Fluid Flow within a Hydrostatic Lobe Pump

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Abstract: *It is obvious that the current technological development has solved the various problems related to the working tasks accomplishment in the various industry fields using hydrostatic drive mainly due to the advantages presented in comparison with other operating systems. The hydrostatic drive system is currently used in most industrial branches for transmitting energy between the source and the working body with remarkable results. The operation of the hydrostatic actuation system involves a working circuit, with the active components represented by fluid circulation pumps, the fluid distributors, the flow rate and pressure regulating device in the circuit, but also the working motors for certain equipment to be driven. The primary component of the hydrostatic circuit is represented by the pump with constructive and functional characteristics that define the drive system type used for a particular application in the industry. A model of hydrostatic lobe pump volumetric unit is presented in this paper. The constructive and functional principle is presented and for an exemplification of the operating principle a fluid flow analysis is performed on the virtual model of the unit using the ANSYS CFX program. The numerical liquid flow analysis is mainly used in order to highlight the primary flow parameter values involved in the volumetric unit operation within a hydrostatic working circuit.*

Keywords*: Fluid flow, volumetric unit, lobe pump, three-dimensional modelling, CFD*

1. Introduction

The sustained development in the field of science and technology in the last decades has been achieved thanks to the demands imposed by the human society to continuously create and improve the increasingly performing machines and equipment that have been used in the various branches of industry.
The drive systems introduced in the equipment of the machinery used in industry are representing their energy component due to the fact that through them the transmission of the necessary energy for the fulfillment of the working principle of the machine is ensured.
There is today a variety of machinery and equipment used in industry branches which through the specific drive component performs the energy transfer from the source to a working body according to the information transmitted by the operator so that the technological characteristic originally imposed for the working equipment is ensured.
All the drive systems currently in use have been upgraded over time in order to reduce the losses and increase in operating efficiency aproaching to the ideal drive concept.
It is presented the hydrostatic actuation model which represents an indirect actuation type which has the possibility to take the mechanical energy in the form of force (displacement or torque), angular displacement and transmits it to the working body in the same form but with successive conversions within the actuation system as fluid volume and working pressure.
The hydrostatic drive system incorporates all the functions and components necessary for the energy transmission between the energy source and the workpiece of the driven machine.
The primary component of the circuit is represented by a pump that is connected to the thermal or electric motor of the machine and the secondary component is represented by the operator's drive motor. The engine has all the functions and components involved in the information transmission represented by control, adjustment and automation systems.
The model of a lobe pump from a constructive and functional point of view is analyzed in this paper.

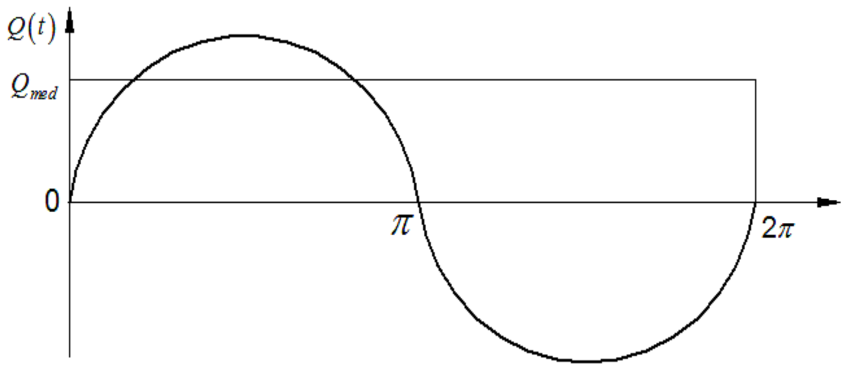
2. Volumetric unit principal characteristics

The hydrostatic actuating system has as a particular feature the circulation of the working fluid inside a circuit in order to drive different technological equipment. The energy amount converted

by means of the working fluid is represented by the volumetric flow rate and hydrostatic pressure parameters.
The primary component of the hydrostatic circuit is represented by the drive pump and the engine considered as volumetric drives for working fluid.
For a volumetric unit, the general characteristic is the volume or cylinder capacity describing the volume of working fluid delivered at a complete rotation of the drive shaft with a zero-pressure difference between suction and discharge.
By evaluating in time, the mode of variation of the momentum volume of fluid delivered by a volumetric unit under ideal conditions it can be written the relation: 0

$$Q(t) = \frac{d}{dt}(V) = A_p \frac{dx}{dt}$$
$$\frac{dx}{dt} = r\omega \sin \omega t \qquad (1)$$
$$Q(t) = A_p r\omega \sin \omega t$$

where: $Q(t)$ represents the pump volumetric flow rate.



The graph of the variation of the instantaneous fluid flow rate transmitted by the drive system pump for a complete drive shaft rotation is shown. The main operating phases of the pump are represented by the discharge or circulation of the fluid in the circuit for the interval between $(0,\pi)$ and the suction phase for the interval between $(\pi,2\pi)$ where the instantaneous fluid flow rate is being absorbed from the tank.
On the interval corresponding to a complete rotation of the pump shaft with the rotation angle $\theta \in (0,2\pi)$, the unit volumes displace a flow rate of working fluid described by the relations: 0

$$2\pi Q_{med} = \left| \int_0^{2\pi} Q(t)\, dt \right| \qquad (2)$$

$$Q_{med} = 2A_p r \frac{\omega}{2\pi} = V_{cp} \frac{\omega}{2\pi} \qquad (3)$$

The relationship highlights the dependence between the theoretical average of fluid flow rates discharged by the drive pump with volume and the angular velocity at the pump shaft. The relation does not take into account the volume losses of the pump.
From an energetic point of view, at a complete rotation of the pump shaft (P) the value of the average energy (E_m) at the volumetric unit axis can be described by the relations: 0

$$dE = p\,dV$$
$$dV = A_p\,dx$$
$$dx = r\sin\alpha\,d\alpha \qquad (4)$$
$$dE = p\,A_p\,r\sin\alpha\,d\alpha$$

By integrating to a complete rotation of the pump shaft the medium energy relation to the pump shaft is obtained: 0

$$E_{med} = \int_0^{2\pi} dE = p\,A_p\,r\int_0^{\pi}\sin\alpha\,d\alpha \qquad (5)$$
$$E_{med} = p\,(2rA_p) = V_g\,p$$

The ratio of average energy to the pump shaft reveals under theoretical conditions the proportional dependence between the value of the average energy and the pressure in the system, and the proportional factor is even the cylinder capacity of the pump.
Extending elemental energy according to the required mean torque at the pump shaft, for a complete revolution of the pump shaft results: 0

$$dE = M_{med}\,d\alpha \qquad (6)$$
$$E_{med} = 2\pi M_{med}$$

The relation for the medium moment in theoretical value can be written at a complete rotation of the pump shaft as follows: 0

$$M_{med} = \frac{1}{2\pi} V_g\,p \qquad (7)$$

The proportional dependence between the value of the mean moment at a complete rotation of the pump shaft and the pressure in the drive system, depending on the pump stroke and the value of the axis of rotation of the axle, can be observed.
For an angular velocity in constant value $(\omega = ct)$ the theoretical value of the mean power to the pump shaft is obtained: 00

$$M_{med}\,\omega = \frac{1}{2\pi} V_g\,p\,\omega \qquad (8)$$

$$N_{real} = M_{real} \cdot \Omega_{real} \quad (9)$$

The value of the required theoretical average power to the pump shaft is directly proportional to the value of the fluid pressure inside the actuation system and the proportionality factor is the value of the average flow rate of the pump in the working circuit.

3. Rotary lobe pump volumetric unit

Rotary lobe pumps belong to the group of rotating positive displacement pumps.
Pump constructive solution is accomplished by arranging two lobe rotors inside a casing.
The constructive particularity is ensured by the fact that the lobes have permanent contact with the housing or with the complementary rotor lobe. The working chambers that are necessary for the operation of the pump are delimitedin this manner.
In order to synchronize the relative position of the two rotors and to precisely delineate the working chambers required for the two suction and discharge phases, toothed wheels are used. 0

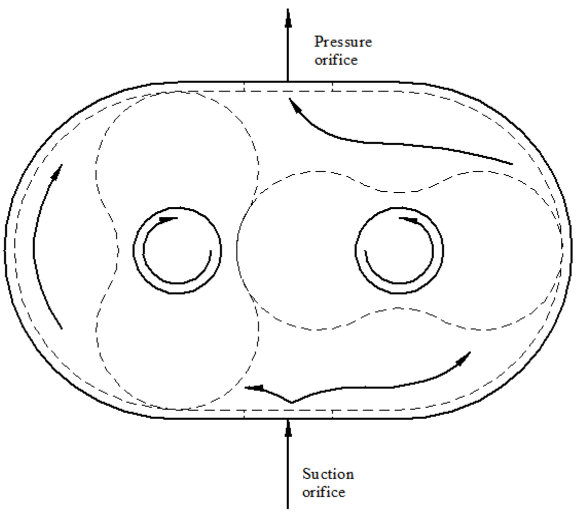


Fig. 1. Lobe pump operation principle

The lobe pump present a compact design ad high performance in fluid circulation.
These pump types are used to continuous convey and dose diferent fluids in relation with to special velocity values.
Following rotor rotation, the fluid is captured from the suction area and sent to the discharge port through the space between the lobes and the housing.
Circulation is provided along the walls of the casing and through the gear made between the two lobes a permanent seal is provided between the two low pressure pump zones and the high pressure zone corresponding to the pressure port area.
The lobe pump has a compact design and high performance in fluid circulation. These pump types are used to continuously transport and deliver different fluids in relation to special rate values.
The pump rotors motion causes a negative pressure at the suction orifice where the fluid is absorbed and circulated along the casing walls to the pressure orifice.
The rotary lobe pumps are equally suitable for low and high-viscous fluid mediums.
Due to their relative large spaces for fluid passage and low rotational velocity they are relatively tolerant to blockage due to solid particles within the circulated fluid.
The lobe pump performance capacity is in higher value relative to many other positive displacement pumps of the same constructive type.
At higher working pressure values over 80 bar these pump types present lower operating efficiency.

These pump types are generally used in auxiliary lubrication systems, but also for the transport and dosing of liquids.

4. Fluid flow aspects within lobe pump virtual model

In order to highlight certain operating aspects of the lobe pump volumetric unit, it is necessary to perform a fluid flow analysis on the virtual model of the lobe pump assembly.
A three-dimensional assembly model was developed and introduced into the analysis made with the Ansys CFX program.
The imported model is shown in the figure 2.

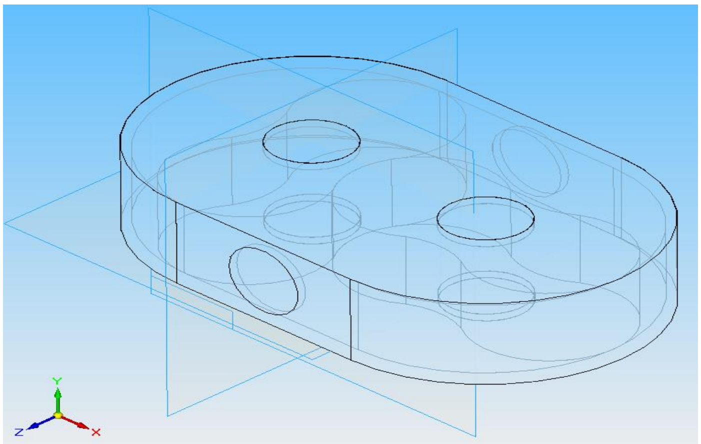
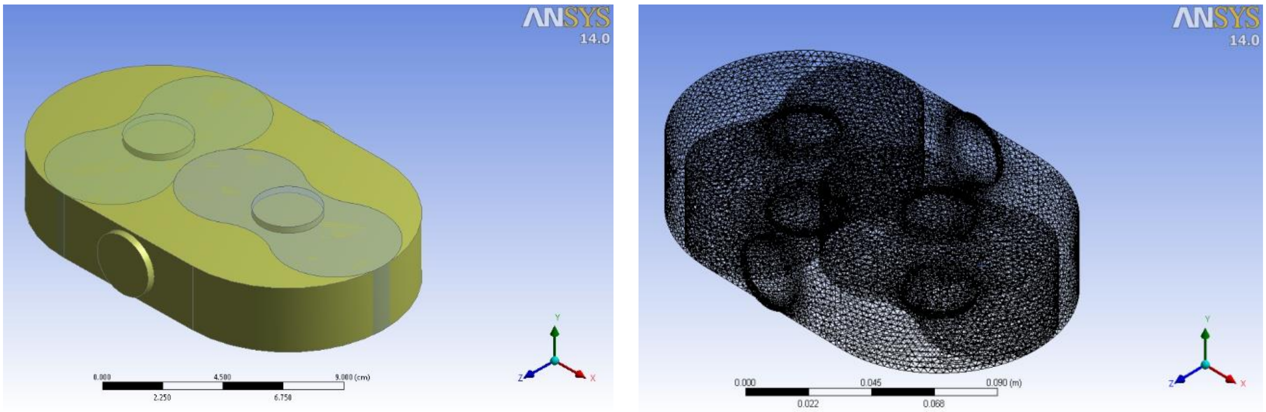


Fig. 2. Lobe pump functional model assembly

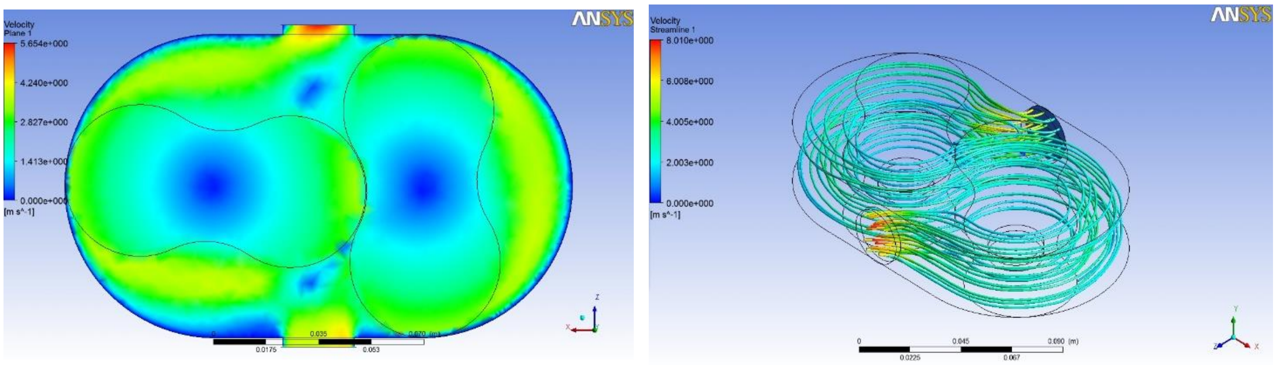


a) imported model b) mesh network of triangular elements

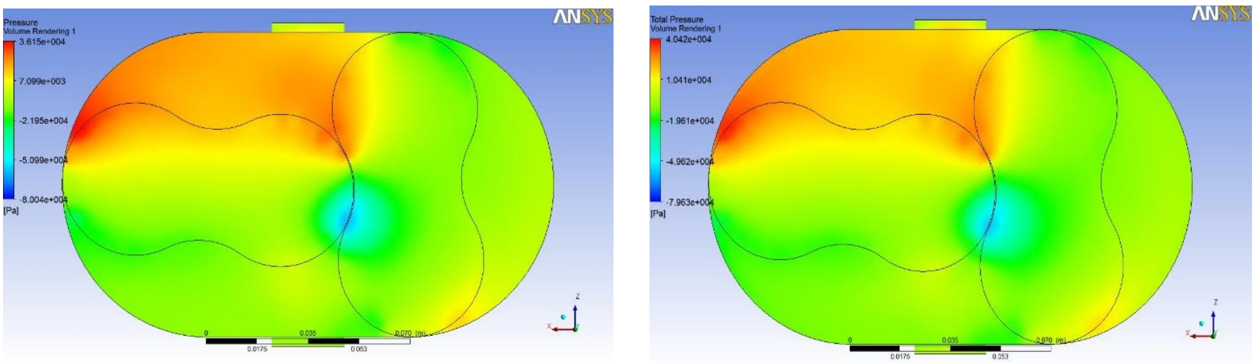
Fig. 3. Three-dimensional assembly model taken into consideration for flow analysis

The operating principle for this volumetric unit is based on the rotational motion of the two rotors which engage the fluid in motion along the casing wall. The pressure at the inlet it is at low values while for the outlet orifice is ensured the requisite pressure values.
The flow rate values of liquid circulation are according with the volumetric capacity at a single rotation of pump shaft.
The declared initial values for the liquid flow analysis within the lobe pump are as total pressure (stable) for the inlet port at 1 at and the axial motion of the lobes positioned inside the pump casing declared as immersed solid, material steel.
The flow analysis main domains of the considered model are represented by the fluid region and the two lobes which are in continuous engagement keeping the permanent contact in the center of the fluid region thereby preventing the liquid leaking back towards the inlet region.

The mesh network was made with triangular shape elements, with 77293 nodes and 246811 elements.
The working fluid is represented by mineral oil at 25 degrees Celsius with the shear stress transport turbulence option for the fluid region.
The analysed fluid model has an inlet port for the working fluid and one outlet. According with the initial has been declared conditions of lobe rotational motion with a velocity of 11 rev/s.
The liquid is taken from the inlet port and circulated along the outer walls to the outlet orifice.
The results are presented in terms of pressure and fluid velocity values registered at the level of analysed fluid region (figure 4).



a) Fluid velocity values

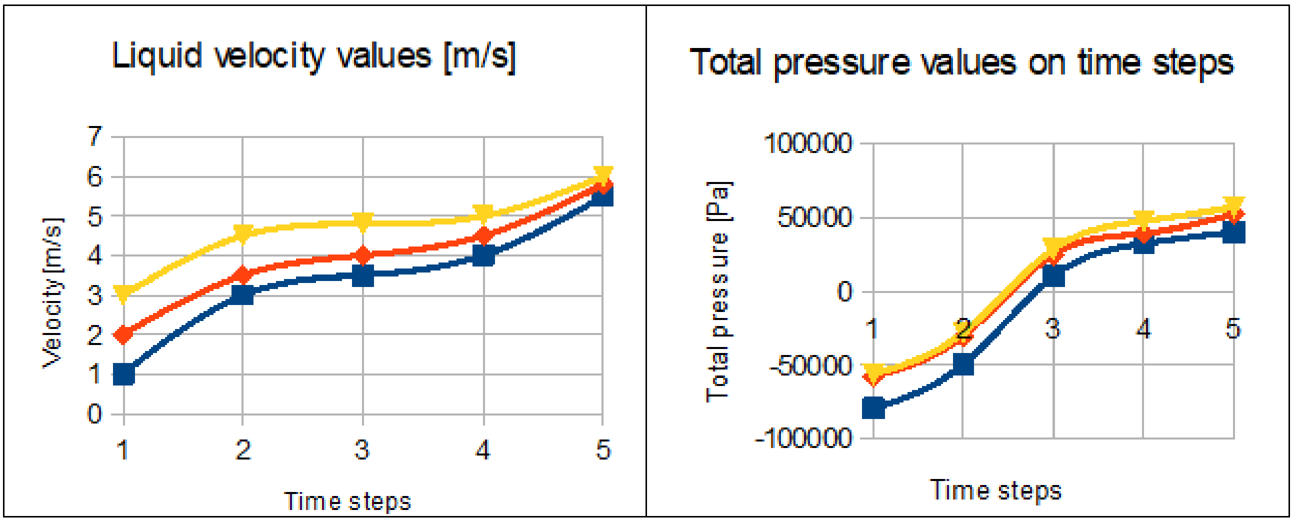


b) Pressure values

Fig. 4. The flow analysis obtained result values

Due to the lobes rotation it is observed on the results obtained the overall operation of the volumetric unit which is of sequential type of liquid transport according to the relative position of the driven rotors.
A low pressure (depression) value is recorded for the fluid area corresponding to the fluid inlet or intake within the analyzed housing or fluid region, which is explicable for the external fluid pickup area through the intake port.
As the fluid is shifted radially along the housing walls, higher pressure values are recorded up to the maximum values corresponding to the volume output region of the volumetric unit for each zone of the lobe that drives the liquid to the outlet.
Velocity values are characteristic of the route followed by the liquid on the analyzed region and are obtained as a result of the specific rotation motion of the drive rotors.
The diagrams for the pressure and velocity values recorded for the liquid flow analysis time steps on the analyzed model are shown in Table 1.

Table 1: The result values obtained from the flow analysis



5. Conclusions

It is obvious that the hydraulic systems has gained great importance over time due to the advantages it has in the practice of actuating the work equipment that belongs to the machinery and industry equipment.
This energy transmission system type has benefited from the continuous upgrading of the devices that are used and here are included the volumetric units for operating the working fluid within the circuit drive.
Such a constructive solution is the lobe pump as volumetric unit whose principle of operation is described in this work.
The three-dimensional model required for the operation is built and analyzed from the point of view of the working fluid movement, depending on the rotation movement of the rotors that provide the driving force inside the casing.
The results are presented in terms of pressure and velocity for the analyzed fluid region.
The fluid volumes with specific values depending on the rotors position are being highlighted.
On the basis of the obtained results optimized solutions can be made regarding the design of the rotors in order to obtain the increase in terms of operation efficiency for these constructive units of volumetric units.

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