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ANALYSIS OF A LOW-PRESSURE HYDROSTATIC DRIVE SYSTEM

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Abstract: *Hydrostatic drive systems are an important component of modern power transmission technology, using fluids to transform mechanical energy into hydraulic energy and then back into mechanical energy. These systems are valued for their ability to provide forces with high precision, for functional flexibility and for energy efficiency in various technological applications. In particular, low-pressure drive systems present significant economic and operational advantages, offering increased component durability, reduced energy losses and simplified maintenance. In this paper, a low-pressure hydrostatic drive system is analyzed, presenting the operating principles and essential elements of hydrostatic drives. The main components, such as the hydraulic pump, the directional control valve, are described, along with the energy conversion processes. A simulation is also performed using the Omegon Fluid software, which offers the possibility of configuring the main circuit parameters and analyzing the behavior of the hydrostatic system under controlled conditions. The program's graphical interface allows investigating interactions between components, evaluating response to electrical actuation, and examining system stability over pressure and flow variations.*

Keywords: *Hydrostatic system, Omegon Fluid, low-pressure, simulation*

1. Introduction

Hydrostatic drive systems are widely used in industrial, agricultural, construction or transportation applications. These systems are based on the conversion of mechanical energy into hydraulic energy and then back into mechanical energy, allowing precise control of movement, the provision of high forces and high adaptability to load variations. Unlike other types of drives, such as hydraulic drives used in industry for the circulation of fluids with high viscosity or mechanical drives, which require greater attention to the profiling of the surfaces of hydraulically driven constituent components and working at high pressures [1,2], low-pressure hydrostatic drive systems focus precisely on the optimal balance between performance, cost and reliability. They allow for reduced energy consumption, reduced internal losses, simplified construction and maintenance, while being, at the same time, safer from an operational point of view. Their applicability extends especially to agricultural equipment, low and medium power machinery, testing equipment, where working pressures (below 10 bar) are sufficient to perform functional loads [3,4].
Research in the field has highlighted an orientation towards volumetric optimization and intelligent control of hydraulic flow. Ma et al. [3] analyzed the behavior of an experimental hydrostatic system, demonstrating the importance of numerical simulation for the optimal configuration of pressure and flow parameters. In a complementary approach, Baroiu et al. [5] developed a constructive-functional

model of hydraulic filters, providing a practical basis for the analysis of pressure losses and filtration efficiency in low-pressure circuits.

The yield optimization and the reduction of energy losses in hydrostatic drives have been treated by complex dynamic models. Takosoglu et al. [4], showed that the use of variable displacement pumps can increase volumetric yield by over 15%. In parallel, the generation of progressive cavity pump screws has been studied by graphical and geometric methods, proposing constructive solutions that ensure uniform flow transmission and reduce pressure pulsations [2].

Another active area of research is that of hybrid drives and coordinated control systems, in which mechanical and hydraulic components are managed simultaneously to improve the stability and energy efficiency of the assembly. Kahandawa et al. [6] presented this concept in which hydraulic and mechanical systems act synchronously to increase the dynamic stability of vehicles. Similarly, in other research, double-acting hydraulic cylinders were analyzed, highlighting how the constructive parameters influence the dynamic behavior of the assembly in the reduced pressure regime [7].

Also, Wos et al. [8] demonstrated that forced flow regulation allows a faster reaction of the system to load variations. Similarly, Costin et al. [9] showed that pressure regulation through hydraulic control circuits ensures superior process uniformity and increased stability of operating parameters.

Developments in the field of hydrostatic system diagnostics have led to the integration of smart sensors and failure prediction algorithms. Also, some studies propose graphical models for studying the variation of operating parameters of hydraulic pumps, demonstrating the importance of correlating simulation data with experimental measurements [10,11,12].

A significant contribution towards improving performance belongs to the research on variable structures and adaptive control. Wang et al. [13] highlighted the influence of pressure on the dynamic behavior of the system and on its stability. In parallel, Berbinschi et al. [14] highlighted the importance of surface and profile modeling in the design process, a method that can be extended to the analysis of geometric elements in hydrostatic drives.

Also, Zhang et al. [15] proposed a modular drive architecture, optimized for large agricultural machinery, which uses gear pumps and proportional directional control valves for movement control. A complementary approach is found in papers [16], [17] and [18], where reverse engineering techniques are used to generate helical hydraulic drive components. This research provides a basis for evaluating functional surfaces and optimizing manufacturing processes of hydraulic transmission elements. Modern development trends are increasingly oriented towards hybrid electro-hydraulic systems. Helduser et al. [19] presented the advantages of the combination of electrical and hydraulic sources, demonstrating the possibility of reducing global energy consumption by up to 25%.

A significant contribution to the understanding and dynamic modeling of hydrostatic drives is brought by paper [20], in which the authors provide an analysis of current trends in hydrostatic system architecture, adaptive control strategies and energy efficiency optimization. The study emphasizes the fact that modern systems tend to be treated as nonlinear, self-regulating entities, in which the interaction between flow, pressure and internal losses must be analyzed simultaneously for a correct prediction of dynamic behavior.

This theoretical approach correlates with the research of Rundo [21], who proposes advanced mathematical models for simulating flow and evaluating volumetric losses in gear pumps, thus providing a solid basis for the development of control algorithms and strategies for optimizing the overall yield of hydrostatic drive systems.

Overall, research is converging towards the development of modular, energy-efficient and intelligently controlled drives, in which low-pressure is no longer a limitation, but an advantage in optimizing system performance. Thus, the analysis of a low-pressure hydrostatic drive system, performed using software tools such as Omegon Fluid, becomes a necessary step in validating theoretical models and identifying correlations between operating parameters - pressure, flow and power - under the influence of variable loads.

The paper aims to investigate these aspects through an integrated approach, which combines the constructive-functional analysis of the main components with numerical simulation and the evaluation of the system's behavior in low-pressure regime.

2. Description of the low-pressure hydrostatic drive system

Figure 1 shows the low-pressure hydrostatic drive system, used as an experimental model to highlight the operating principles of hydraulic elements under reduced pressure conditions. The system is placed on a modular platform and has the role of reproducing, in a functional way, a linear drive circuit, being composed of real components, dimensioned according to the experimental requirements.

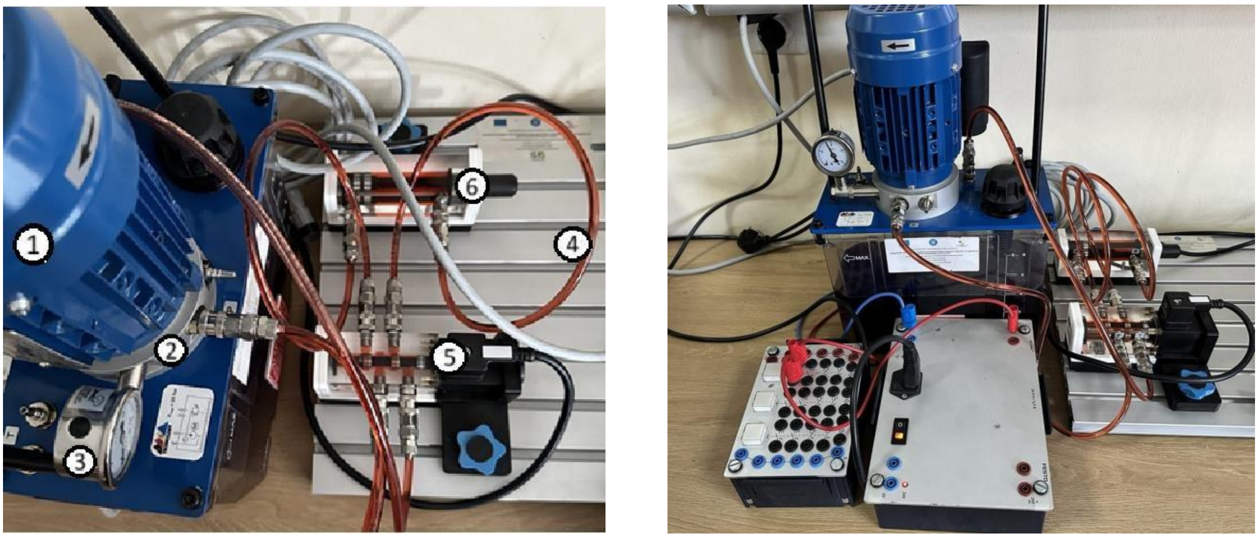


Fig. 1. Assembly of the low-pressure hydrostatic system: electric motor (1); hydraulic pump (2); pressure gauge (3); flexible hydraulic pipes (4); 4/2-type directional control valve (5); hydraulic cylinder (6)

Figure 1 shows the functionality of a simple circuit in which the following components are found:
- *the pumping gr*oup, consisting of an electric motor (1) and a hydraulic pump (2), which ensures the circulation of the fluid in the circuit at a reduced pressure; the pressure is monitored using a pressure gauge (3) mounted on the pump housing;
- *the flexible hydraulic pipes* (4), made of a transparent material, which allow visual observation of the fluid circulation and facilitate the connection between the elements;
- *the 4/2 type directional control valve* (5), which controls the movement direction of the fluid and, implicitly, the direction of the hydraulic cylinder operation;
- *the linear hydraulic motor (hydraulic cylinder)* (6), which has the role of transforming the hydraulic energy of the working fluid into linear mechanical energy, achieving the translational movement required by the drive system.

Figure 2 shows the symbolic diagram of the hydrostatic system operation, which provides a logical, standardized and easy-to-interpret representation of the working principle of the low-pressure hydrostatic drive system.

This diagram allows highlighting the connections between the components, illustrating how hydraulic energy is transmitted and controlled within the hydrostatic circuit. Through this representation, the fluid flow paths, the positions, as well as the functional states of the directional control valve and the operating mode of the linear hydraulic motor can be identified, in correlation with the pressure and flow variations.

The operation of the diagram is based on the supply of the circuit by a pump (1) driven by an electric motor (2). The generated flow is directed through a relief valve (3) and controlled by a 4/2-type directional control valve (4).

Depending on its position, the fluid is directed either to chamber A or to chamber B of the linear hydraulic motor (5). Thus, the piston moves in one direction or the other, achieving the necessary mechanical movement. When the directional control valve returns to its original position, the circuit is discharged and the piston movement stops.

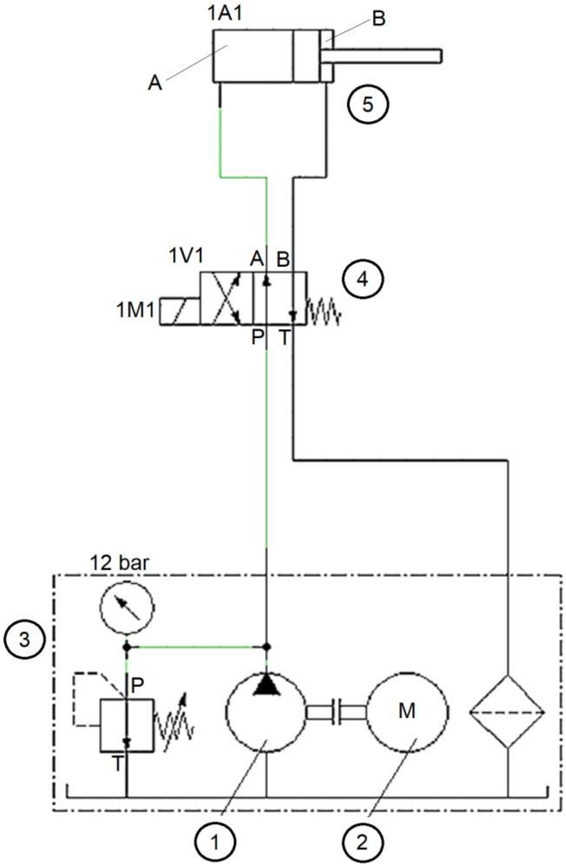


Fig. 2. Symbolic operating diagram of the hydrostatic system: hydraulic pump (1); electric motor (2); relief valve (3); 4/2-type directional control valve (4); linear hydraulic motor (5)

Unlike the physical assembly, which reflects the actual positioning of the equipment, the symbolic diagram eliminates the construction details and highlights only the functional relationships between the elements. This allows a quick analysis of the operating mode, possible losses, critical points in the system and provides support in the design, sizing and diagnosis of the circuit.

The hydraulic pump, Figure 3, is a compact equipment, consisting of a cylindrical metal body in which two gears (one driving and one driven), responsible for transporting the fluid, are mounted. In the figure, both the real shape of the pump and its technical representation with dimensions and fixing points are observed.

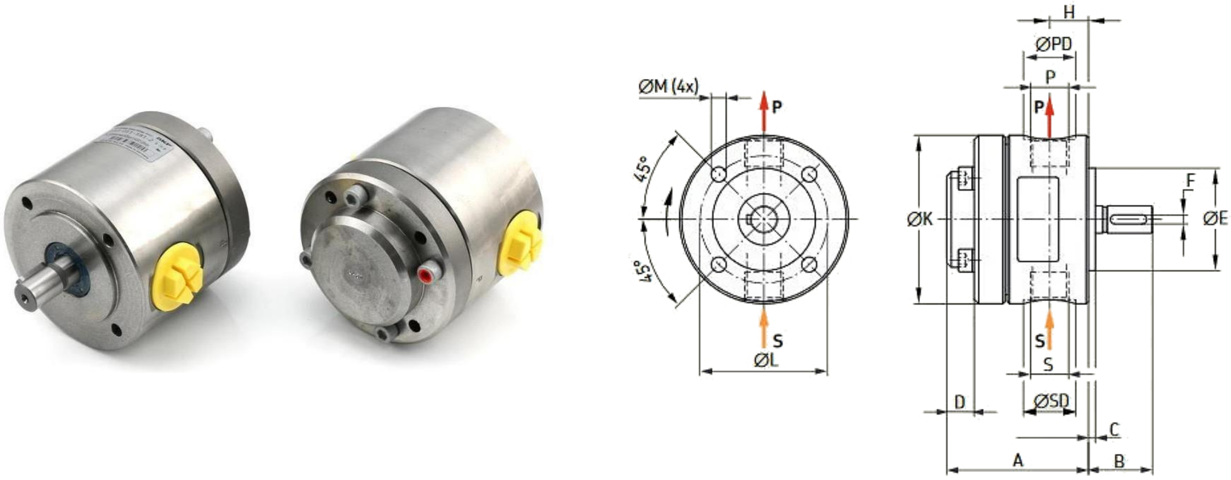


Fig. 3. Gear pump [22]

Through the suction and discharge ports, the liquid is taken in and pumped under pressure, and the drive shaft transmits the movement to the gears. The robust body of the pump indicates its use in industrial applications where reliability and pressure resistance are essential.

The figure highlights the main dimensions and mounting method. The front view shows the positioning of the discharge (P) and suction (S) ports at 45°, as well as the mounting holes. The side view shows the total length of the pump (A, B, C), the position of the drive shaft (ØE) and the essential housing diameters (ØK, ØSD, ØPD).

To characterize the low-pressure hydrostatic drive system, it is necessary to highlight the main technical parameters of the components that make it up. These parameters determine the overall performance of the system, influencing both energy efficiency and dynamic behavior under various operating conditions.

Table 1 summarizes the main technical parameters relevant for the system analysis and sizing process, their values constituting the starting point for the numerical simulations performed during the study.

Table 1: Gear pump technical parameters [22]

Crt. no.	Parameters	Symbol	Value	Unit
1.	Normal pressure	p	10	[bar]
2.	Volume flow	Q	0.48	[l/min]
3.	Nominal rotational speed	n_n	1500	[rot/min]
4.	Viscosity range	-	20-1000	[mm²/s]
5.	Characteristic curve	-	1	-
6.	Nominal volume	V_n	0.61	[cm³]
7.	Actuating power	P	0.20	[kW]

At the same time, measurements were taken to determine the dimensions of the functional components of the hydrostatic system. For the calculation of the operating parameters, standardized values will be adopted for the pressure, p = (2, 4, 6, 8, 10) bar and the rotational speed, n = (700, 900, 1100, 1300, 1400) rot./min. The flow rate, driving moment and power will be determined, taking into account the following characteristics of the gear pump: outer diameter, D_e = 22 mm; inner diameter, D_i = 17 mm; rolling diameter, D_r = 19.5 mm; tooth heigh, h = 2.5 mm; width of the gears, l = 4 mm.

The flow rate of a gear pump indicates the volume of fluid transported in a certain time interval and is an essential parameter for evaluating its performance. It is influenced by the geometric characteristics of the gears, the pump rotation speed and the internal losses in the system.

To determine the theoretical flow rate, the pump's construction dimensions, such as the rolling diameter, the tooth height and the width of the gears, will be used. The volumetric yield will also be taken into account to estimate the actual flow rate of the pump under actual operating conditions. Thus, the flow rate is calculated in the form [11]:

$$Q = V \cdot n \cdot 10^{-6} \left[\mathrm{l/min}\right], \tag{1}$$

where:

$$V = \pi \cdot D_r \cdot h \cdot l \left[\mathrm{mm}^3\right]. \tag{2}$$

$$V = \pi \cdot 19.5 \cdot 2.5 \cdot 4 = 612.3\,\mathrm{mm}^3.$$

Next, the flow rate was calculated for each of the normalized rotational speed values represented in Table 2.

Table 2: Pump rotational speed and flow values

Crt. no.	n [rot/min]	Q [l/min]	
1	$n_1 = 700$	$Q_1 = V \cdot n_1 = 428610 \cdot 10^{-6}$	$Q_1 = 0.43$
2	$n_2 = 900$	$Q_2 = V \cdot n_2 = 551070 \cdot 10^{-6}$	$Q_2 = 0.55$
3	$n_3 = 1100$	$Q_3 = V \cdot n_3 = 673530 \cdot 10^{-6}$	$Q_3 = 0.67$
4	$n_4 = 1300$	$Q_4 = V \cdot n_4 = 795990 \cdot 10^{-6}$	$Q_4 = 0.80$
5	$n_5 = 1400$	$Q_5 = V \cdot n_5 = 857220 \cdot 10^{-6}$	$Q_5 = 0.86$

The driving moment of a gear pump is the torque force required to turn the gears and move the fluid through the system. It depends on the working pressure, the geometrical dimensions of the gears and the internal losses in the mechanism.
The moment is calculated using the relationship [11]:

$$M = \frac{p \cdot V}{2 \cdot \pi} \cdot 10^{-4} \left[\mathrm{N \cdot m}\right]. \tag{3}$$

The calculation of the driving moment was performed for several pressure values, Table 3.

Table 3: Values of the moment and pump pressure

Crt. no.	p [bar]	M [N·m]	
1	$p_1 = 2$	$M_1 = \frac{p_1 \cdot V}{2 \cdot \pi} \cdot 10^{-4}$	$M_1 = 0.19$
2	$p_2 = 4$	$M_2 = \frac{p_2 \cdot V}{2 \cdot \pi} \cdot 10^{-4}$	$M_2 = 0.38$
3	$p_3 = 6$	$M_3 = \frac{p_3 \cdot V}{2 \cdot \pi} \cdot 10^{-4}$	$M_3 = 0.57$
4	$p_4 = 8$	$M_4 = \frac{p_4 \cdot V}{2 \cdot \pi} \cdot 10^{-4}$	$M_4 = 0.76$
5	$p_5 = 10$	$M_5 = \frac{p_5 \cdot V}{2 \cdot \pi} \cdot 10^{-4}$	$M_5 = 0.96$

The power of a gear pump represents the energy transmitted to the system to ensure the movement of fluid under pressure. The determination of the power is based on the relationship between the driving moment and rotational speed, respectively between the pump flow and the pressure difference.
The hydraulic power generated by the pump is given by the relation [11]:

$$P = \frac{p \cdot Q}{612 \cdot \eta} \left[kW\right], \tag{4}$$

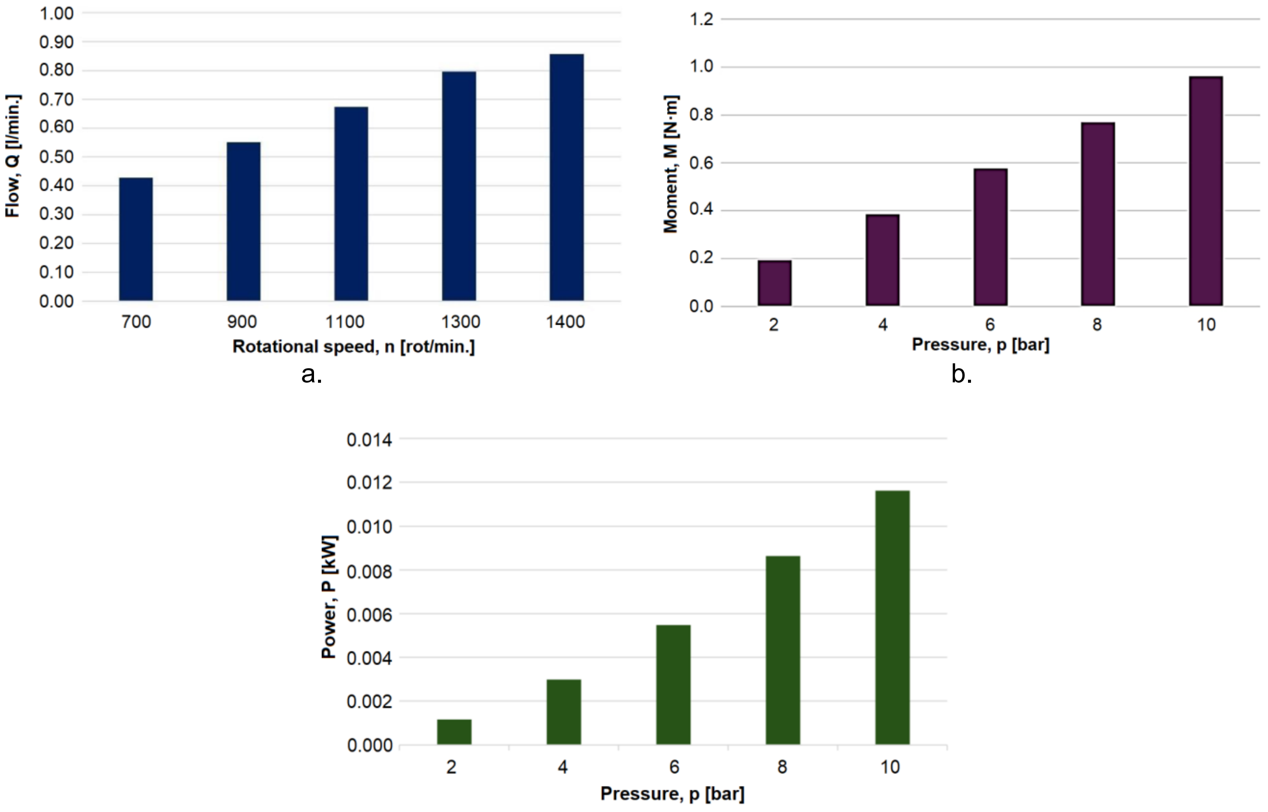
where η represents the yield, between 0.5 ÷ 0.9.

To analyze the influence of the working pressure on the power developed by the gear pump, the calculation was performed for different distinct values, Table 4.

Table 4: Values of the power and pump pressure

Crt. no.	p [bar]	P [kW]	
1	$p_1 = 2; \eta = 0.5$	$P_1 = \frac{p_1 \cdot Q_1}{612 \cdot \eta} \cdot 1.66$	$P_1 = 0.0011$
2	$p_2 = 4; \eta = 0.5$	$P_2 = \frac{p_2 \cdot Q_2}{612 \cdot \eta} \cdot 1.66$	$P_2 = 0.0029$
3	$p_3 = 6; \eta = 0.5$	$P_3 = \frac{p_3 \cdot Q_3}{612 \cdot \eta} \cdot 1.66$	$P_3 = 0.0054$
4	$p_4 = 8; \eta = 0.5$	$P_4 = \frac{p_4 \cdot Q_4}{612 \cdot \eta} \cdot 1.66$	$P_4 = 0.0086$
5	$p_5 = 10; \eta = 0.5$	$P_5 = \frac{p_5 \cdot Q_5}{612 \cdot \eta} \cdot 1.66$	$P_5 = 0.0116$

The graphical representation of flow, moment and power is shown in Figure 4.



a. b.

c.

Fig. 4. Graphical representation of flow (a), moment (b) and power (c).

The directional control valve used in the low-pressure hydrostatic drive system is of the 4/2 type, Figure 5.a, with electric drive and elastic return and has the role of switching the direction of fluid flow between the pump, actuator and the tank.

The directional control valve is integrated in a transparent body, which allows direct observation of the position of the spool valve and the fluid path. The connections are made with quick couplings and the control is provided by an electrical connector. The assembly is fixed on a modular platform and the orange tubes indicate the pressure and return lines.

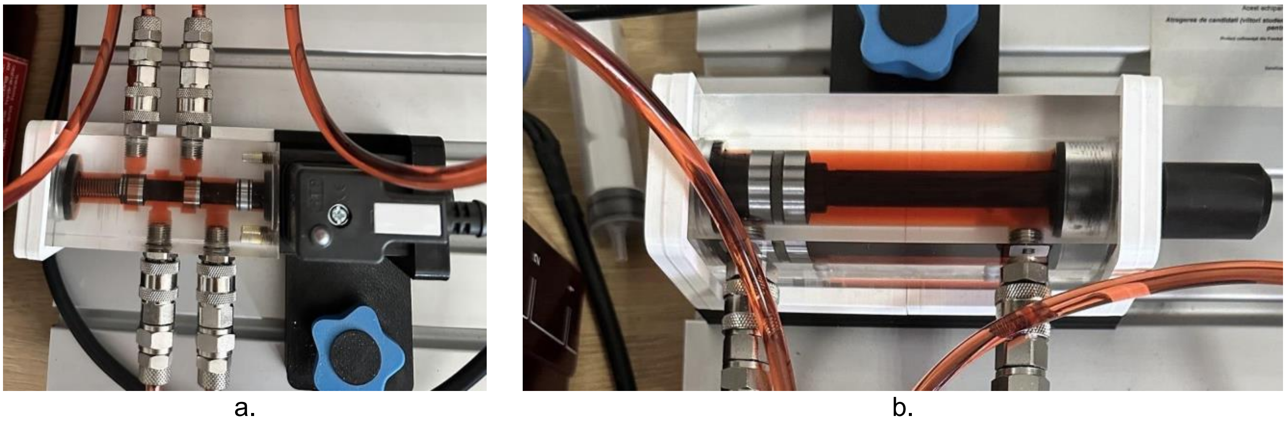

a. b.

Fig. 5. Mounting of the 4/2-type directional control valve (a) and the linear hydraulic motor (b).

The 4/2 type directional control valve has four ports and two switching positions. Depending on the position of the spool, it allows the fluid flow to be directed to one of the chambers of the hydraulic cylinder, while the other is connected to the discharge. The initial position is maintained by a return coil and the switching is done electrically.

Table 5 presents the main characteristics of the 4/2 type directional control valve. These specifications were taken into account in the selection and integration process of the directional control valve within the low-pressure hydrostatic drive system, ensuring the functional compatibility and performance required to achieve directional control of the hydraulic circuit.

Table 5: Technical parameters of the 4/2 type directional control valve [23]

Working fluid	HM class hydraulic oils, viscosity class ISO VG 32, 46 and 68
Liquid temperature range [°C]	-20 ... +60
Maximum ambient temperature [°C]	-20 ... +50
Viscosity range [mm²/s]	10 ... 500
Liquid purity class	Class 21/18/15
Permissible voltage fluctuations [%]	± 10 (alternating current), ± 15 (direct current)
Maximum switching frequency [1/h]	15.000
Working cycle	100 %
Weight [kg]	0.20
Maximum tightening torque - directional control valve [N·m]	30
Flow diameter [mm]	15

In order to analyze the behavior of the directional control valve and the entire low-pressure hydraulic drive system, it is necessary to determine the fluid flow velocity. This is a parameter for evaluating pressure losses, flow rate and geometric dimensions of hydraulic components.

The speed can be determined using the relationship:

$$v = \frac{4 \cdot Q}{\pi \cdot D^2} \left[\mathrm{m/min} \right]. \tag{5}$$

To highlight how the fluid flow rate varies depending on the operating conditions, it will be determined based on the five flow rates previously calculated. Each of these values corresponds to a different operating scenario of the hydraulic system. The results are presented in Table 6.

Table 6: Values of the flow and the directional control valve speed

Nr. crt.	Q [l/min]	v [m/min]	
1	$Q_1 = 0.43$	$v_1 = \frac{4 \cdot Q_1}{\pi \cdot D^2}$	$v_1 = 0.0024$
2	$Q_2 = 0.55$	$v_1 = \frac{4 \cdot Q_1}{\pi \cdot D^2}$	$v_2 = 0.0031$
3	$Q_3 = 0.67$	$v_1 = \frac{4 \cdot Q_1}{\pi \cdot D^2}$	$v_3 = 0.0037$
4	$Q_4 = 0.80$	$v_1 = \frac{4 \cdot Q_1}{\pi \cdot D^2}$	$v_4 = 0.0045$
5	$Q_5 = 0.86$	$v_1 = \frac{4 \cdot Q_1}{\pi \cdot D^2}$	$v_5 = 0.0048$

The linear hydraulic motor (hydraulic cylinder) is an actuator used to transform hydraulic energy into linear movement. The operating principle is based on the action of fluid under pressure on the surface of a piston, thus generating a force capable of moving loads in one direction or alternatively. The performance of a hydraulic motor depends on several parameters, including: piston diameter, working pressure, fluid flow rate and assembly efficiency.

In this paper, a linear hydraulic motor shown in Figure 5.b was used. The motor contains a transparent cylinder that allows viewing the piston movement during fluid supply. Quick couplings ensure connection to the hydraulic circuit and visible metal seals at the ends of the piston delimit the working chambers.

3. Assembly and simulation schemes with Omegon Fluid

In the design of a low-pressure hydrostatic drive system, simulation of operation plays an essential role in validating the calculated parameters and in anticipating the mechanical behavior of the assembly. Through simulation, it is possible to analyze how the hydraulic energy is transmitted to the mechanical execution elements and how they respond to various loads.

Omegon Fluid [24] is a software dedicated to the simulation of hydraulic and pneumatic circuits, used to analyze the behavior of drive systems. The program allows the configuration of individual parameters for each component and the simulation of the dynamic behavior of the entire circuit. Important quantities such as pressure, flow, speed or force can be analyzed, all in the context of a mechanical system that responds to hydraulic drive.

One of the advantages of using the Omegon Fluid software is the real-time graphical representation of the fluid movement and the driven mechanical components, which allows a clear understanding of the system's operation and its easy adaptation according to the application requirements.

Omegon Fluid is a graphical simulation environment used for modeling and analyzing hydraulic and pneumatic circuits. The program interface is intuitive, based on standardized symbols according to ISO standards, which allows the rapid construction of realistic functional diagrams that are easy to understand and interpret.

The program also provides a visual legend of the colors used in the simulation: for example, red indicates high pressure, blue indicates low pressure and green represents normal fluid circulation. This color code facilitates the rapid interpretation of the circuit behavior.

Another useful aspect is the possibility of placing measurement points inside the pipes, to track real-time values: pressure, flow rate or fluid speed at a specific node. This contributes to a detailed understanding of the circuit dynamics, which is essential in projects that involve the verification of mechanical components operated by hydraulic forces.

With these functionalities, Omegon Fluid presents itself as a complete tool for functional testing of a hydrostatic system in a visual and interactive way, allowing the simulation of various working scenarios and the rapid adaptation of parameters.

An important aspect in using the program is the possibility of configuring the simulation conditions, as well as the control over the input and output parameters of the system. For example, constant or variable supply pressures, mechanical loads applied to linear actuators, logical or automatic controls via directional control valves can be introduced. For low-pressure systems, Omegon allows testing of behavior in regimes with reduced pressure values, which is ideal for simulating drives where energy efficiency, fine movement control and loss limitation are priorities.

3.1. Low-pressure hydrostatic drive system assembly diagram

In order to analyze the operation of the low-pressure hydrostatic drive system, a schematic diagram was created in Omegon Fluid that reproduces the physical circuit. The hydrostatic system includes the main components, such as: pump, tank, directional control valve, linear hydraulic motor and connecting pipes.

The electrical part has the role of controlling the activation of valves, pump or other drives via signal panels and logic interfaces.

According to Figure 1, the following components can be seen on the front panel: the electrical signal panel, which includes buttons and LEDs for ON/OFF commands, direction reversal, manual or automatic cycle triggering; the modular electrical connectors, which allow the connection of control wires between different devices (such as directional control valve); the areas dedicated to power and safety, where the power supplies, fuses and ground terminals are located. These panels are an integral part of the Omegon Fluid environment and facilitate the simulation of dynamic behavior through manual or automatic commands, allowing real-time observation of the circuit response.

Subsequently, in Figure 6, the diagram created in the Omegon Fluid program is shown, in its initial state, before any action is triggered.

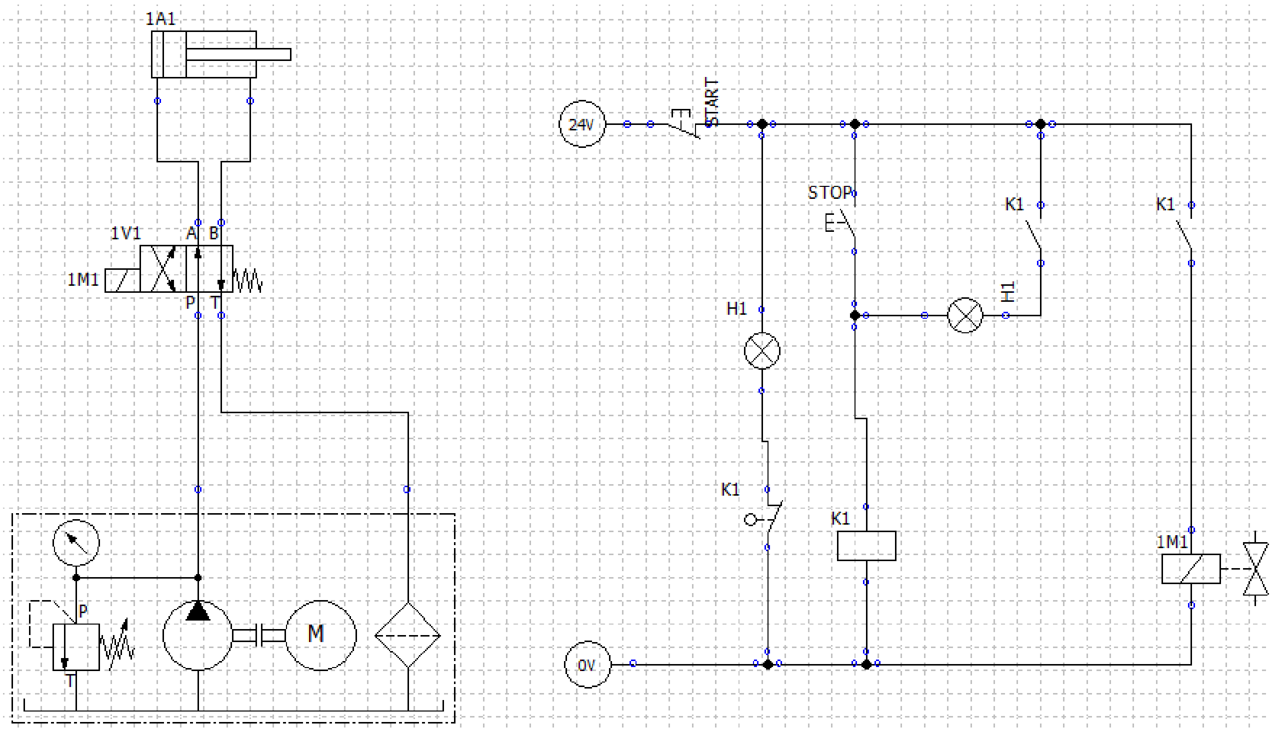


Fig. 6. System diagram, simulated in the Omegon Fluid program

The pipes are positioned between the elements according to the principles of a standard hydraulic circuit and their directional control valve follows logical paths between the tank, pump, directional control valve and hydraulic cylinder. The initial position of the directional control valve is neutral-centered, without directing the flow to the cylinder. The cylinder rod is fixed and the colors of the pipes indicate that there is no active pressure in the system (resting state). This visualization provides a starting point for the analysis of subsequent operation and allows understanding of how the hydraulic and electrical components are connected.

3.2. Configuring parameters in the Omegon Fluid software

In order for the simulation performed in Omegon Fluid to reflect the real behavior of a low-pressure hydrostatic drive system, it is important to correctly configure each component element with precise data. The parameters that describe the system components, from the pump to the directional control valve, cylinder, pipes and protective elements, have a direct influence on the results obtained in the simulation, both from a kinematic, functional and energetic point of view. The values resulted from a detailed analysis presented in the previous chapter, in which the basic system parameters were dimensioned and calculated.

Thus, the data configured in the Omegon Fluid interface is consistent with the theoretical design of the system and ensures complete coherence between the analytical and simulation parts.

A gear pump was used to supply the circuit, configured with a maximum flow rate of 10 l/min and a maximum working pressure of 10 bar. The operating rotational speed set in Omegon Fluid was 1400 rpm and the direction of rotation was set to clockwise.

The directional control valve is a 4/2 type with a centered neutral position, being returnable to the initial position. It was configured in such a way as to allow the correct direction of the hydraulic oil flow to the cylinder, depending on the applied electrical signal. The electrical control has an activation voltage of 24 V, and in the neutral position, the pump is discharged directly to the tank.

The hydraulic cylinder is double-acting and has the following characteristics configured in Omegon: piston diameter: 20 mm; rod diameter: 10 mm; stroke: 58 mm; average force: 14 N; average speed: 2.50 m/min. These dimensions were entered into the software to reproduce the linear movement of the rod during the simulation. The cylinder was connected directly to the directional control valve via rigid pipes, so as to ensure control of the direction of movement.

The hydraulic pipes were configured with the following characteristics: inner diameter: 5 mm; total length: 0.3 m; connection type: rigid, without significant losses; fluid: hydraulic oil. They ensure the connection between the pump, directional control valve and cylinder and in Omegon Fluid, the pipe route was organized so as to respect real assembly principles.

In addition to the hydraulic system, electrical components play a fundamental role in controlling the directional control valve and controlling the operating cycles. To make these connections, work-specific equipment was used. The power supply in the hydrostatic system, Figure 7, has an output voltage of 24 V DC and a maximum current of 4.5 A. It is equipped with standardized output terminals for +24 V (red) and 0 V (blue), a power switch and a light indicator. Connections are easily made via plugs, and the outputs are protected.

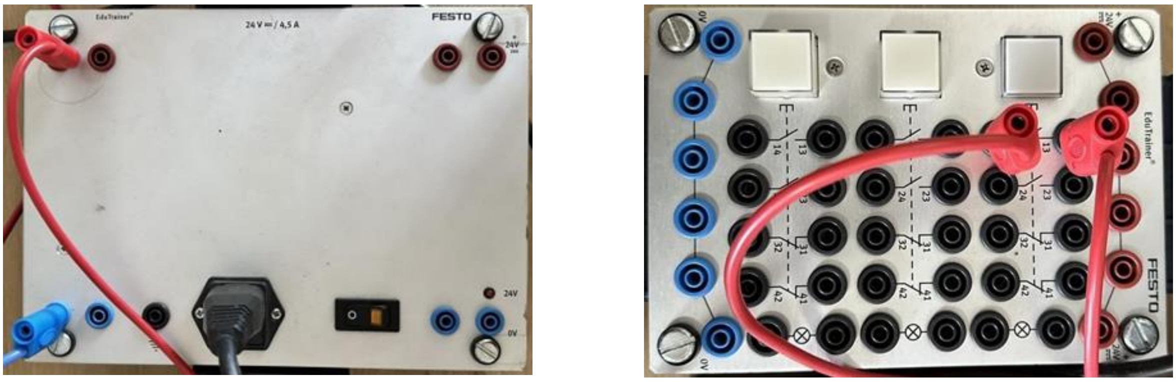


Fig. 7. Power supply and relay

The electrical control module is responsible for activating or deactivating the hydrostatic system circuit. When the start button is pressed, the electrical signal causes the directional control valve to switch, which leads to the supply of hydraulic oil to the cylinder and the start of its stroke. Once the button is pressed to stop, the directional control valve returns to the neutral position. Thus, the module allows precise control of automatic or manual operation, being essential in simulating repeated system cycles.

3.3. Operation of the hydraulic system simulated in Omegon Fluid

To evaluate the dynamic behavior of the low-pressure hydrostatic drive system, it is essential to analyze its operation in a full operating mode. In this stage, the concrete operation of the modeled system is analyzed, following the synchronization of the electrical control with the movement of the hydraulic cylinder and the way in which the main elements of the scheme interact in a full drive cycle. Figure 8 shows the scheme of the low-pressure hydrostatic system at the time of simulation.

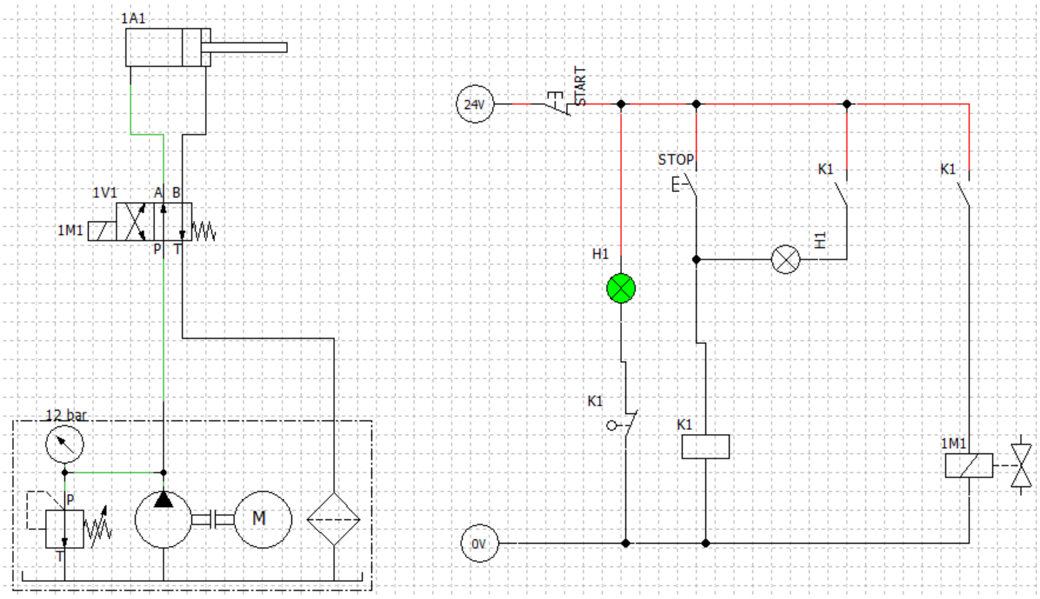


Fig. 8. System diagram at the time of simulation

a.

b.

Fig. 9. The pressure gauge that records the pressure during the active stroke of the cylinder (a) and the passive stroke (b)

As the simulation progresses, the flow continues to feed the cylinder and the rod movement occurs in a controlled manner, supported by constant oil pressure. The electrical control is maintained throughout the stroke, ensuring a complete work cycle.

In this phase, the pressure in the circuit increases with the mechanical stress, and this phenomenon is also confirmed by reading the pressure gauge attached to the pumping group, Figure 9.a.

During the active stroke of the cylinder, the pressure gauge indicates a value of approximately 4.2 bars. This value corresponds to the working pressure developed at that moment in the circuit, being in accordance with the specifications of the designed low-pressure system. The pressure gauge, mounted between the pump and the safety valve, allows the pressure to be monitored in real time, thus providing a direct indicator of the system stress in the active phase.

Once the stroke is completed, the pressure in the system also progressively decreases, and the pressure gauge gradually returns to its initial value, indicating a state of hydraulic rest, Figure 9.b. This return confirms the correct functional behavior of the valve and the discharge to the tank.

At the end of the stroke, once the electrical control is interrupted, the distributor automatically returns to its neutral position, according to the internal configuration. This condition is shown in Figure 10, where the connections between the pump and cylinder are broken and the oil is directed back to the tank. At this point, the piston rod remains stationary, marking the completion of a complete operating cycle of the system.

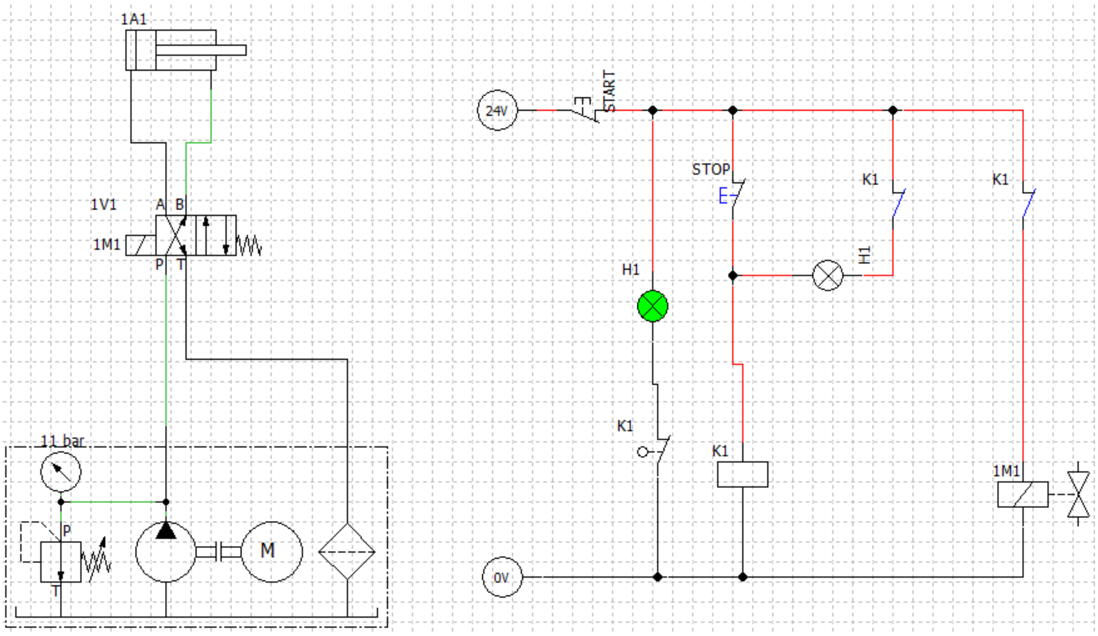


Fig. 10. Returning the system to a resting state during simulation

The entire simulated process highlights the correct synchronization between the electrical control and the mechanical response, with hydraulic parameters adapted to low-pressure operation, thus validating both the theoretical and practical parts of the project.

3.4. Graphical analysis of the operating cycle

To highlight the dynamic behavior of the actuator system simulated in Omegon Fluid, a graphical analysis of the main signals in the circuit was performed.

Figure 11 shows how several successive cylinder strokes are performed, correlated with the directional control valve command. The red curve (1A1 - Hydraulic actuator) represents the position of the cylinder rod over time, expressed as a percentage (0 -100%).

A cyclic variation is observed, with four complete advance and retraction cycles. The increase in the value towards 100% indicates the rod advance, while the decrease to 0% reflects its retraction to the initial position. The duration of each stroke is approximately 4 seconds, the system having a repetitive and stable behavior.

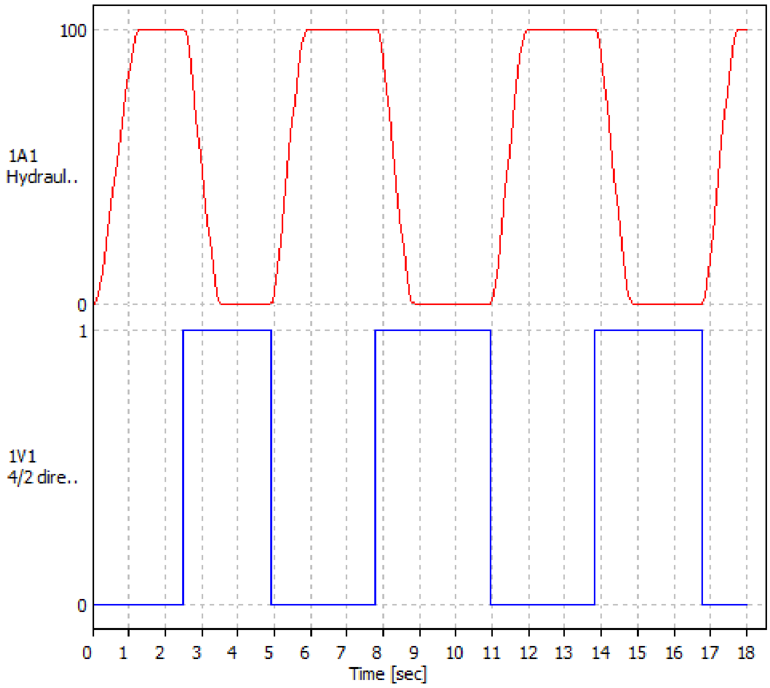


Fig. 11. Diagram of the hydraulic system's cyclic operation in Omegon Fluid

The blue curve (1V1 - 4/2 directional control valve) represents the electrical command applied to the valve. The binary values 0 and 1 indicate the activation state (1 = active, 0 = inactive). It can be seen that the valve is activated (blue line at position 1) during the period in which the rod is in the forward stroke, and upon the complete return of the rod, the command signal is reactivated to initiate a new stroke.

This graph demonstrates the synchronization between the valve command and the position of the hydraulic actuator, in a fully automated system. The operation is cyclical and controlled, and each activation of the valve generates a new work cycle, ensuring the repeatability of the movement and thus validating the correctness of the control logic implemented in the simulation.

4. Conclusions

The paper aimed at the theoretical analysis and functional simulation of a low-pressure hydrostatic drive system, aiming to highlight the advantages that this category of drives offers in industrial and educational applications. By integrating the constructive-functional design stages with the numerical simulation performed in the Omegon Fluid software program, a complete picture of the behavior of the hydraulic system under reduced pressure conditions was obtained, confirming the viability and efficiency of this type of drive.

The obtained results demonstrated that low-pressure hydrostatic drive systems can operate stably and energy-efficiently when the parameters are carefully dimensioned and correlated with each other. These systems ensure a significant reduction in internal losses and energy consumption, extend the life of components and contribute to increasing operational safety, while being easier to maintain and diagnose.

Although the working pressure is relatively low, the analyzed system has proven to be able to generate sufficient actuation forces for the intended practical applications, such as test equipment, laboratory installations or low-power machines. The determined values for flow, torque and power, depending on speed and pressure, were within the calculated theoretical limits, confirming the validity of the analytical model used. The simulation performed in the Omegon Fluid program allowed the verification of the correlation between the electrical controls and the mechanical response of the system.

A precise synchronization between the electrical signal applied to the directional control valve and the movement of the cylinder rod was found, which demonstrates the reliability of the control scheme and the smooth functioning of the interaction between the hydraulic and electrical components. During the simulation, the variations in the pressure in the circuit, monitored with the help of the pressure gauge, revealed a stable evolution, without major fluctuations, confirming the correct behavior of the safety valve and the unloading system.

The graphical analysis of the operating cycle showed a repetitive, stable and controlled behavior of the system, with a constant duration of the successive cylinder strokes. The automatic return of the directional control valve to the neutral position after the end of each cycle demonstrated the dynamic balance of the assembly and the efficiency of the control scheme implemented in the simulation.

This concordance between the theoretical and the practical part emphasizes the high level of accuracy of the modeling and the relevance of the simulation method used.

Through the complete analysis carried out, it was confirmed that low-pressure hydrostatic systems represent high-performance and economical solutions for applications where low energy consumption, high precision and increased reliability are searched.

The Omegon Fluid simulation environment proved to be an effective tool, offering the possibility of detailed parameter configuration, interactive visualization of hydraulic flows and testing of dynamic scenarios under controlled conditions. It allows the study to be extended to more complex systems with electro-hydraulic or adaptive control, opening up research and optimization perspectives in the field of hydraulic drives. In conclusion, the research highlighted the importance of numerical simulation as an indispensable step in the design process of hydrostatic drives.

The obtained results validate both the analytical calculations and the practical configuration of the system, demonstrating the coherence between theory and application. Low-pressure hydrostatic drives are thus emerging as a viable and sustainable option for modern applications, offering an optimal balance between performance, costs, safety and energy efficiency.

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