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# THE USE OF NUMERICAL ANALYSIS IN ORDER TO HIGHLIGHT THE FLUID DYNAMICS INSIDE A HYDRAULIC GEAR PUMP MODEL

***Abstract:*** *An experimental method for the investigation of hydraulic fluid flow inside a gear pump model was performed during this study. The external gear pump model was chosen because this volumetric unit is capable to take over the fluid at atmospheric pressure at the inlet, to carry it through tooth gaps on the external walls and convey it further to the outlet at high pressure values. This volumetric unit type is the most commonly used in hydraulic medium power actuation because it shows a reduced complexity, a high reliability and easy maintenance in use. Due to specific structural solution, a gear pump transmits a constant fluid flow rate into circuit. This computational research will be used as an experimental method to study the fluid flow phenomenon inside different volumetric models used in the field of industrial hydraulic actuation.*

***Key words:*** *gear pump, hydraulic unit device, flow simulation.*

## 1. INTRODUCTION

The hydraulic actuations have acquired increasingly more importance over time due to multiple advantages presented in relation to mechanical or electrical systems.

Hydraulic volumetric units allow placement in any position inside power machines and this represent a major advantage compared to mechanical transmissions, greatly simplifying machine working design.

Small dimensioned hydraulic volumetric units have the ability to transmit large forces and moments and to adjust continuously the velocity during operation or maintaining it constant.

Hydraulic gear units are capable of transforming mechanical energy received from a source of energy (thermal or electric motor) into hydrostatic energy transmitted through working fluid as pressure and flow rate.

Due to simple constructive solutions these types of hydraulic units are widely used in industry, as part of hydrostatic circuits at agricultural and construction machinery, machine tools or for driving various types of fluids.

Gear pumps are used in all types of industrial applications for the circulation of both viscous and less viscous fluids because they have a rugged construction offering a high operating reliability and long life.

## 2. MATHEMATICAL CALCULATION RELATIONSHIPS

The hydraulic actuation use pressure forces for energy transmission made in a less compressible fluid called working agent or hydraulic agent.

General computational relations used to choose the pump type inside a hydraulic circuit are presented as follows [9]:

Flow pressure P = 0;

$$Q_0 = \frac{1}{1000} V_0 n \; [l/min] \tag{1}$$

Nominal flow rate:

$$Q_n = Q_0 \eta \; [l/min] \tag{2}$$

Power consumption at effective pressure $P_{ef}$ :

$$N = \frac{1}{600} \frac{Q_0 P_{ef}}{\eta} \; [kW] \tag{3}$$

The driving moment at effective pressure $P_{ef}$ :

$$M = \frac{1}{60} \frac{V_0 P_{ef}}{\eta} \tag{4}$$

where:

$V_0$ - geometric volume;

$P_{ef}$ - effective pressure;

$n$ - rotation speed;

$\eta$ - efficiency %;

## 3. EXTERNAL GEAR PUMP MATEMATICAL MODELLING

Gear pumps are robust hydraulic units, provides constant flow rates, can circulate high viscosity as well as low viscosity fluids, works with high pressure values and they can be self-aspirant.

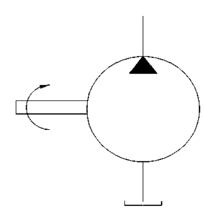


**Fig. 1** Hydraulic gear pump symbolization

In figure 1 the corresponding symbol of a gear pump with external gearing is shown according to STAS 7145/86.

A hydraulic external gear unit is composed of two gear wheels placed in a hermetically sealed enclosure.

One of the wheels is declared conductive due to her connection with the engine drive shaft and through the gear manages to involve in motion the second wheel declared conducted.

The working fluid enters through the inlet orifice inside the hydraulic unit under the effect of atmospheric pressure, filling the spaces between the teeth, being then taken up and directed on wheel radial direction to the outlet port.

The driving torque is received at the drive shaft level and can be achieved through other gear, chain or belt transmission.

Mounting in the installation is usually done using flange assembly and rotation of the hydraulic unit must be correlated with the motor rotation.

An external gear pump achieves flow rates of up to 1500 l/min and pressures up to 300 bars. It is used as engine only in rare cases due to reduced torque it develops.

In figure 2 is schematically represented the principle of operation for an external gear pump hydraulic unit.

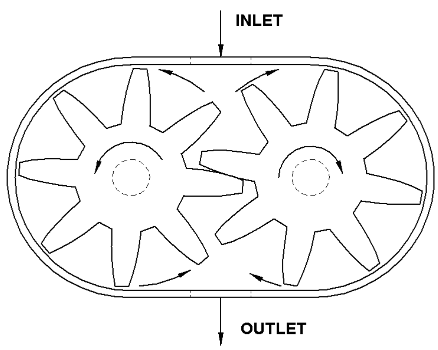



**Fig. 2** Schematically representation for external gear pump principle of operation

There are two regions with different values of pressure, bounded by teeth contact line. The constant contact line provides a good isolation between the two areas so that fluid can not enter from the high pressure outlet to low pressure region from inlet.

A portion of the transported fluid to the discharge area is brought into the suction during the wheels rotation, because the spaces between the teeth are greater than teeth.

A hydraulic volumetric unit with external gearing wheels can work both as pump as well as a hydraulic motor can be considered as a reversible unit.

The main characteristic of such units it is represented by volumetric capacity. The relationship between volumetric capacity and constructive dimensions for gear pump is the following [1]:

$$V_0 = 4\pi rbh \tag{5}$$

$$V_0 = 2mzbh \tag{6}$$

where:

$V_0$ – volumetric capacity;

$r$ - teeth average radius;

$b$ - teeth width;

$h$ - teeth height;

$m$ – modulus;

$z$ - teeth number.

The dynamic model of a gear pump must consider the maximum amount of circulated fluid, the maximum pressure values, maximum angular velocity and the nature of the circulated hydraulic fluid and its filtering smoothness.

In order to achieve a model of the dynamic behavior of a gear pump is necessary to establish the momentary flow rate equation for the amount of circulated fluid calculated at outlet region, but also the equation of motion for the elements involved in gear pump operation.

This simplified model can be presented as the following equations [3]:

$$Q_p = \frac{1}{2\pi}\omega - \Delta Q_{tp} \tag{7}$$

$$J_p \frac{d\omega}{dt} = M_p - \Delta M_p \tag{8}$$

where:

$Q_p$ - flow rate;

$\Delta Q_{tp}$ - hydraulic fluid losses;

$\omega$ - angular velocity;

$J_p$ - moment of inertia;

$M_p$ - active moment applied to the hydraulic unit shaft;

$\Delta M_p$ - torque total losses.

The presented equations form a multi-polar dynamic model for a hydraulic gear pump unit that highlights the input and output operation parameters of the component.

## 4. CFD ANALYSIS RESULTS

The gear pumps can be modeled as a fluid flow source since they actuate in motion the working fluid using gears. Through this behavior it is achieved a continuous fluid flow between the inlet region of small pressure while the outlet pressure values are high according to the encountered resistance that fluid had to pass inside the hydraulic circuit.

Gear pumps are considered as hydraulic generators inside hydrostatic circuits. The main characteristic is represented by a constant geometric volume and unique driving direction. The fluid flow velocity at the inlet can be achieved up to *2.5 [m/s]*. For this case the gear pump can work in a continuous mode with an intake pressure value between *0.2* and *0.5 [bar]* and a discharge pressure according to defining characteristics and standard dimensions [11].

A simplified three-dimensional model assembly for gear pump with external gearing was designed using Solid Edge V20 software presented in figure 3.

The three dimensional model was launched in a CFD analysis using FLOWIZARD software from ANSYS to highlight the working fluid flow inside the pump body being driven by the moving parts of the pump namely the toothed wheels.

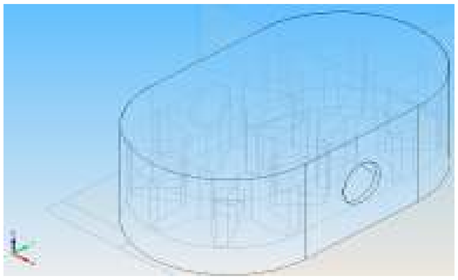


**Fig. 3** The three-dimensional simplified model for gear pump hydraulic unit

The working fluid used is a glycerin having a density of $1259.9\left[kg/m^3\right]$ and a viscosity of $0.799\left[kg/ms\right]$.

The imported model dimensions in *[mm]* of the gear pump are given in figure 4 and the mesh information for this model are presented in figure 5.

## File Import

| File Name | Dimensions |
|---|---|
| PRD 1905.stp | 66.0 x 114.0 x 40.0 mm |

**Fig. 4** Three-dimensional model dimensions

## Mesh Information

| Variable | Value |
|---|---|
| Mesh type | Tetrahedral mesh |
| Total number of cells | 29745 |
| Tetrahedral cells | 29745 |

**Fig. 5** Mesh type information

A meshing network was made for the imported assembly model of tetrahedral form, with a number of 29745 cells.

For the geared wheels inside the body was imposed a rotational motion which simulates the hydraulic unit operation that is able to take over the fluid at the inlet with a small pressure value and convey it along the walls to the outlet at high pressure value.

In order to achieve an operation simulation of a volumetric external gear they were declared the initial conditions:

- it have been declared intake and discharge regions of the pump model as inlet and outlet;
- at the pump inlet region the pressure value was set at atmospheric pressure $\left(p_a = 101325\,[Pa]\right)$;
- was declared the moving elements as rotating gears inside the pump body with a value of angular velocity.

Between the inlet and outlet regions it was declared a single continuous fluid region surrounding the gear wheels which drives the fluid in motion. Within this fluid region that represents the volumetric capacity of the gear pump the program performs the analysis of motion parameters.

The analysis results are presented in figure 7 in terms of total and static pressure, velocity magnitude on regions, turbulence kinetic energy and dissipation rate recorded inside the model as the volumetric space containing the working fluid.

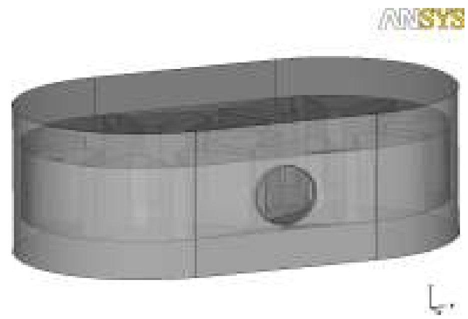
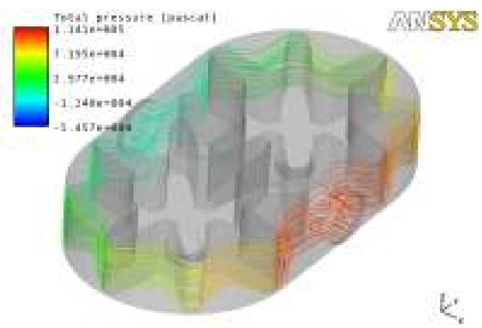
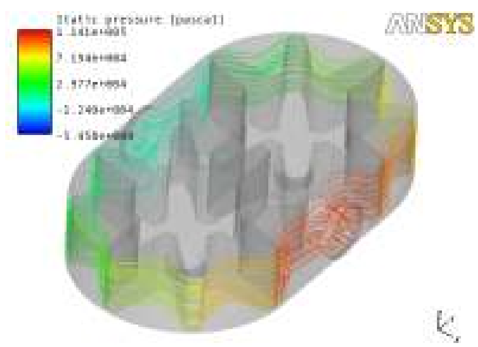


**Fig. 6** ANSYS FLOWIZARD import model



a). Total pressure within fluid region

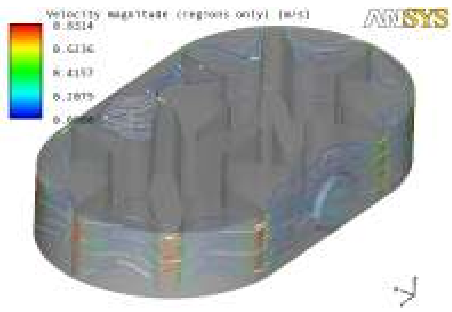


b). Static pressure within fluid region

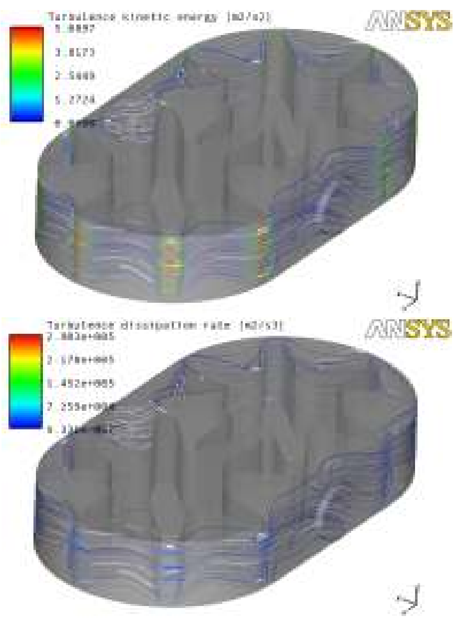
As expected, the analysis confirms the pathway for the working fluid within the model body. The fluid is taken over from inlet zone where is recorded a value for static pressure of *-54580 [Pa]* and transported by the wheels in the radial direction along walls to the discharge zone at the outlet where the value for static pressure is about *114100 [Pa]* (figure 7 a, b).

It is demonstrated the positive displacement character for the gear pump model, by fluid movement using the wheel rotation which create vacuum at the inlet region, capturing in this way the working fluid and convey it to the outlet region at high pressure values.

Due to the permanent contact between wheel teeth the fluid can not circulate back assuring a continuous working cycle for the gear pump without big losses.



c). Velocity magnitude information



d). Turbulence dissipation rate information

**Fig. 7** Model analysis results

In figure 7c are presented the recorded values for fluid velocity on regions, while in figure 7d are the values for turbulence kinetic energy and dissipation rate.

## 5. CONCLUSIONS

The volumetric hydraulic units pump type represents power machines that convert mechanical energy received from a power supply into hydrostatic energy that is taken up by fluid and used in hydraulic actuation systems.

Usually, for hydraulic actuation systems, energy transmission between the power source and working body is accomplished by applying impulse or pressure forces applied on a less compressible fluid like mineral oil or other fluids with special viscosity properties.

The actuations using momentum forces for energy transmission are considered hydrodynamic drives, while the actuations that use pressure forces are considered hydrostatic drives.

The hydraulic gear units are part of hydrostatic units group because they make use of pressure forces applied to the working fluid. Gear pumps are generally used in circulating of hydraulic fluid capable to maintain the viscosity characteristics during operation. The optimal functioning is within a viscosity range of *25-100 [cSt]* and the operating temperature ranges from *-10* up to $80\left[{}^{\circ}C\right]$. The gear pumps can be optionally equipped with flow rate controllers and pressure regulators.

A numerical CFD analysis was performed on a gear pump three-dimensional model. It was established a rotation motion of the wheels inside the model containing the fluid region. The results show the functionality of this volumetric unit capable of taking fluid at low pressure and send it further into circuit at higher values depending on the needs within the hydrostatic circuit.

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