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Simulation and Improvement of Hydraulic Systems with FluidSim

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Abstract: *The paper presents the importance of the hydraulic systems. The article contains material on the study of the basics of hydraulics: Pascal's law, Navier-Stokes equation and Darcy-Weisbach relationship. Besides, in this article we present two hydraulic circuits. In fact, the design and simulation of these circuits are prepared in the FluidSim software from Festo. Thus, the first hydraulic circuit is composed of the following devices: pump, tank, two throttle valves, 4/2-way hand-level valve and double acting cylinder (Doa 1). The second hydraulic circuit is composed of the following parts: pump unit, two non-return valves, 2-way flow control valve, 4/3-way solenoid valve and double acting cylinder (Doa 2).*

Keywords: *System, Pascal, equation, hydraulic, tank*

1. Introduction

Hydraulic systems are utilized in various applications to convey force by utilizing pressurized oil. Depending on the mode of operation, hydraulic systems are divided into two main categories:

- Open hydraulic systems: After each cycle, the oil is returned to the reservoir, which is utilized in applications where fine control of movement is not necessary.
- Closed hydraulic systems: The oil circulates in a continuous circuit, being ideal for applications that require high precision.

In difficult conditions (e.g. great depths), some hydraulic systems are very complex [1].
Such as using the hydraulic system to operate the arms of an ROV (Remotely Operated Vehicle), Fig. 1.

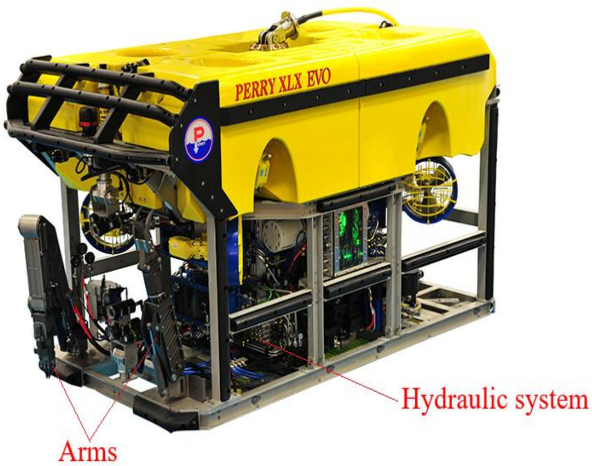

Fig. 1. ROV with arms and a hydraulic system

The basic components of a hydraulic system are:
a) The tank - serves to store the oil to ensure proper functioning of the hydraulic system.
b) The hydraulic pump - is a device that has the ability to convert mechanical energy into hydraulic energy.

c) The hydraulic filter - the purpose of this is to preserve and purify the oil before it is has been used by the system.
d) The hydraulic cylinder - is a device that transforms hydraulic energy into mechanical energy by moving a piston.
e) Hydraulic pipes - are essential elements of a hydraulic system, as they have the role of transporting the oil between the various components of the system, such as: pumps, actuators and tanks.
f) Valves - are devices that allow the pressure, flow and direction of the oil to be controlled.
The design and simulation of the hydraulic systems in the work is carried out in the FluidSim program from Festo.

2. The study of hydraulic systems

Hydraulic systems can be simulated using specialized software (e.g. FluidSim) to study their behavior, detect and repair any defects.
Most often, hydraulic systems are being used in applications where high power demand and fast response are required.
Theoretically, any hydraulic system uses Pascal's Law. That is, pressure applied anywhere on the surface of a body of fluid in a hydraulic installation causes a force to be transmitted equally in all directions and the force acts at right angles to any surface in contact with the fluid.
The principle of fluid pressure transmission (Pascal's Law), can be formulated mathematically as follows:

$$\Delta p = \Delta h \cdot \rho \cdot g \tag{1}$$

Where:
- Δp - hydrostatic pressure.
- Δh – height of the fluid above the measuring point.
- ρ – fluid density.
- g – gravitational acceleration (9.81 m/s^2).

A set of equations that best characterizes the flow of a fluid in a hydraulic system is the Navier-Stokes relation [2]:

$$\bar{F} + \frac{\upsilon}{3}\nabla(\nabla\bar{v})\frac{\eta}{\rho}\Delta\bar{v} - \frac{1}{\rho}\nabla p = \frac{d\bar{v}}{dt} \tag{2}$$

And the scalar form of the Navier-Stokes equation is:

$$F_x - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\upsilon}{3}\frac{\partial\theta}{\partial x} + \upsilon\left(\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right) = \frac{\partial v_x}{\partial t} + \frac{\partial v_x}{\partial x}v_x + \frac{\partial v_x}{\partial y}v_y + \frac{\partial v_x}{\partial z}v_z \tag{3}$$

$$F_y - \frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{\upsilon}{3}\frac{\partial\theta}{\partial y} + \upsilon\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right) = \frac{\partial v_y}{\partial t} + \frac{\partial v_y}{\partial x}v_x + \frac{\partial v_y}{\partial y}v_y + \frac{\partial v_y}{\partial z}v_z \tag{4}$$

$$F_z - \frac{1}{\rho}\frac{\partial p}{\partial z} + \frac{\upsilon}{3}\frac{\partial\theta}{\partial z} + \upsilon\left(\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right) = \frac{\partial v_z}{\partial t} + \frac{\partial v_z}{\partial x}v_x + \frac{\partial v_z}{\partial y}v_y + \frac{\partial v_z}{\partial z}v_z \tag{5}$$

Hydraulic fluids are used in hydraulic systems for power transmission, component lubrication, corrosion protection, and heat dissipation. In practice, the oil is most commonly used as a hydraulic fluid.
A fundamental equation in hydraulic fluid dynamics is the Darcy-Weisbach equation:

$$h_f = \frac{L \cdot v^2 \cdot f_D}{2g \cdot D} \tag{6}$$

Where:
- L – pipe length.
- v – fluid velocity.
- f – Darcy friction factor.
- v – fluid velocity.
- D – internal diameter of the pipe.
- g – gravitational acceleration (9.81 m/s^2).

In fact, the Darcy-Weisbach equation calculates the pressure loss due to friction in the flow of fluid through the pipes of the hydraulic system [3].
The first hydraulic system in this work is simple, Fig. 1.

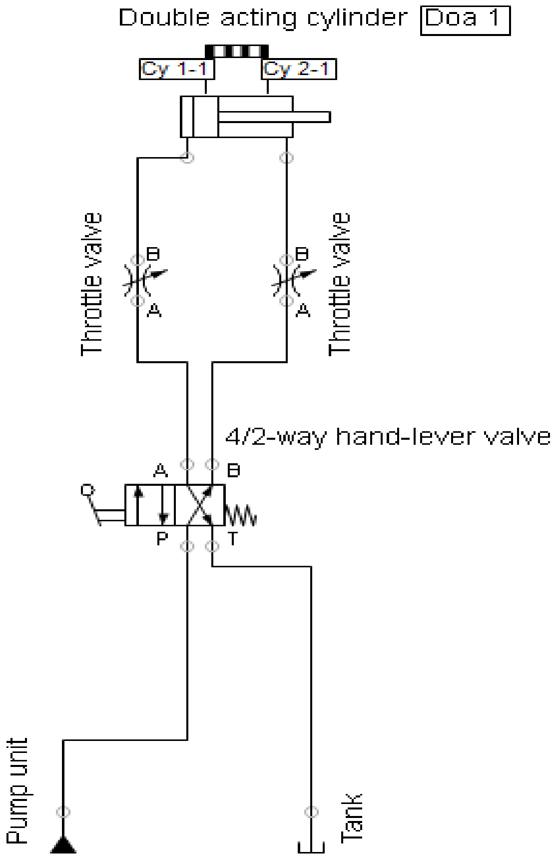

Fig. 2. Simple hydraulic system

The first system hydraulic in the work consists of six devices, which are presented in the table below [4].

Table 1: Devices of the first hydraulic scheme

Description	Number of components
Pump unit	1
Tank	1
Throttle valves	2
4/2-way hand-lever valve	1
Double acting cylinder (Doa 1)	1

The usual parameters of the double-acting cylinder (Doa 1) in the first hydraulic installation are: position (x), velocity (v) and acceleration (a), Fig. 3.

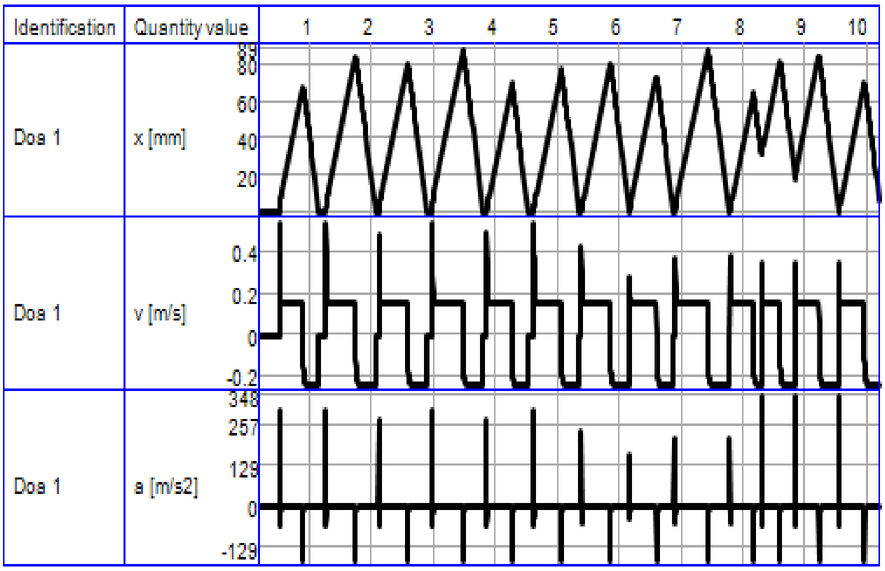

Fig. 3. Simple hydraulic system – Diagram

If the operator pushes the lever on the 4/2-way valve to the right, then the piston moves from point Cy1-1 to point Cy1-2 [5]. After that, the piston moves back because the 4/2-way valve has a spring on the right side, Fig. 4.

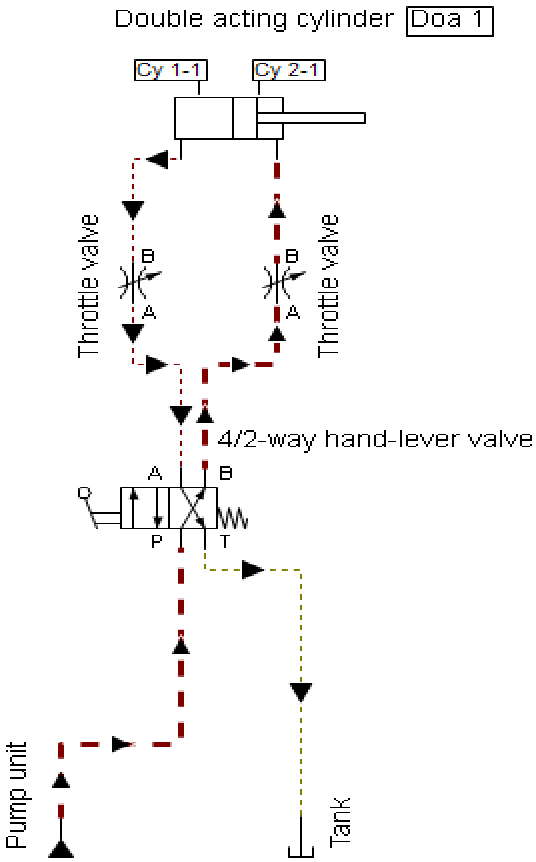

Fig. 4. Simple hydraulic system - Simulation

In this article, the second hydraulic system is more complex than the first, Fig. 5.
Since some modern devices (e.g. pressure relief valve) have been introduced [6].

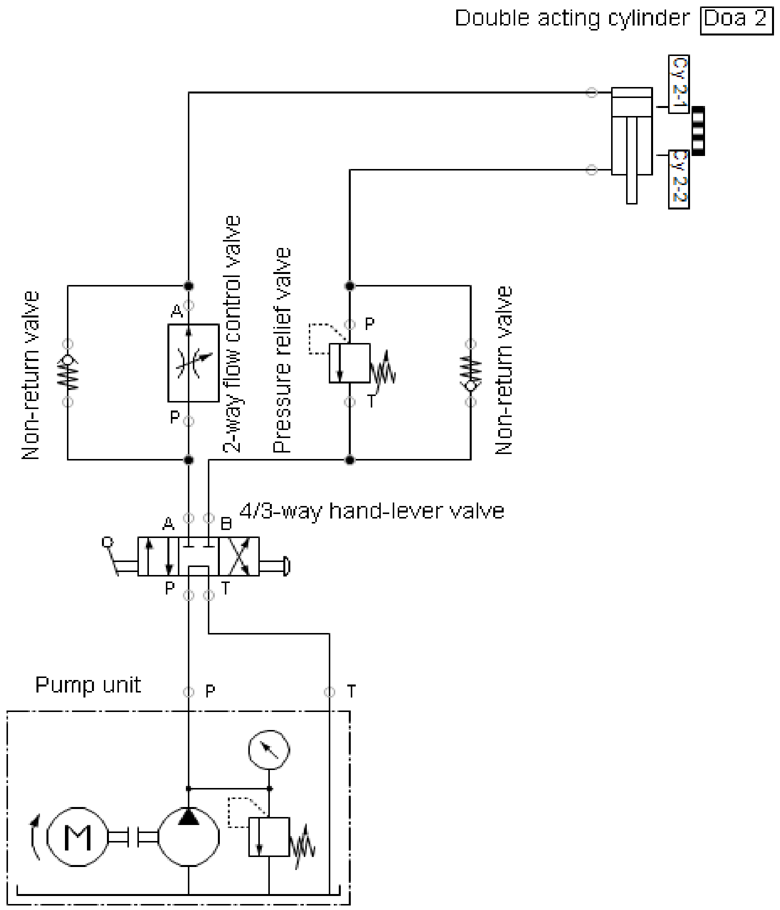

Fig. 5. Complex hydraulic system

The second hydraulic system consists of seven devices, which are presented in the table below [7].

Table 2: Devices of the second hydraulic scheme

Description	Number of components
Pump unit	1
Non-return valves	2
Pressure relief valve	1
2-way flow control valve	1
4/3-way hand-lever valve	1
Double acting cylinder (Doa 2)	1

When the operator pushes the lever of the 4/3-way (4-way, 3-position) valve manually to the right, the piston moves from point Cy 2-1 to point Cy 2-2, Fig. 6.

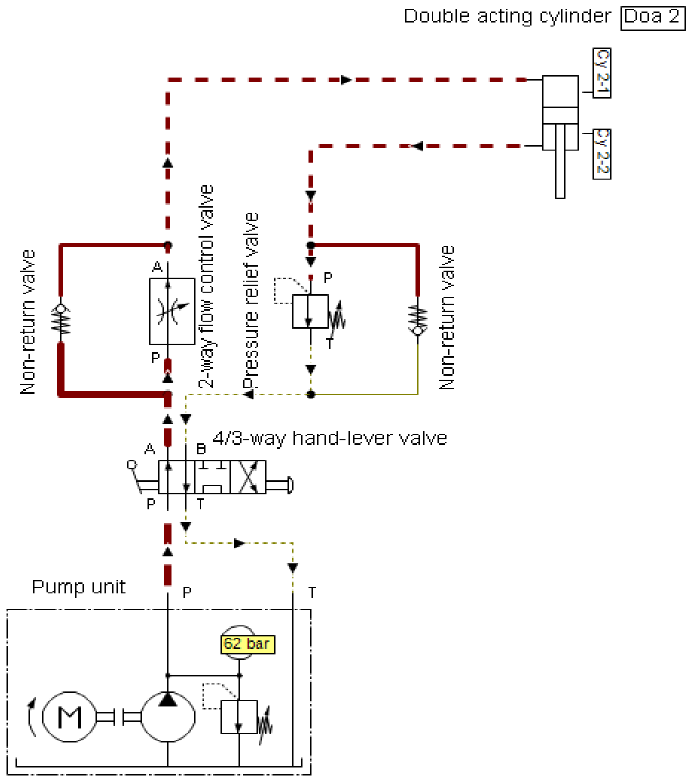

Fig. 6. Complex hydraulic system – Simulation 1

If the operator pushes button B1 of the 4/3-way valve to the left, then the piston moves back to point Cy 2-1, Fig. 7.

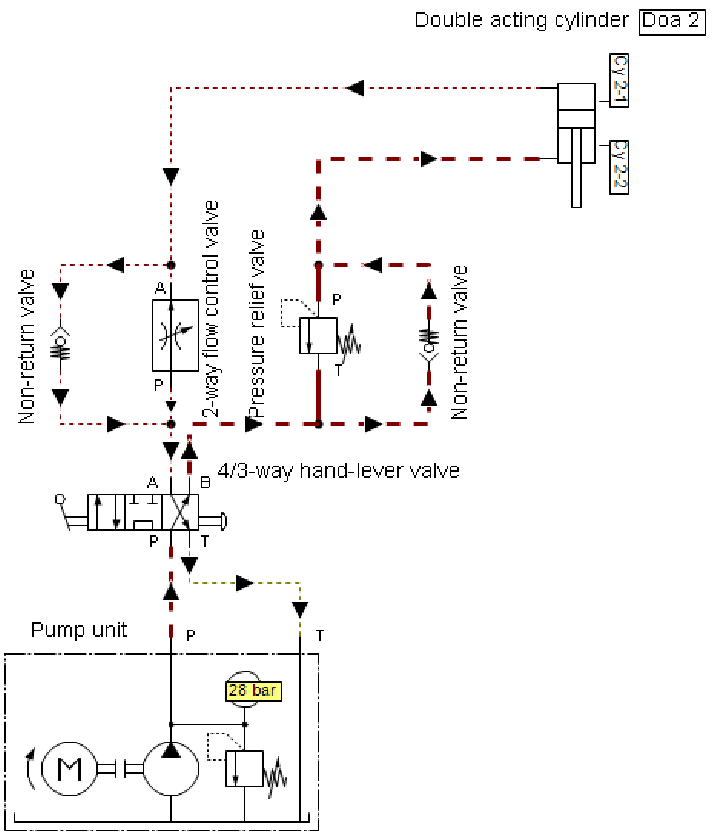

Fig. 7. Complex hydraulic system – Simulation 2

3. Conclusion

Designing and simulating hydraulic systems in FluidSim is accomplished in a relatively short time. Consequently, the FluidSim software from Festo is apply in research and education due to the following advantages of the hydraulic system:

- Small size and low weight.
- High rigidity, high precision and fast response.
- High driving force, suitable for direct driving of heavy loads.
- Offers high efficiency, long service life.

In the future, research should focus on developing more resilient and adaptive hydraulic systems designed in the FluidSim software. Moreover, modernized hydraulic systems must withstand extreme situations. By addressing these challenges and opportunities, the longevity and performance of hydraulic systems is ensured.

References

[1] Haugen, G.K., F. Conrad, and M. Grahl-Madsen. "Innovative new ROV technology utilising water hydraulics." Paper presented at the 6th JFPS International Symposium on Fluid Power, Tsukuba, Japan, November 7-10, 2005.
[2] Lohrasbi, Alireza, Moharram Dolatshahi Pirooz, and Alireza Lavaei. "Hydraulic Model of Dam Break Using Navier Stokes Equation with Arbitrary Lagrangian-Eulerian Approach." *IACSIT International Journal of Engineering and Technology* 8, no. 4 (2016): 249-253.
[3] Brown, Glenn O. "The History of the Darcy-Weisbach Equation for Pipe Flow Resistance." *Environmental and Water Resources History* (2002): 34-43. Environmental and Water Resources History Sessions at ASCE Civil Engineering Conference and Exposition 2002, Washington D.C., United States, November 3, 2002.
[4] Blejan, M., I. Dutu, I. Ilie, P. Drumea, and M. Comes. "Electronic intelligent module for a hydraulic briquetting press." Paper presented at the 31st International Spring Seminar on Electronics Technology (ISSE 2008), Budapest, Hungary, May 7-11, 2008.
[5] Slămnoiu, G., O. Radu, V. Roșca, C. Pascu, G. Surdu, E. Curcă, R.G. Damian, and A. Rădulescu. "Efficient Use of AUVs in the Maritime Environment." *IOP Conference Series: Materials Science and Engineering* 209 (2017): 012098. Paper presented at the International Conference on Innovative Research - ICIR Euroinvent 2017, Iasi, Romania, May 25–26, 2017.
[6] Scupi, A.A. "The use of numerical programs in research and academic institutions." *IOP Conference Series: Materials Science and Engineering* 145, no. 8 (2016): 082002. Paper presented at ModTech International Conference – Modern Technologies in Industrial Engineering IV, Iasi, Romania, June 15-18, 2016.
[7] Panaitescu, M., F.V. Panaitescu, and I. Voicu. "Optimizing the flow through the hydraulic installation of a port crane." *Hidraulica Magazine*, no. 4 (December 2024): 17-28.