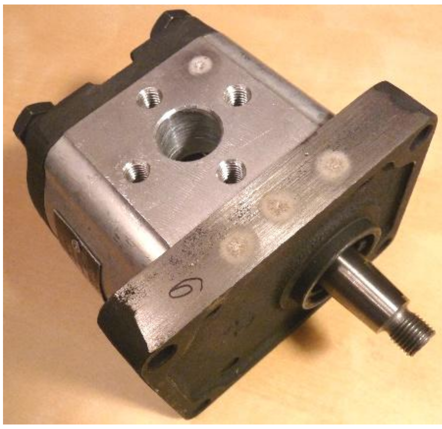


Fig. 9. *Actual pump in a test configuration* [11]

4. Conclusions

This paper presents preliminary results of the research conducted within the research project GEX, Ctr. No. 57/2017, *Composite Magnetic Pumps* and new concepts of pumps applicable in industrial environment. The proposed methodology of parametric design of a gear pump series [28] is conditioned by knowing the influence of the dimensional parameters of the pump on forces, moments and pressures in real operation in the certain hydraulic installations. This allows an optimal 3D design and product validation, important steps in the testing and launch process in serial production, with further development potential.

The parametric design procedures lead to the optimal conception of the constructive variants of the magnetic drive pump with the elaboration of a methodology for the selection and calculation deviation values and tolerances in the case of the gear parametric design.

The pump body will also be conceived and developed based on a precision criterion, but also on the fact that the ingot stock used as the body of the magnetic drive variant must remain in certain dimensions not to incur additional costs. Both for the series of pumps developed by parametric design, especially for the magnetic drive variant [26], we will consider the optimal solution of the technological and manufacturing parameters.

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