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EXPERIMENTAL ANALYSIS OF AN OPEN/CLOSED HYDRAULIC SYSTEM

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Abstract: *The paper presents the conception and design of a hydraulic system that can work both in closed circuit and in open circuit - which can be used in the laboratory for teaching purposes. The system contains both classical and proportional equipment, sensors for different fluidic (flow, pressure, temperature) and mechanical (speed) quantities and will be managed using a dedicated controller. From a functional point of view, the system will have several operating modes, which can be set by the user. The data provided by the sensors will be acquired and they will be analysed and in real time the controller will decide certain corrections so that the system evolves according to an imposed algorithm.*

Keywords: *Hydraulic System, Open circuit, Closed circuit*

1. Introduction

Today, hydraulics represents an increasingly important technology. Its qualities are highlighted whenever large and very large forces need to be developed under conditions of superior efficiency. The scope of application of hydraulic drive systems is extremely broad, ranging from the operation of robots, machine tools, automated lines, presses, lifting machines, chemical, metallurgical, and mining equipment to military and aerospace technology.
As a result, these systems find a wide field of application wherever automatic control of work phases is required, along with the programming of forces/moments, displacements, and speeds. They ensure various functions, facilitating the transition from one speed level to another, which is necessary for achieving high-precision positioning, ease, and flexibility in programming. A careful evaluation of this field allows the identification of the main trends and perspectives. Among these, a strong development in this field in the future must be noted; for this, fundamental and sustained applied research is necessary. At the same time, the significant role of equipment manufacturers in innovating and adapting to Industry 4.0 is evident.
The aspects presented above justify the importance given to this field in the curriculum of the Mechatronics study program, where a series of courses are planned to enable students to acquire competencies in the field of hydraulic drive systems. These courses include Pneumatic and Hydraulic Automations, Hydronics and Pneutronics, Intelligent Fluid-powered Drive Systems, Theoretical and Experimental Analysis of Hydronic and Pneutronic Systems. The theoretical aspects presented in these courses need to be accompanied by laboratory work to assist students in understanding the principles and methods presented in class. For this purpose, an appropriate material base is needed to align with the intended goals.
This is also the direction in which the subject of this applied work falls. The designed and currently under construction stand aims to help students understand the following aspects:

- The functional role of the automation equipment used; both classical and proportional equipment are considered.
- Highlighting the difference between a hydraulic drive system operating in a closed circuit and one operating in an open circuit.
- Presentation of methods for flow control through the resistive method and the volumetric method.

- Emphasizing pressure losses that occur due to fluid flow through various equipment (especially at the throttle level) and their effect on the working fluid's temperature.
- How to adjust the pressure in the system.
- How information is acquired, processed, and interpreted from the system.
- How the controller is programmed and a series of control algorithms are designed and implemented.

2. Material and Method

The system studied in this article is composed of an adjustable flow hydraulic pump P, hydraulic directional control valves with classical operation DH2 (used to operate the system) and DH1 (used to supply the pump), pressure transducers PAM and PAV, flow transducer TD, as well as pressure gauges M1 and M2 mounted upstream and downstream of a proportional throttle valve DROSEL_PROP. The system is also equipped with an accumulator, serving as a flow compensator ACC, along with the filter F, pressure relief valve Ssig and reservoir T. The hydraulic circuit is depicted in Fig. 1, along with the main characteristics of some of its constituent equipment. It is configured to allow a switch between the open circuit mode, which includes a reservoir, and the closed-circuit mode by decoupling the reservoir.

The operational steps for transitioning from open circuit mode to closed circuit mode are as follows:
Step 1: System startup – the DH1 directional control valve establishes the left distribution field, allowing circuit supply through the hydraulic pump (P). The DH2 directional control valve can be in either of its two positions – for hydraulic circuit operation or return. In both cases, the pressure relief valve (Ssig) is included in the loop.
Step 2: If a transition to closed circuit mode is desired, the DH2 directional control valve is actuated through the ALIM_ON electromagnet, enabling pressurized oil supply to the operated circuit. Once the desired pressure is reached, the DH1 directional control valve can be switched to the CI position.

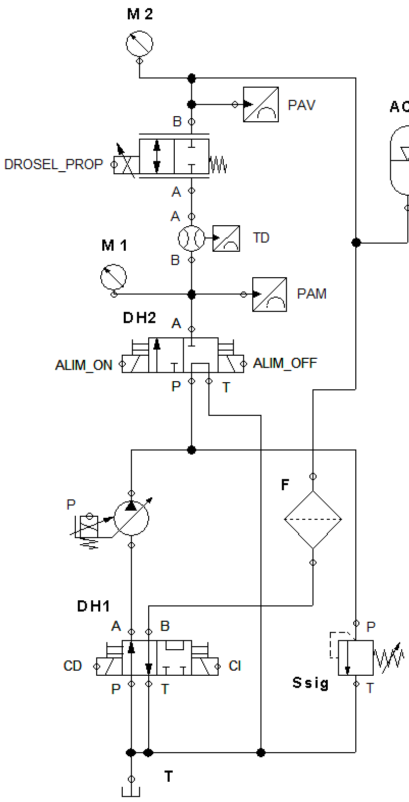

Fig. 1. Simulation network

Table 1: Components parameters

Component description	Characteristics
T – Hydraulic reservoir	Capacity: 80 liters
DH1 – Hydraulic distributor 4/2 with dual control (electric and manual)	Max. pressure: 350 bar Max. flow rate: 60 l/min Control voltage: 24V
P – Variable capacity hydraulic pump	Max. pressure: 350 bar Max. flow rate: 59 l/min Max. speed: 3300 Control voltage: 24V
DH2 – Proportional distributor 4/2	Nominal pressure: 280 bar Max. pressure: 350 bar Max. flow rate: 60 l/min Control voltage: 24V
M1 – Glycerin-filled pressure gauge	Measuring range: 0-310 bar
PAM – Analog pressure sensor, upstream	Measurement range: 0-250 bar Supply voltage: 18-30V
TD – Turbine flow meter	Accuracy: ± 0.5%, ± 1% Power supply: +24VDC
DROSEL_PROP – Proportional throttle valve	Max. pressure: 420 bar Nominal flow rate: 320 l/min Number of connections: 2 Switching positions: 2 Supply voltage: 24 VDC
PAV – Analog pressure sensor, downstream	Measurement range: 0-250 bar Supply voltage: 18-30V
M2 – Glycerin-filled pressure gauge	Measuring range: 0-310 bar
ACC – Hydraulic Accumulator	Max. flow rate 360 l/min Gas valve type: 7/8' 14 UNF high pressure Max. operating pressure: 690 bar Nominal volume: 1 l
F – Particle Filter	Height: 170mm Outer diameter: 64mm Inner diameter: 34mm
Ssig – Safety valve with direct-acting	Pressure range: up to 350 bar Flow rate: 26 l/min

In fig. 2, the logic control module is presented, where the connections between the logic stage and the control stage can be observed. On the left side of the figure, the inputs and outputs of the programmable controller are highlighted. The inputs of the programmable controller are denoted as I1 to I8, and the outputs as Q1 to Q8; its power supply is provided from a 24V source.
On the right side of the figure, the logical scheme behind the system's operation can be observed. By supplying I1, the system's working cycle is initiated. To ensure the system's stoppage, a button and a reset block have been installed simultaneously.

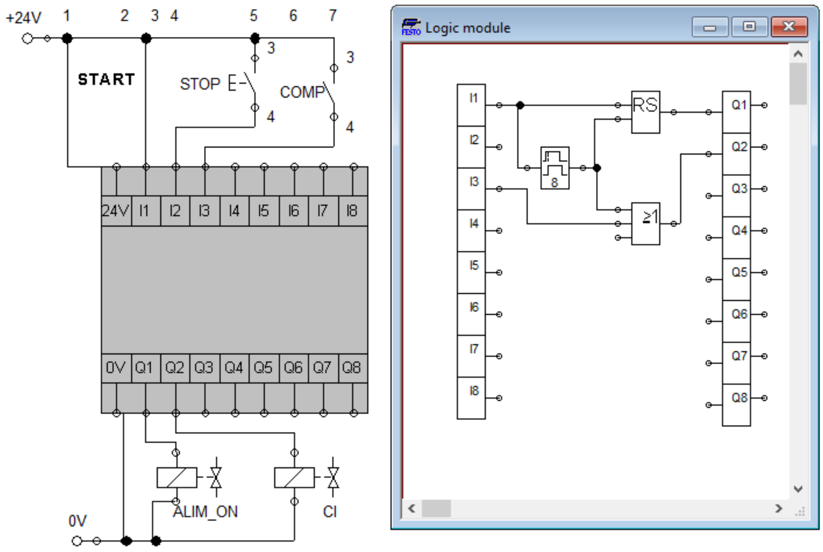

Fig. 2. Logic module connections

At the output port, Q1, the proportional electromagnet is connected, receiving the control signal for moving the hydraulic directional control valve drawer from the P-T position to the P-A position. When the pump starts, the fluid is not sent into the system but is directed back to the reservoir. The return to the preferential P-T position is achieved through the command of the second electromagnet, ALIM_OFF. The transition from an open hydraulic circuit to a closed one is done using a 4/2 directional control valve with proportional control. The preferred position of the directional control valve drawer is P-A, B-T, which means that the fluid enters the system through port A and returns to the tank through port B. The transition from an open circuit to a closed one is achieved by commanding the proportional electromagnet, CI, which once it receives the command signal, it moves the drawer to the P,T position - blocked and A-B - connected. The proportional throttle has the role of regulating the speed of the working fluid, respectively the speed of the actuation elements that could be connected in the system. The flow section through the throttle changes proportionally with the command signal sent through the Q2 port of the programmable controller. The flow section can be changed in several situations: when the pump has a low flow rate, and a too large passage section would lead to pressure losses in the system; another situation in which it is necessary to adjust the flow section is when the system does not require a large flow of fluid, and reducing the flow section leads to an increase in the pressure in the system, which can lead to the opening of the pressure relief valve and sending the fluid to the tank. The purpose of the hydraulic accumulator is to compensate the flow losses in the system, but also to store the hydraulic fluid when adjusting the flow section of the proportional throttle. The pressure relief valve ensures constant pressure in the system and does not allow exceeding the maximum pressure allowed in the system. When the set maximum threshold is reached, it opens and allows a quantity of fluid to exit the circuit.

Fig. 3 shows the control scheme for the hydraulic pump and regulation of the flow section for the proportional throttle. The pump flow rate variation law is given by means of a function generator, whose signal is amplified and transmitted to the actuation element. The movement of the mobile element, which changes the geometric volume, is proportional to the command signal. The control law of the proportional throttle is obtained based on the variations of the geometric volume of the pump. With the modification of the pump capacity, the throttle receives a command signal proportional to the displacement it must achieve. In order to determine the pressure drop on the throttle, it was decided to mount two analog pressure sensors upstream and downstream, the pressure difference between the two values is determined by a comparator. The comparator is provided with two analog inputs, one for each sensor. It allows real-time visualization of the upstream-downstream pressure difference on a display, as well as in the program. An analogue flow sensor, TD, has also been installed in the system, which allows monitoring the speed variations of the hydraulic fluid, provides an additional safety factor in the system and better control over possible flow losses, which could occur as a result of the operation defective components as well as anomalies in the operation of the pump.

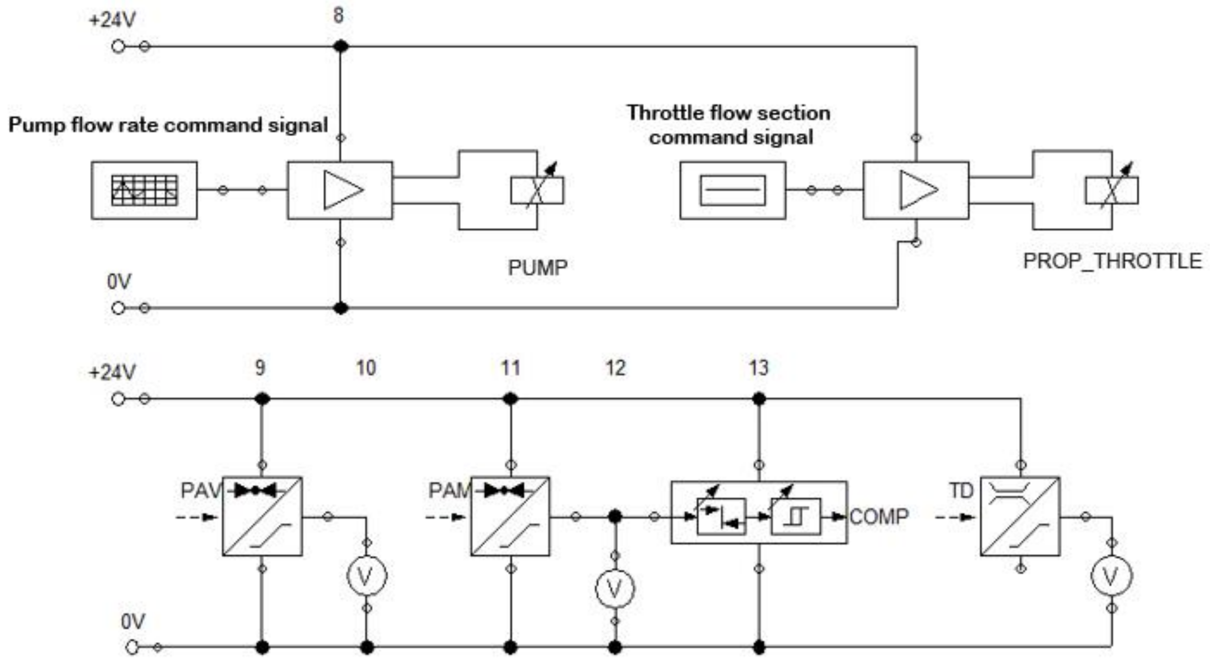

Fig. 3. Control scheme

3. Conclusions

In conclusion, the hydraulic system described in the article is a complex configuration involving various components such as an adjustable flow hydraulic pump, hydraulic directional valves, pressure and flow transducers, pressure gauges, a proportional throttle valve, an accumulator, a filter, pressure relief valve, and a reservoir. The system is designed to operate in both open circuit and closed-circuit modes, with the ability to transition between the two. The operational steps for transitioning from open circuit mode to closed circuit mode involve system startup, where the DH1 directional control valve establishes the left distribution field, allowing circuit supply through the hydraulic pump. If a transition to closed circuit mode is desired, the DH2 directional control valve is actuated to enable pressurized oil supply to the operated circuit, and the DH1 directional control valve can then be switched to the closed-circuit position. The logic control module, depicted in Fig. 2, highlights the connections between the programmable controller's inputs and outputs, which play a crucial role in initiating and stopping the system's working cycle. The proportional electromagnet, controlled by the programmable controller, is responsible for moving the hydraulic directional control valve drawer, facilitating the transition between open and closed-circuit modes. Fig. 3 provides a detailed control scheme for the hydraulic pump and regulation of the flow section for the proportional throttle. The pump's flow rate variation is governed by a function generator, and the control law for the proportional throttle is based on variations in the geometric volume of the pump. Analog pressure sensors upstream and downstream of the throttle, along with an analogue flow sensor, contribute to real-time monitoring and control of pressure and flow variations in the system. Overall, the system is designed with precision to regulate fluid flow, ensure safety through pressure control mechanisms, and allow for efficient operation in both open and closed-circuit modes. The integration of logic control and sensors enhances the system's adaptability and responsiveness to varying operational conditions.

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