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NUMERICAL AND EXPERIMENTAL STUDY OF THE PRESSURE-COMPENSATED FLOW CONTROL VALVE IN AN HYDRAULIC SYSTEM USING, MATHEMATICAL MODEL AND LABVIEW

Spartak Poçari*, Majlinda Alcani** , Parid Alimhillaj***, Andonaq Londo**** Artan Hoxha*****

Energy Department, Polytechnic University of Tirana, Albania

ABSTRACT

In hydraulic systems, the flow control valve is mainly used to regulate the speed of the output node of the hydraulic motor by changing the passage space of the fluid in the valve. However, the inlet and outlet pressures of the valve do not always remain constant. Any change in pressure will change the flow rate of the fluid passing through the valve and therefore will change the speed of the hydraulic motor. Pressure compensated flow control valves are often used in hydraulic systems when precise speed control is required under varying pressures due to load variation. Since for all industrial processes where hydraulic power plants are used, the presence of a stable state of the working characteristic of the hydraulic motor is necessary, we studied the pressure-compensated flow regulating valve with the aim of building a mathematical model and after a simulation program, through which will simulate the working characteristics of the valve and by combining experimental data we can improve the characteristic of this component by changing its constructive elements.

Keywords: flow control valve, mathematic model, computer simulation, fluid power, LabView

1 INTRODUCTION

Pressure-Compensated Flow Control Valves have an important role in maintaining the working regime in hydraulic power systems. regardless of the load change in the consumer, they self-regulate the amount of fluid that passes through them, guaranteeing a constant working regime of the hydraulic motor. Its main elements are the piston which is pre-tensioned by a spring and a flow limiting valve connected in series. The main task of the piston is to change the section of the passage of the fluid depending on the change of the pressure of the fluid in the consumer (in the hydraulic engine). The pressure difference across the main throttle (P1 – P2) acts on the spool by the force $F_p = A_s(P1 – P2)$, against the spring force F_x. The compensator keeps a constant pressure drop, ΔP_t, across the main throttle. Typically, the value of the pressure difference is selected in the range 4 to 10 bar. In the steady state, this pressure difference produces a force equal to the spring force.

Contact author: Spartak Poçari[1], Majlinda Alcani[2]

[1,2]Square “Mother Theresa” no.1, 1019 Tirana, Albania.
E-mail: spocari@fim.edu.al, malcani@fim.edu.al

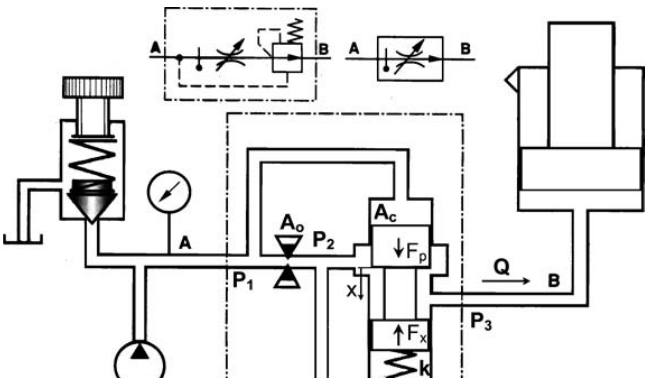

Figure 1 Schematic representation of the pressure-compensated flow control valve [10][11][13].

The two-way flow control valve operates as follows: In the steady state, the pressure difference across the main throttle reaches its required value, ΔP_t. The pressure and spring forces are in equilibrium and the spool gets in its steady-state position.

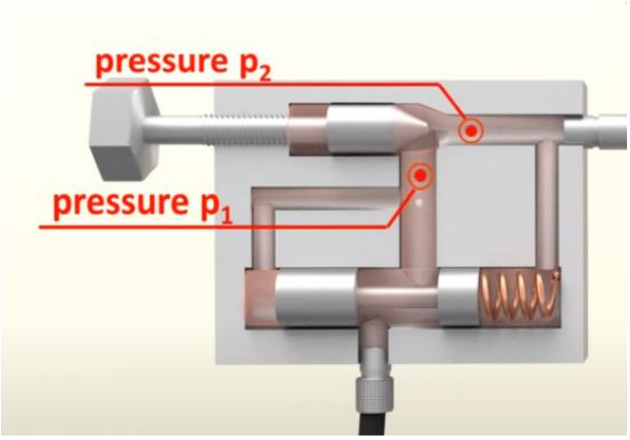

Figure 2 Cross section of the valve [10][11][14].

If the pressure difference is increased, $P_1 - P_2 > \Delta P_t$, the flow rate increases. Simultaneously, the spool moves downward, against the spring, to decrease the area of the spool valve restriction. The flow rate through the main throttle decreases and so does the pressure difference across the main restriction. Afterward, the valve again reaches the steady state, where $P_1 - P_2 = \Delta P_t$.
If the pressure difference is decreased, $P_1 - P_2 < \Delta P_t$, the flow rate decreases. The pressure force acting on the compensator spool becomes less than the spring force. The spring pushes the spool upward, increasing the restriction area of the spool valve. The flow rate through the main throttle and the pressure difference ($P_1 - P_2$) increase until they reach the required steady-state values. The pressure compensator acts constantly to compensate for the effect of the variation of supply and load pressures. In the steady state, the spool of the pressure compensator is in equilibrium. To study the behavior of this valve, we built a mathematical model. Through the LabView program we have built a simulation program. To confirm the truth of the simulation program, we have also built an experimental stand as shown in Figure 3.

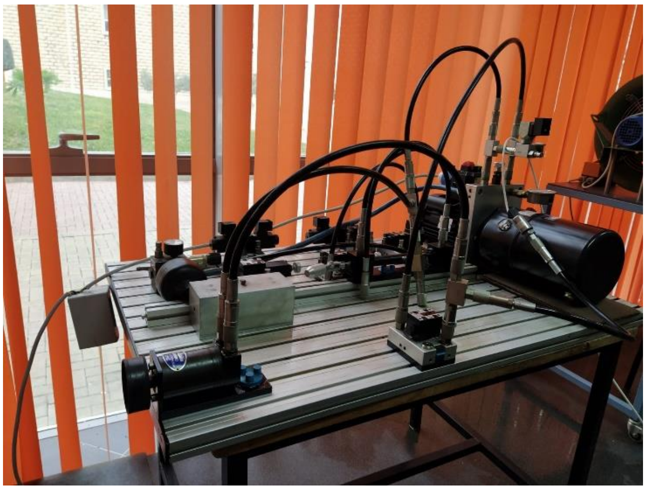

Figure 3 Experimental panel for measuring valve characteristics [15].

Figure 4 Pressure-Compensated Flow Control Valves [15].

2 MATHEMATICAL MODEL

For the construction of the mathematical model of the flow regulating valve with pressure compensation, we will refer to the force balance equation:

$$M \cdot x'' = -k_s \cdot (x_0 + x) - c \cdot x' + F_p \tag{1}$$

Where:
- x piston displacement
- x_0 the initial compression of the spring
- M mass of spool and spring together
- c coefficient of friction of the fluid
- k_s spring stiffness coefficient
- F_p force created by pressure differential

$$F_p = A \cdot (p_1 - p_2) \tag{2}$$

Where:
- A piston surface
- P_1 pressure at the inlet of the narrowing of the valve
- P_2 pressure in the pipe connecting the hydraulic motor

Substituting Eq. 2 in equation 1, and simplifying the mathematical relation, we get:

$$M \cdot x'' + k_s \cdot (x_0 + x) + c \cdot x' = A \cdot (p_1 - p_2) \tag{3}$$

The relation that expresses the passage of fluid in narrowed sections:

$$Q = C_d \cdot A_o \cdot \sqrt{2 \cdot (P_1 - P_2)/\rho} \tag{4}$$

Where:
- A_0 passage area
- C_d discharge coefficient
- P_1 pressure at the inlet of the narrowing of the valve
- P_2 pressure in the pipe connecting the hydraulic motor
- ρ fluid density

3 PROGRAMMING IN LABVIEW

To study the behavior of the valve in dynamic working conditions, as well as to analyze and improve its performance, based on the mathematical model described above, we have built a simulation program in LabView.

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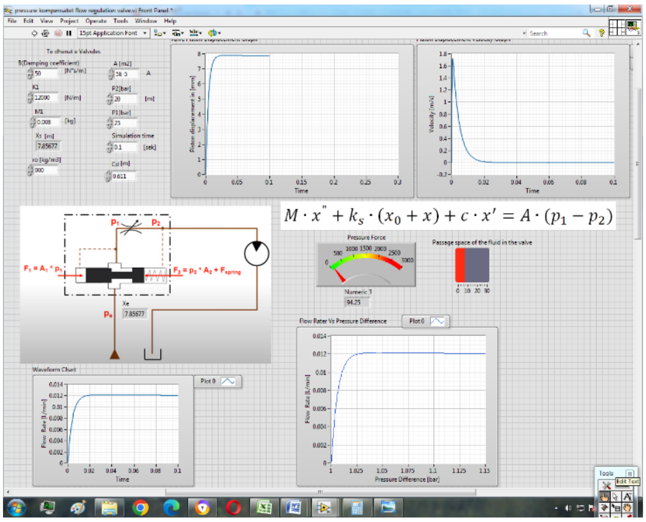

Figure 5.1 Front panel of the program built in LabView [15].

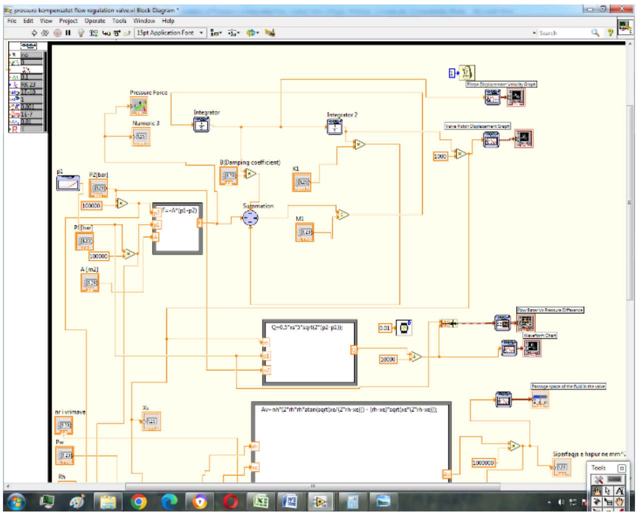

Figure 5.2 Block diagram of the program build.

4 SIMULATION RESULTS

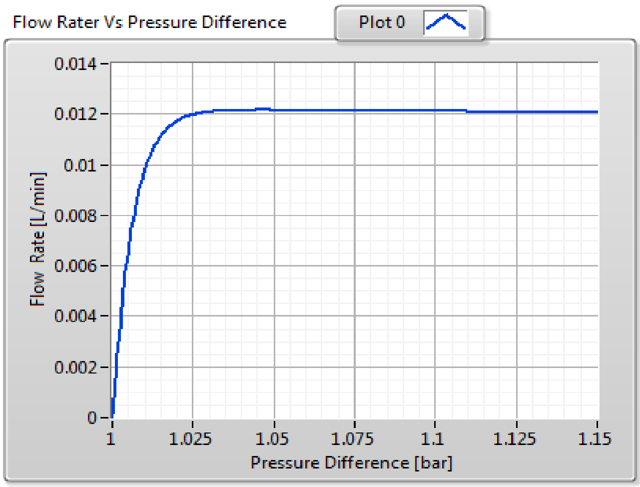

Figure 6 The dependence of the flow passing through the valve on the pressure difference.

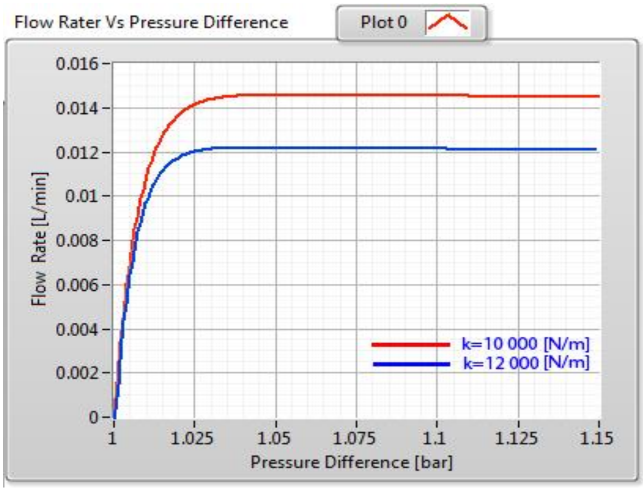

Figure 7 The influence of the value of the spring stiffness coefficient on the performance of the pressure-compensated flow valve.

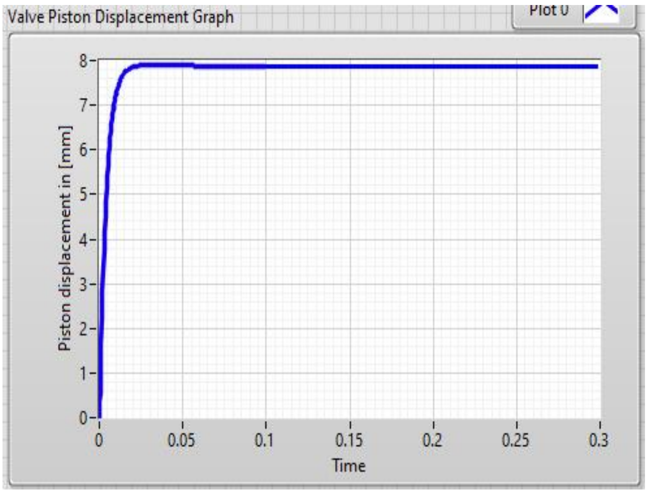

Figure.8 Spool displacement in time with damping coefficient 50 [N·s/m].

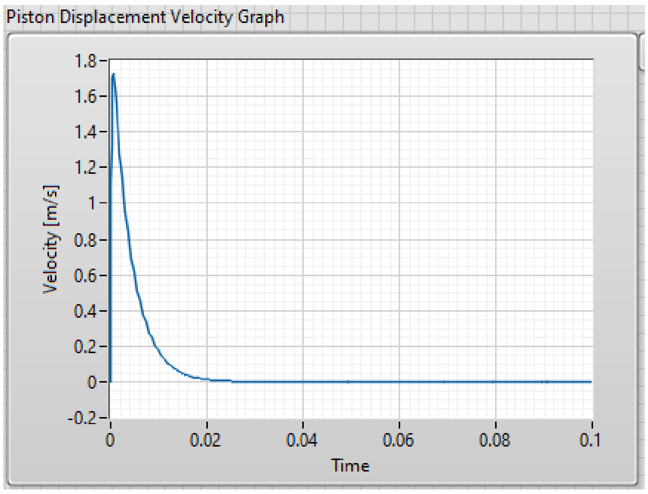

Figure 9 Spool velocity m/s with damping coefficient 50 [N·s/m].

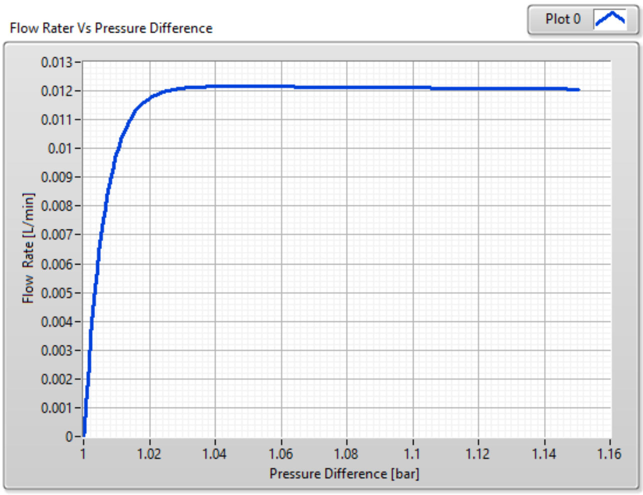

Figure.10 Flow rate Vs Pressure difference, with damping coefficient 50 [N·s/m].

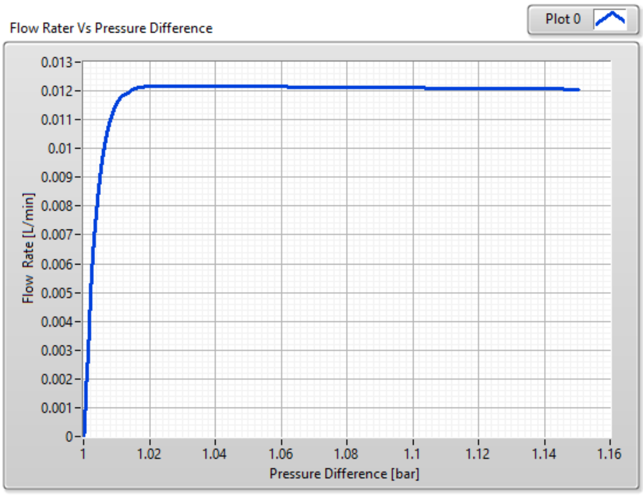

Figure 13 Flow rate Vs Pressure Diffesence, with damping coefficient 30 [N·s/m].

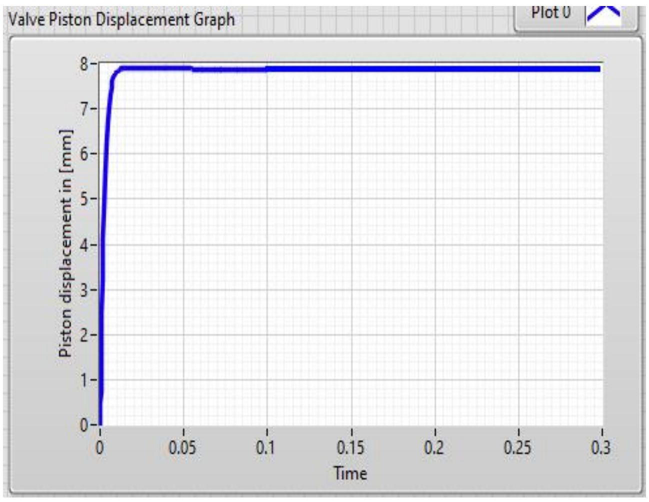

Figure 11 Spool displacement in time with damping coefficient 30 [N·s/m].

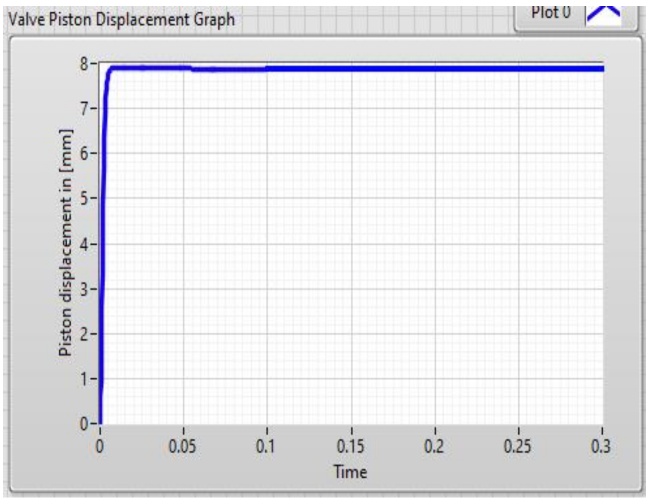

Figure 14 Spool displacement in time with damping coefficient 20 [N·s/m].

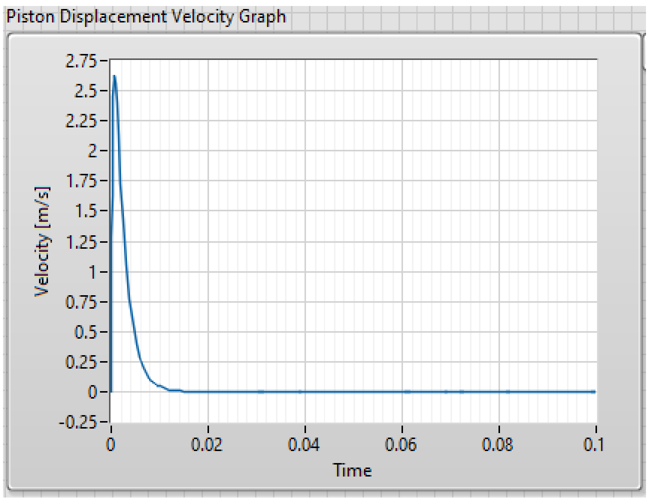

Figure 12 Spool velocity m/s with damping coefficient 30 [N·s/m]

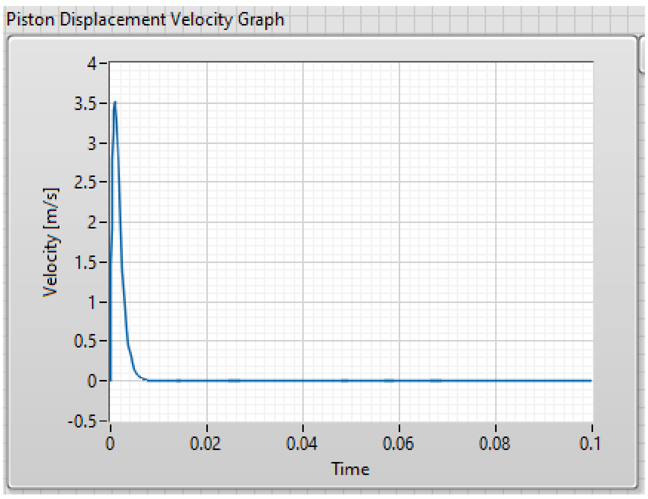

Figure 15 Spool velocity m/s with damping coefficient 20 [N·s/m].

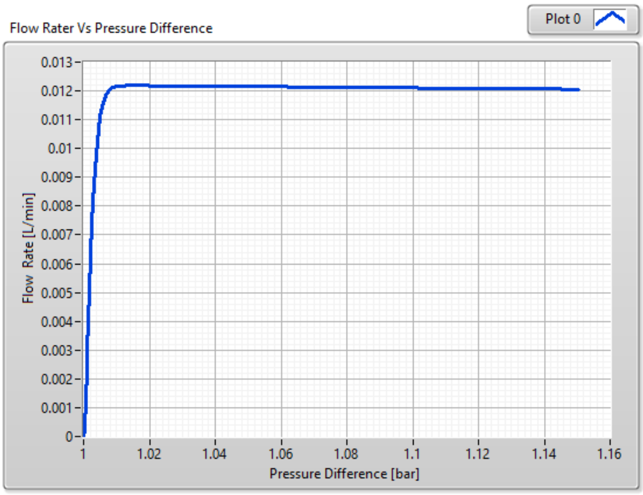

Figure 16 Flow rate Vs Pressure difference, with damping coefficient 20 [N·s/m].

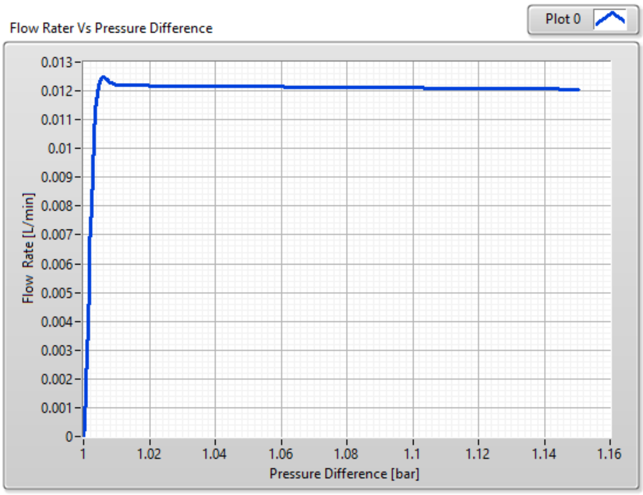

Figure 19 Flow rate Vs Pressure Diffesence, with damping coefficient 15 [N·s/m].

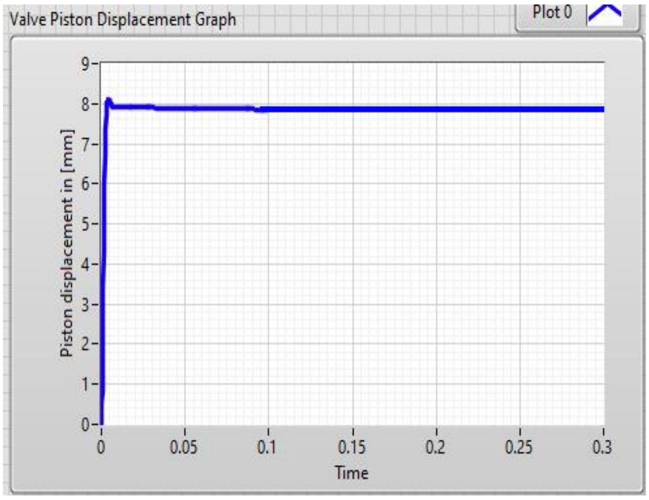

Figure 17 Spool displacement in time with damping coefficient 15 [N·s/m].

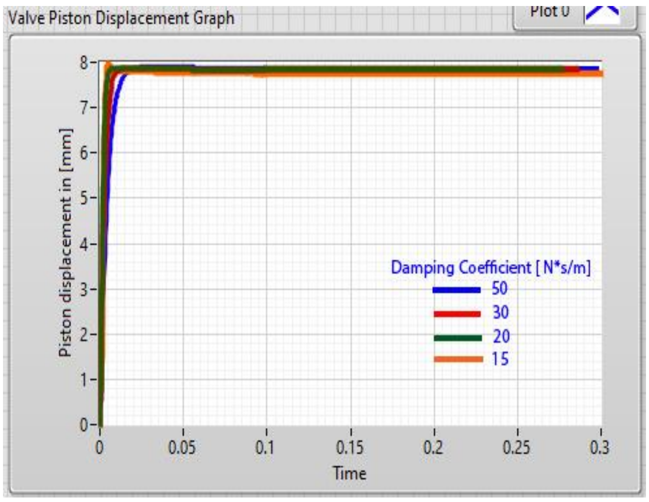

Figure 20 Superimposition of spool displacement graphs for different values of damping coefficient.

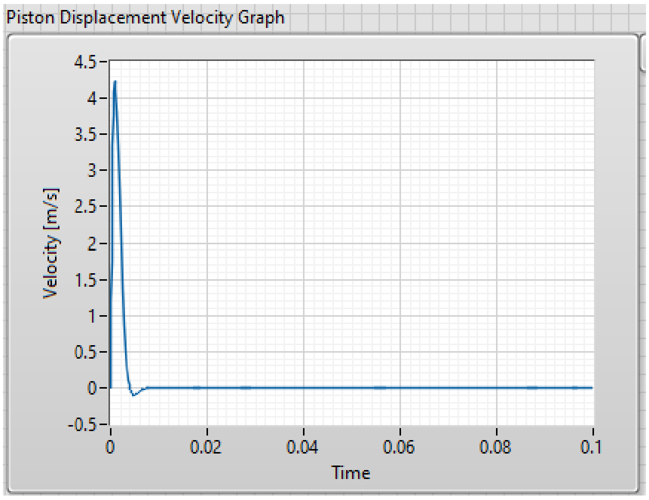

Figure 18 Flow rate Vs Pressure difference, with damping coefficient 15 [N·s/m].

5 EXPERIMENTAL RESULTS

To study the behavior of the pressure-compensated flow limiting valve, we built an experimental stand consisting of the pump, oil tank, pressure-compensated flow control valve, hydraulic motor and connecting pipes. During the experimental tests, the pressure was measured at the outlet of the valve and at the inlet of the hydraulic motor for different engine loads. the rotation speed of the motor was measured. As can be seen from the graphs in the figure. 22 and figure 23, the application of the load in the hydraulic motor is accompanied by an increase in the pressure at the outlet of the valve and at the inlet of the hydraulic motor.

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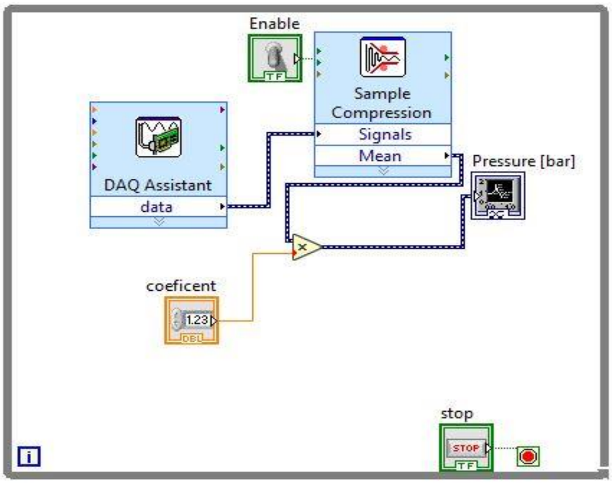

Figure 21 The program built in LabVIEW for measuring pressure [15].

Figure 22 Pressure graph measured at the inlet of the hydraulic motor, without load.

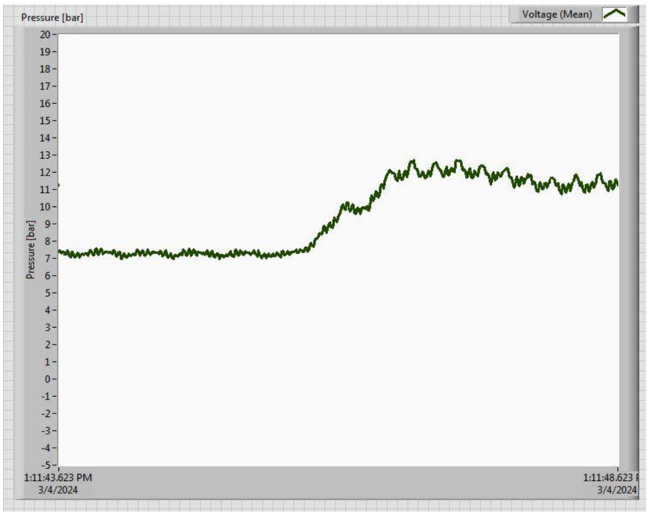

Figure 23 Pressure graph measured at the inlet of the hydraulic motor, with variable load.

6 CONCLUSIONS

1. The pressure-compensated flow control valve is an important component in hydraulic plants. it keeps the speed of the hydraulic motor constant even if the load on the motor changes.
2. The adjustment of the speed of the hydraulic motor is carried out according to the construction and the pressure difference. The adjustment of the speed of the hydraulic motor is carried out according to the construction and the pressure difference. To extinguish pressure fluctuations in the system which directly affect the flow given by the valve and the latter in the speed of rotation of the engine or the hydraulic piston, the valve system is equipped with a hydraulic shock absorber. The influence and values of which we have studied through the built simulation program.
3. From the performed simulations, it is noticed that by reducing the value of the damping coefficient from 50 N*s/m to 30 and then 20, we have an increase in the performance of the valve, its reaction to load changes is faster, as it can be seen from the graphs of the dependence of the flow on the pressure figure 10,13,16. which is also confirmed by the graphs of the speed of the python shown in figure 9,12,15. where the increasing value of the piston action speed is seen as a response to the change in oil pressure as a result of the load change.
4. With the reduction of the value of the damping coefficient to 15 N*s/m, it is noticed that the system goes into a non-stationary state, as shown in figure 17,18,19.
5. Another parameter that significantly affects the performance of the valve is the stiffness coefficient of the spring, as shown in the graph in Figure 7.

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