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GRAPHICAL MODELLING AND STUDIES ON HYDRAULIC PUMP PARAMETERS

Abstract: *Hydraulic drive can be defined as a set of technical functions through which the transmission of mechanical energy is carried out, from a driver element to a driven one, using a hydraulic environment. Hydraulic pumps are hydrostatic, flow-generating, wide-use power generation machines that receive mechanical energy produced by a force machine and convert it into hydrostatic energy, which imprints it to the hydraulic working environment. In the paper, the graphic modeling of two different types of hydraulic pumps is performed, a gear pump and an axial piston pump, as well as a calculation that highlights the value differences of flow, moment and hydraulic power of the two types of pumps.*

Key words: *hydraulic pumps, spur gears, axial pistons, flow, moment, power*

1. INTRODUCTION

Among the most efficient and modern mechanization and automation means of machinery, implements and equipments are hydraulic actuators, whose area of use has considerably increased in recent years due to their remarkable advantages [1], [2], [3]. In a pressure engine, Figure 1, the pump aims to provide the hydraulic energy required to perform a certain machine work.

Together with the oil engine, the pump forms the generator-transformer unit of mechanical energy in hydraulic energy, respectively, hydraulic energy in mechanical energy. Fundamental in facts, a hydraulic pumps carries a Q fluid flow between intake at pressure p_0 and upset at an exert pressure $p_1>p_0$ [4].

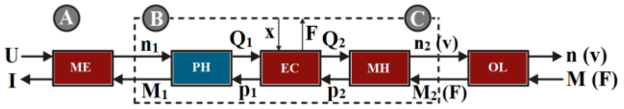


Figure 1 Block scheme of the hydraulic drive [5].

Gradual energy conversions are carried out as follows: in zone *A* electricity into mechanical energy, in zone *B* mechanical energy into hydrostatic energy, and in zone *C* hydrostatic energy into mechanical energy, each transformation intervening with its own working capacity, Figure 1.

Hydraulic pumps can be classified according to several criteria, Figure 2, given the huge variety of constructive and functional types made by manufacturer companies:

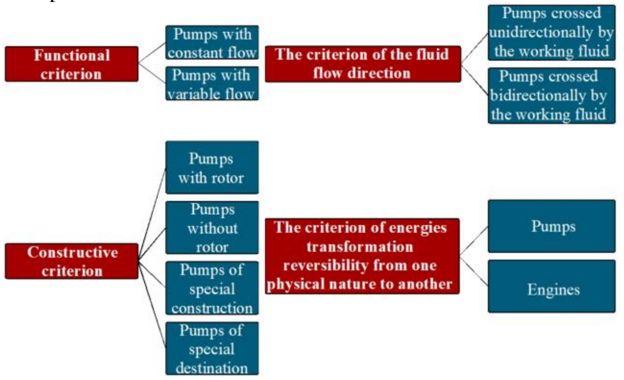


Figure 2 Hydraulic pumps classification.

2. GEAR PUMP

Gear pumps have a great spread in machine construction due to their constructive simplicity, low-cost and high-operating safety. They are used for a wide range of pressures and flows [4].

The basic elements of the gear pumps are the gears of which, one driver and the other or the others, if there are more than one gear, driven. The rotating motion of the gears is achieved by driving from an external power source of a pump belonging to the shafts on which they are mounted, transmitting the motion to the driven shaft by gearing [5].

Gear pumps shall be ranked according to the following criteria [6]:

a. by the gearing mode: with outer gearing; with inner gearing;

b. by the number of gears engaged simultaneously: with two rotors; with multiple rotors;

c. by the discharge pressure: of low pressure ($p<30$ *bar*); of medium pressure ($30<p<100$ *bar*); of high pressure ($p=100÷300$ *bar*); with hypocycloidal section;

d. by the possibility of adjusting the flow: with adjustable flow; with constant flow.

e. by gear shape: with straight teeth; with inclined or *V*-shaped teeth;

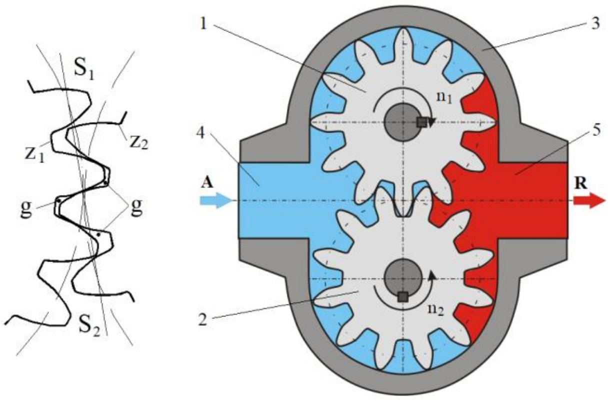
f. by the shape of the tooth section: with involute section; with epicycloidal section.

Figure 3 shows the constructive-functional scheme of a two-gear pump. The driving gear (*1*) is mounted with a pan on the drive shaft, the gear (*2*) being driven. The guide gear is driven by an electrical or heat engine. The encasing (*3*) has an inlet (*4*) next to the recess and a discharge orifice (*5*) next to the approach path.

During the recess, the immediate volume of the inlet increases, producing a negative pressure due to the fact that the oil in the tank at an atmospheric pressure is inducted into the pump suction chamber *A*. The oil sucked into the gaps between the teeth of the gears and is transported by rotating the gear to the recession space *R*.

The profile of the teeth z_1 and z_2 is single-curved, and the contact between the teeth is made on the line of contact S_1S_2, Figure 3a. The gaps between the teeth carrying the liquid are closed by toothing before the entire amount of liquid in them is pumped out into the discharge chamber.

Thus, in the gaps *g* remains a quantity of pressure oil, which calls forth additional mechanical stress in the pump shell by the depression produced on the shafts and bearings. That's why the oil left between the teeth should be pumped out.



a. b.

Figure 3 Pump with 2 spur gears: a - teeth section; b - gearing zone.

Figure 4 presents the constructive-functional diagram of a three-geared pump, to which, in addition to the advantages of increasing the flow and balancing the radial forces, a series of pressure steps can also be achieved by developing a cascade circuit of the impellers (the upset of an impellers couple binds to the intake of the second, etc.), or in series-parallel, which increases the volume power and the pressure extent.

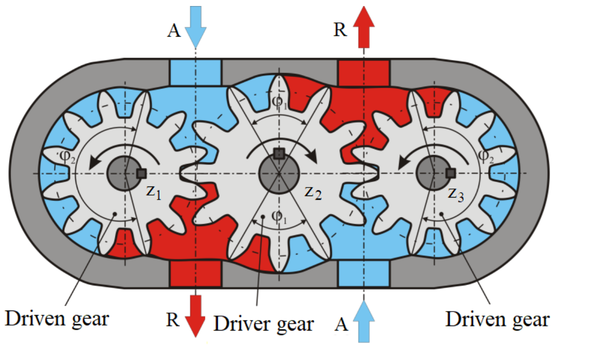


Figure 4 Pump with 3 spur gears [7].

3. AXIAL PISTON PUMP

This pump consists of a cylindrical block in which the axial pistons are located, a paring disc, on which are, at one end, the piston rods and a distribution plate.

Three main categories are distinguished by the location of the piston block in relation to the paring disc: *with inclined block, with inclined disc and with fulant disc* [8].

Pumps with inclined block (Figure 5.a) at which the block (*1*) with the pistons (*2*) can be tilted at an angle *α* form the spindle plate (*3*).

Pumps with inclined disc (Figure 5.b), unlike the previous type, have the block (*1*) with the pistons fixed (*2*) and the disc (*3*) together with the drive shaft (*4*) tilting with the angle α.

Pumps with fulant disc (Figure 5c) are characterized by a single, non-sloping shaft on which the swash plate (*1*) is mounted pin-ended, which can take different angle *α*.

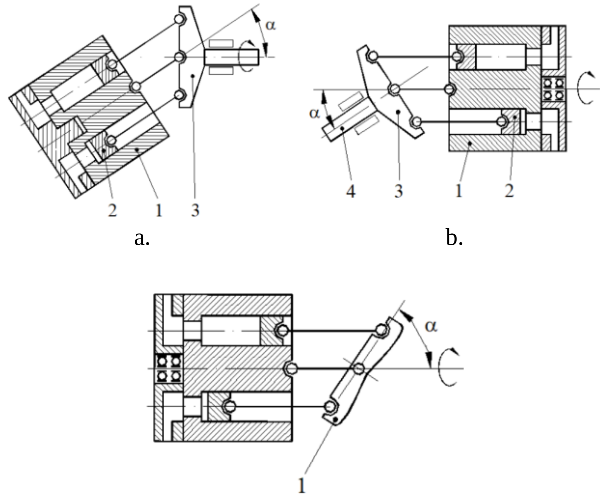


Figure 5 Axial piston pump: a - with inclined block; b - with inclined disc; c - with fulant disc [2].

Figure 6 shows a pump with axial pistons and sloping bloc. The impeller (*1*) has a number of cylindrical gaps with axes parallel to the impeller's axis. A corresponding number of pistons may be moved in the mouths (*4*). The rods (*5*) of the pistons are connected by spherical joints to the disc (*2*), whose inclination may vary. The impeller is driven by the universal joint (*6*) to the rotary plate (*2*), in turn driven by an electromotive through the drive shaft (*7*).

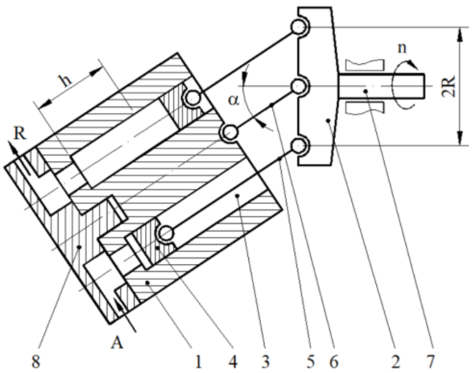


Figure 6 Axial piston pump with inclined block [2].

Since the piston block is tilted at the angle *α*, the pistons are required to run a *h*-length run during the pump's rotational motion, inducting the oil out of room *A* and upsetting it into room *R*.

The induction and upset of the oil is carried out through the distributor (*8*) locked to the impeller. By rotating the disc (*2*), i.e. the impeller (*1*), from *0* to *180°*, the piston moves inside the cylinder over the distance *h*, achieving the induction of the oil from the pump suction chamber of the distributor. Continuing to rotate from *180°* to *360°*, the pistons move in reverse with the same stroke length *h* towards the interior of the cylinder, releasing the oil into the recession space.

4. CALCULATION OF WORKING PARAMETERS FOR GEAR PUMP AND AXIAL PISTON PUMP

4.1. Gear pump

The flow of the gear pump can be calculated approximately, determining the volume of liquid transported between pump suction chamber *A* and the *R* discharge chamber at a rotation by a gear.

According to Figure 3, the front surface of all the teeth is approximately equal to the surface of the gaps between the teeth:

$$S = \frac{1}{2} \cdot \pi \cdot D_r \cdot h, \qquad (1)$$

and the fluid volume is:

$$V_1 = \frac{1}{2} \cdot \pi \cdot D_r \cdot h \cdot l, \qquad (2)$$

where D_r is the rolling diameter of both gears; h - the height of the teeth; l - gear's width and V_1 - volume for a single gear.

For the pump with two equal gears, operating at the rotational speed n, the pump flow will be:

$$Q = V \cdot n \cdot 10^{-6} \, [\text{l/min.}], \qquad (3)$$

where V is the unit volume given by the relation:

$$V^{'} = 2 \cdot V_1 = \pi \cdot D_r \cdot h \cdot l \left[\text{mm}^3\right] \text{- for pump with 2 spur gears;} \qquad (4)$$

$$V^{''} = 3 \cdot V_1 = \frac{3}{2} \cdot \pi \cdot D_r \cdot h \cdot l \left[\text{mm}^3\right] \text{- for pump with 3 spur gears.} \qquad (5)$$

Driving moment of the pump is calculated by the relation:

$$M_a = 10^{-4} \cdot \frac{p \cdot V}{2 \cdot \pi} [\text{N} \cdot \text{m}], \qquad (6)$$

where p is the working pressure, in *bar*; V - volume of the pump, in mm^3.

The power required to develop the pressure p is calculated by the relation:

$$P_h = \frac{p \cdot Q}{612 \cdot \eta_t} [\text{kW}], \qquad (7)$$

where Q is the actual output at the exit of the pump; η - overall efficiency of the pump ($\eta = 0,5 \ldots 0,9$).

4.2. Axial Piston Pump

Theoretical flow of the axial piston pumps is given by the relation:

$$Q = V \cdot n \left[\text{m}^3/\text{s}\right], \qquad (8)$$

where V is the oil volume discharged at a rotation; n - pump rotational speed, in *rot/min*.

The oil volume discharged at a rotation of the block is:

$$V = \frac{\pi \cdot d^2}{4} \cdot h \cdot z \left[\text{mm}^3\right], \qquad (9)$$

where d is the actual diameter of a piston, in *mm*; z - number of pistons; h - stroke of the piston, in *mm*.

4.3. Calculation of hydraulic parameters of volumetric pumps

This paper examines three types of volumetric pumps: the two-gear pump, the three-gear pump and the pump with axial pistons with inclined block. For this purpose, measurements have been made to determine the dimensions of some functional components.

In order to calculate the working capacity, normalized values will be adopted for:

- rotational speed, *n=(1500, 1700, 1900, 2100, 2300, 2500, 2700, 2900) rot/min.;*
- pressure, *p*=(*50*, *75*, *100*, *125*, *150*, *175*, *200*, *225*) *bar*.

The flow, drive time and power shall be calculated, taking into account the following data:

- *two-gear pump*: rolling diameter (rolling) of both gears, $D_r = 30$ *mm*, tooth height, $h = 5.75$ mm and gear width, $l = 13$ *mm*;
- *axial pistosn pump*: the diameter of a piston, $d = 20$ *mm*, the piston stroke, $h = 60$ *mm* and the number of pistons, $z = 7$ *pistons*.

The results are summarised in Figures 7÷12.

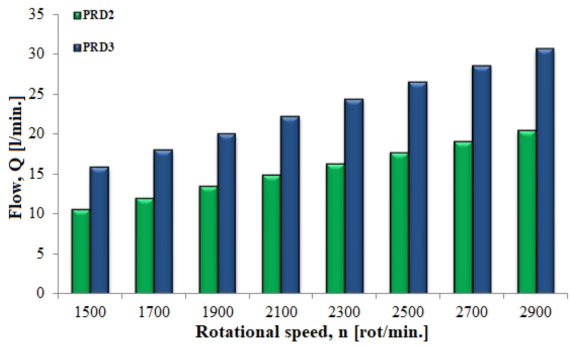


Figure 7 Flow variation, *Q [l/min.]*, for spur gear pumps.

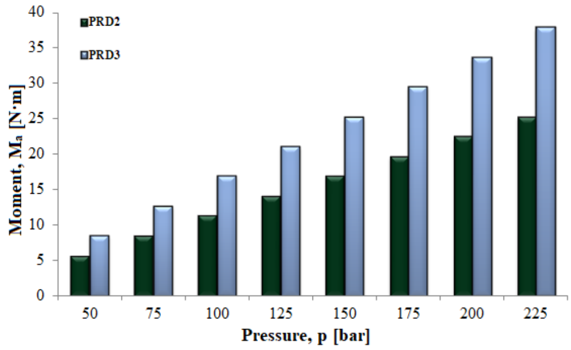


Figure 8 Moment variation, M_a *[N·m]*, for spur gear pumps.

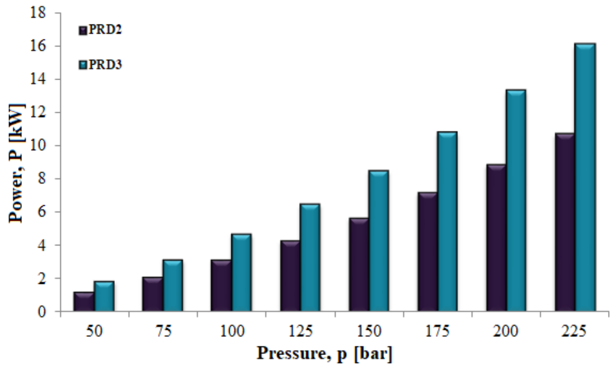


Figure 9 Power variation, *P [kW]*, for spur gear pumps.

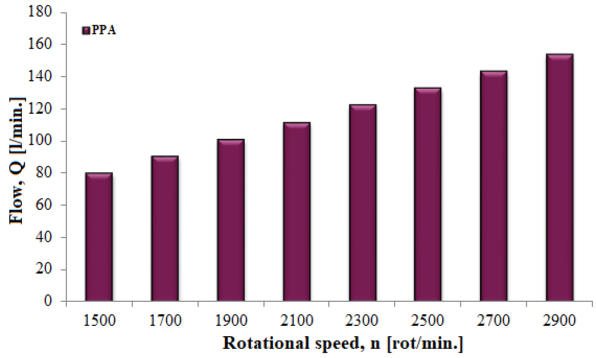


Figure 10 Flow variation, *Q [l/min.]*, for axial pistons pump.

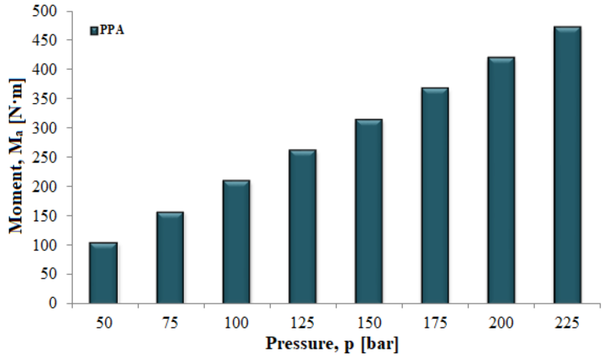


Figure 11 Moment variation, M_a *[N·m]*, for axial pistons pump.

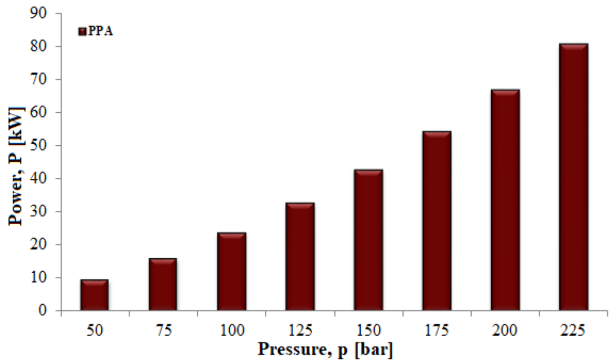


Figure 12 Power variation, *P [kW]*, for axial pistons pump.

5. GRAPHICAL MODELLING OF THE HYDRAULIC PUMPS

The two-gear pump and the axial piston pump have been modelled with the *Autodesk Inventor*, a software package that streamlines the *3D* modelling of solids as concretely and precisely as possible.

Each component was made in *Autodesk Inventor Part (*.ipt)*, following their assembly in *Autodesk Inventor Assembly (*.iam)*, obtaining the final models. This paper presents only a series of the modelled components, the other elements being elaborated in a similar way and using roughly the same defining commands.

Therefore, modeling the components of the two-gear pump, in the *Sketch* module, Figures 13÷15, was done in a simplistic way, highlighting the *2D, Line, Circle, Arc* drawing commands, as well as the *3D, Extrude, Hole, Revolve, Sweep, Loft* and the editing commands, *Mirror, Thread, Fillet* and *Chamfer*.

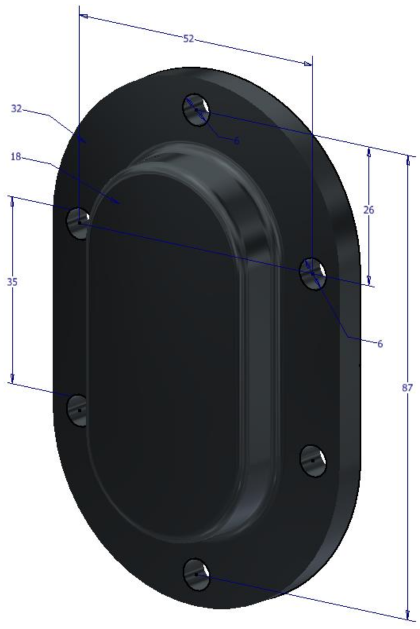


Figure 13 Modelling of the cap.

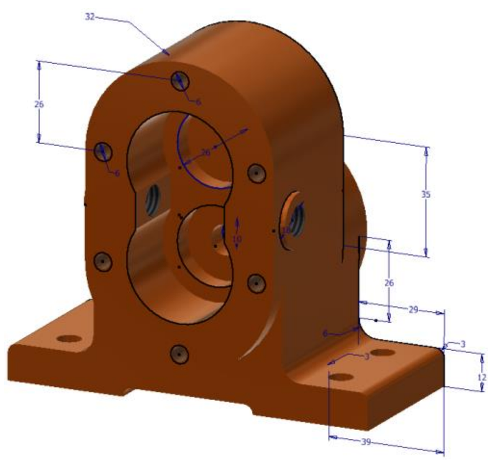


Figure 14 Modelling of the pump shell.

In order to achieve the serration of the driving gear, i.e. driven, the *Spur Gear* control was used, in this respect being necessary to carry out only the models of the gears created without serration, and then to be generated by this control.

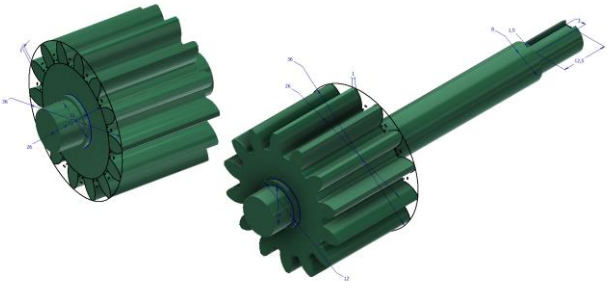


Figure 15. Modelling of the driver and the driven gear.

In the assembly module, there are some enforcements used in order to help merge all components in a subassembly or assembly, all of these being surface enforcement - *Mate* and *Flush*. They help create the contact between two surfaces, one from the other, the selected geometry being usually defined by the faces of the components, axes, planes of the two elements, edges or points, distance enforcements - *Offset Constraint*, setting the angles between two surfaces - *Angle Constraint*, enforcements of fixing the main element against the rest of the components - *Grounded* etc.

Therefore, from the main menu, select the *Standard* module *(mm).iam* and, by selecting the *Place* button, insert the components necessary to assemble the two-gear pump, the control being made for each component.

The first component is the pump's bonnet which is automatically locked, having the lock counter applied, *Grounded*.

The purpose of the enforcement is both to block the six degrees of freedom (DOF) and to assemble the other components in relation to the bonnet.

The assembly between the bonnet and the gears shown in Figure 16 is carried out by coincidence enforcements, i.e. the openings of the components shall have the same axis of symmetry, but also contact enforcements between the surfaces of the gears and that of the bonnet, for which it shall be established that the distance between them shall be zero.

Figure 16 Assembly between the cap and the spur gears.

Similarly, by applying enforcements, all the components of the two-gear pump are assembled, thus, obtaining its final model, Figure 17.

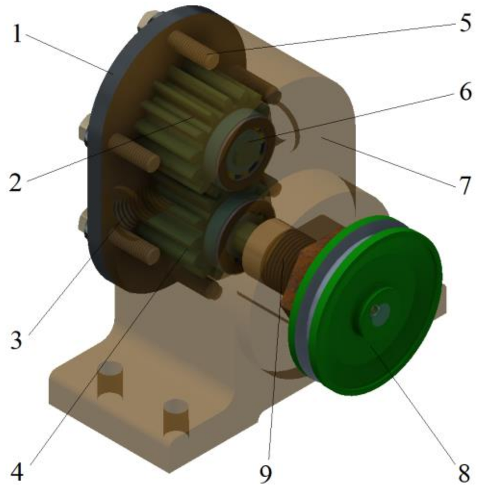


Figure 17 Pump with 2 spur gears:
1 - pump cap; 2 - driven gear; 3 - suction port; 4 - driver gear; 5 - M6 screw; 6 - bearing; 7 - pump shell; 8 - pulley; 9 - drive shaft.

Similarly, each component belonging to the axial piston pump, were made the same way as the components of the two-gear pump, using approximately the same *2D* and *3D* editing commands, Figures 18÷21.

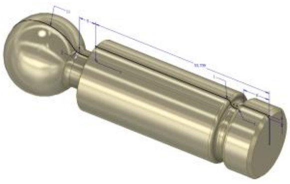


Figure 18 Piston modelling.

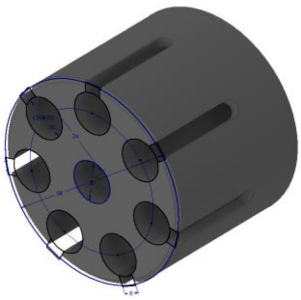


Figure 19 Barrel modelling.

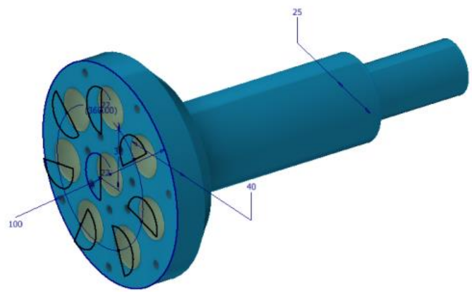


Figure 20. Modelling of the central shaft.

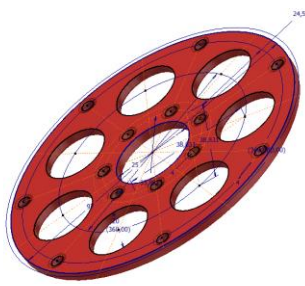


Figure 21 Modelling of the disc.

The pistons have both a translational motion, inside the piston block, and a rotational motion around a shaft that is materialized by the central shaft. The pistons are set in motion by a central shaft which has spherical hollows intended to drive them in their circular motion. In the assembly module, the same enforcements are used, as in the case of the two-gear pump, Figure 22.

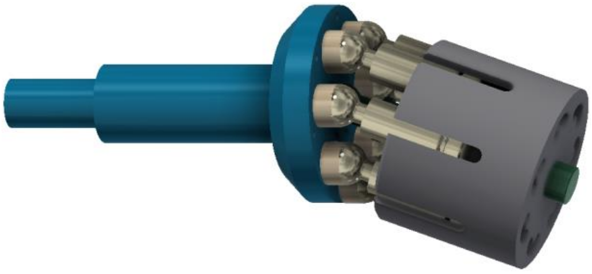


Figure 22 Pistons assembling.

Figure 23 shows the virtual model of the axial piston pump.

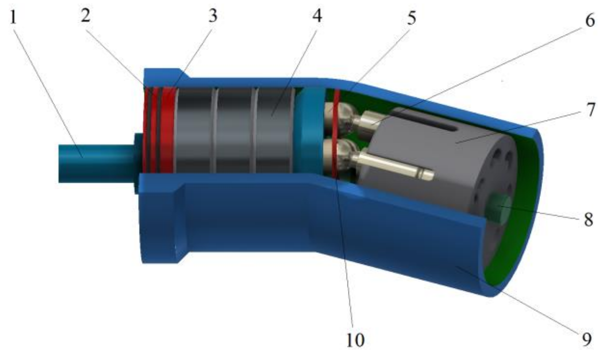


Figure 23 Axial piston pump:
1 - drive shaft; 2 - O-ring; 3 - mechanical sealing element; 4 - bearing; 5 - spherical joint; 6 - piston; 7 - piston bloc; 8 - central shaft; 9 - pump shell; 10 - disc.

a.

b.

Figure 24 Pumps: a-gear pump; b-axial piston fixed pump [9].

6. CONCLUSIONS

Hydraulic pumps in hydrostatic installations are focused on performance, productivity and profitability for various applications ranging from mobile to industrial, mining, oil or gas extraction. This meets the market requirements for higher speed, improved performance, more precise control, reduced noise and flexibility.

In order to develop the design and design of some products, numerous systems of 2D and 3D graphical representation of information have emerged in a virtual environment.

These software applications are also used to model CAD hydraulic pumps, some of which are dedicated or generalized - *Autodesk Inventor, Pro/ENGINEER, NX Siemens, CATIA*, etc. The advantage of 3D modelling of the axial piston pump, as well as the gear pump, is that they can be optimised in terms of geometric and constructive parameters or design before being physically achieved.

From the analysis of the calculation of the working parameters, the following conclusions can be drawn:
- the flow of the fluid spread through pumps depends on their speed, i.e. the volume of fluid, increasing with the increase in speed, respectively, volume;
- the pump's driving moment is dependent on the value of the operating pressure and volume, increasing with their increase;
- the power is dependent on the values of the pressure and the working flow, increasing in direct ratio to their increase.

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