

NUMERICAL ANALYSIS OF A CONTROL STRUCTURE FOR VARIABLE PUMPS

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Abstract: *Due to the advantages of hydraulic systems with variable displacement was necessary to design a control system, that contain sensors required for different structures of adjustment and that can be easily integrated into the pump construction without change of its mechanical structure. The mathematical model of the control system studied in this paper is based on differential equations that take into account nonlinear influences such as pressure and flow rate dependence of leakage, saturation flow, pressure limiting, etc., so the deviations from the real behavior be as small.*

Keywords: *electro-hydraulic system, numeric simulation, mathematical model.*

1. Introduction

Essential trends, manifested today in construction of hydraulic machines are those of flexibility and automation, meaning to increase their level of intelligence and adaptation to possible disturbances.

Introducing the concept of flexible system that involved the creation of auto-tuning systems capable to adapt to changes in manufacturing technology, through minimum intervention, and also adaptation in relation of any disturbing factor, gathered in a fully automated assembly in which human intervention is minimized or not required. The elimination in general almost complete of the human operator has led to increased productivity by drastically reducing the time needed for big decisions, the handling of semi-manufactured products, by intervening in the case of tool wear, the diagnosis and the service.

A synthesis of experimental studies and researches conducted in recent years, on adjustable pumps and motors is presented in the paper [1]. Are presented in a coherent manner both experimental studies and numerical analysis for a wide range of control structures. This paper is actually a synthesis of studies over two decades of a team of researchers at the Institute Hydraulic and Control Aachen, Germany.

Variable displacement pumps allow a control of energy, virtually with no loss in the main hydraulic circuit. Their use in hydraulic systems under perturbations, implies the existence of a regulator, to ensure a parameter of hydraulic power or even the power at a required level.

Currently this types of variable displacement hydraulic machines are manufactured:

- with vanes
- with axial pistons
- with radial pistons

The command of the displacement can be done in two ways:

- proportional to a mechanical parameter (pressure, force, movement);
- proportional to an electrical parameter (voltage, current intensity).

As above, automatic control systems of pumps are classified in:

- mechano-hydraulic;
- electro-hydraulic.

Although starting from the '80, companies with a tradition in manufacturing pumps and motors with axial piston and variable displacement, produce this machineries for high automation hydraulic systems (Rexroth, Bosch, Vickers, Parker.) the existing data in the literature on constructive solutions are few.

2. Electro-hydraulic system description and mathematical model

Below is presented a schematic diagram for automatic control system proposed for implementation in a research program, in two versions. The difference between the two diagrams lies in the linear hydraulic motor control. In the first case the motor is commanded with two variable hydraulic resistors for motor control, and in the second case we have four variable hydraulic resistor that control the hydraulic linear motor.

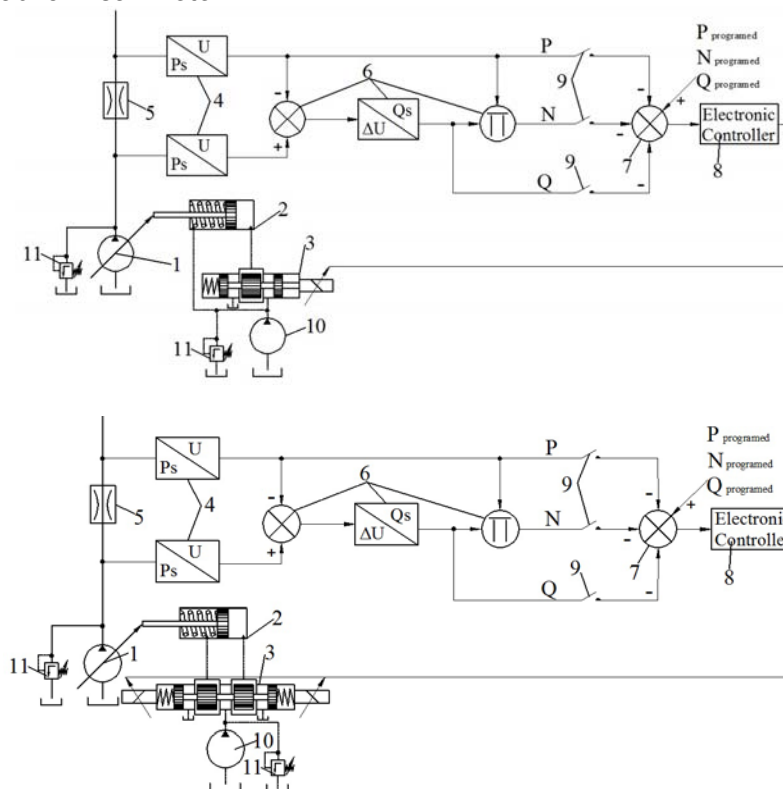


Fig.1. Electro-hydraulic control system for variable displacement hydraulic machines

The system contains the following components: 1 - variable displacement pump with axial pistons; 2 - linear hydraulic motor need to change the angular position of the piston block holder so modify the flow of the pump; 3 – proportional directional valve, that control the position of the linear motor; 4 - pressure sensors; 5 – diaphragm, needed to measure the flow rate of the pump; 6 – electronic circuits with the following attributes: calculate the pressure drop on the diaphragm, then determine the flow, and then with the signal from a pressure sensor and the signal that represents the flow is obtained the hydraulic power consumption; 7 - electronic comparator, designed to find the error between programmed and actual value of the adjusted parameter (pressure, flow, power); 8 – electronic controller, used to compensate the error and gives the command signal for proportional valve; 9 - switches whose state determines the control structure; 10 – fixed displacement pump, provides the necessary flow for positioning hydraulic motor; this flow can be taken from the adjustable

pump's flow, in this case the auxiliary pump is no longer required; 11 – relief valve, protects the system to not exceed the permissible pressure in hydraulic components.

The equations system of the model in which the motor is controlled by a bridge with hydraulic resistors of type A+E is:

$$\left\{ \begin{array}{l} \dot{p}_A = \frac{E_u}{V_A + A \cdot x_m} (k_v \cdot x_{v1} \cdot \sqrt{p_a - p_c} - A \cdot \dot{x}_m - k_v \cdot x_{v2} \cdot \sqrt{p_a}) \\ \dot{p}_B = \frac{E_u}{V_B + \alpha \cdot A \cdot x_m} (Q_c - \alpha \cdot A \cdot \dot{x}_m - k_v \cdot x_{v1} \cdot \sqrt{p_a - p_c}) \\ m_p \cdot \ddot{x}_m = A \cdot p_A - \alpha \cdot A \cdot p_B + F_{am} + k_m \cdot x_m - (c_3 + c_4) \dot{x}_m + \frac{m \cdot \omega^2 \cdot R^2}{a^2} \cdot x_m - \frac{\pi \cdot d^2 \cdot R}{4a} \\ U = K_p \cdot (U_{ref} - U_r) + T_d \cdot (\dot{U}_{ref} - \dot{U}_r) + \frac{1}{T_i} \int (U_{ref} - U_r) \cdot dt \end{array} \right. \quad (1)$$

The equations system of the model in which the motor is controlled by a bridge with hydraulic resistors of type A+A is:

$$\left\{ \begin{array}{l} \dot{p}_A = \frac{E_u}{V_A + V_T} \cdot [Q_A - A \cdot \dot{x}_m - c_{LG} \cdot \dot{x}_m + c_{LP} \cdot (p_A - p_B)] \\ \dot{p}_B = \frac{E_u}{V_B + V_T} \cdot [-Q_B + \alpha \cdot A \cdot \dot{x}_m - c_{LG} \cdot \dot{x}_m + c_{LP} \cdot (p_A - p_B)] \\ Q_A = \begin{cases} \alpha_Q \cdot d_v \cdot \pi \cdot x_v \cdot \sqrt{\frac{2}{\rho} \cdot (p_c - p_A)}, & x_v \geq 0 \\ \alpha_Q \cdot d_v \cdot \pi \cdot x_v \cdot \sqrt{\frac{2}{\rho} \cdot (p_A - p_T)}, & x_v < 0 \end{cases} \\ Q_B = \begin{cases} \alpha_Q \cdot d_v \cdot \pi \cdot x_v \cdot \sqrt{\frac{2}{\rho} \cdot (p_B - p_T)}, & x_v \geq 0 \\ \alpha_Q \cdot d_v \cdot \pi \cdot x_v \cdot \sqrt{\frac{2}{\rho} \cdot (p_c - p_B)}, & x_v < 0 \end{cases} \\ T_v \cdot \dot{x}_v + x_v = K_v \cdot U \\ U = K_p \cdot (U_{ref} - U_r) + T_d \cdot (\dot{U}_{ref} - \dot{U}_r) + \frac{1}{T_i} \int (U_{ref} - U_r) \cdot dt \\ m_p \cdot \ddot{x}_m = A \cdot p_A - \alpha \cdot A \cdot p_B + F_{am} + k_m \cdot x_m - (c_3 + c_4) \dot{x}_m + \frac{m \cdot \omega^2 \cdot R^2}{a^2} \cdot x_m - \frac{\pi \cdot d^2 \cdot R}{4a} \end{array} \right. \quad (2)$$

Thus without change in pump construction, this can be integrated into any control circuit for adjustable hydraulic machines, by simply actuation of an electrical switch.

In the following are presented the programs carried out using software package MATLAB (Simulink) for numerical simulation of two models.

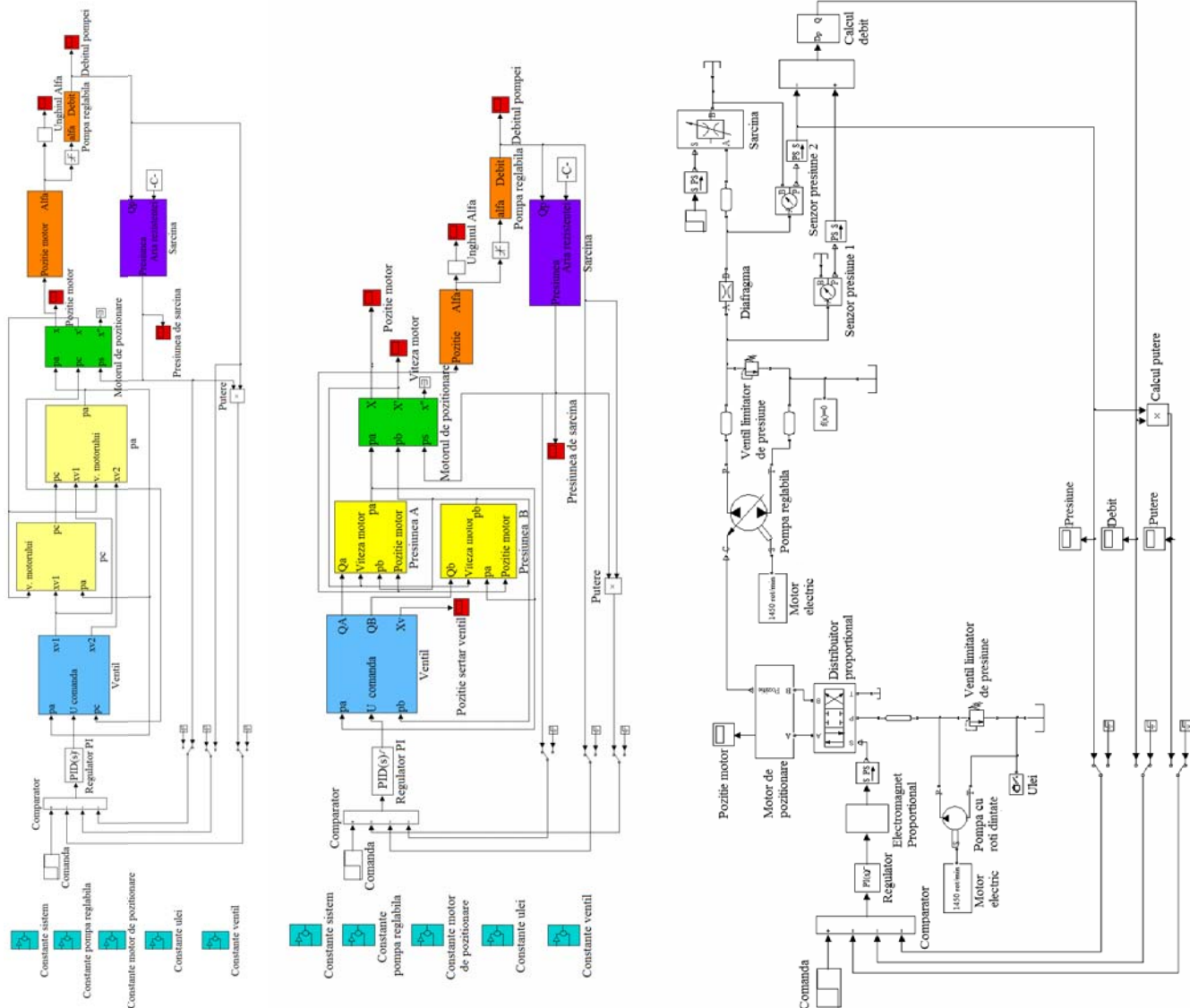


Fig.2. Simulink program

3. Simulations results

The objective of this work was to study the dynamic behavior of an electro-hydraulic control system for adjustable hydraulic pumps. This involved the use of concrete values for the physical and geometrical sizes involved in the model. Thus was chosen a F3 type, axial piston pump with variable displacement, made in Romania.

The PID controller was tuned using Ziegler-Nichols method.

First its analyzed the behavior of the system like response to step command for pressure, flow and power.

When adjusting the pressure the control step represents the input signal corresponds to a variation in load pressure of 0 to 200 bar. When setting the flow the control step representing the input

signal corresponds to a variation in flow of 0 to 30 l / min. In the version of control the power the step control that represents the input signal corresponds to a change in power in 0-5 kW.

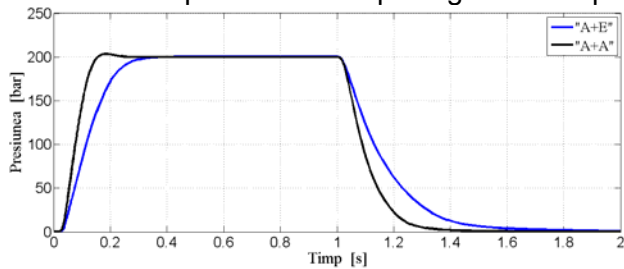


Fig.3. System response to step command from 0 to 200 bar

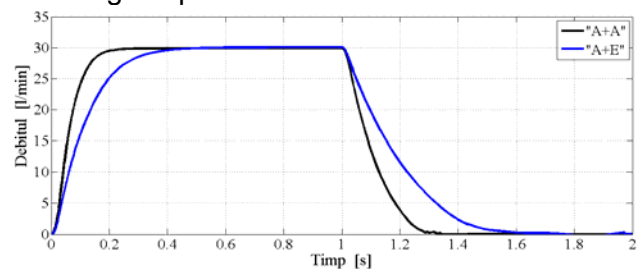


Fig. 4 System response (0 to 30 l/min)

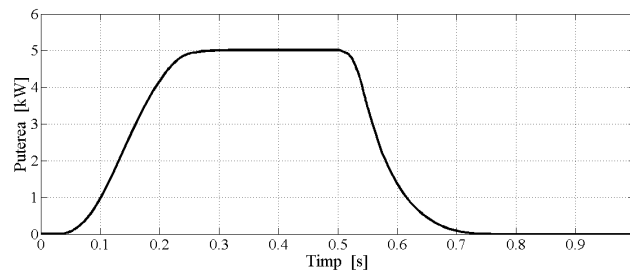


Fig. 5 System response (0 to 5 kW)

Then was studied the influence of hydraulic capacity, the areas ratio of the positioning motor and the load on the dynamic behavior.

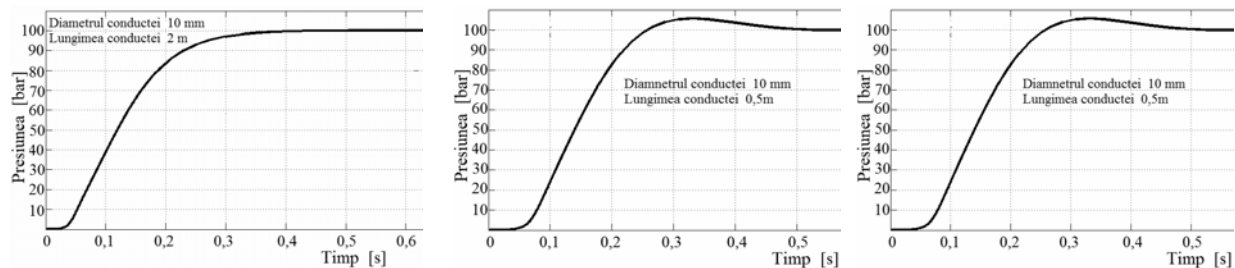


Fig. 6 Hydraulic capacity influence

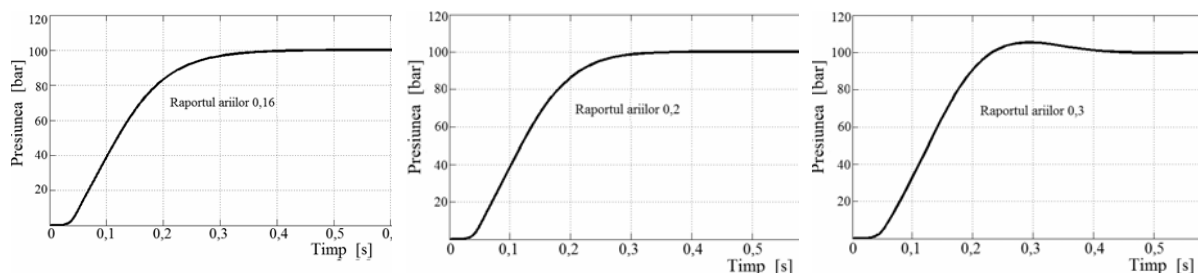


Fig. 7 Influence of the surfaces ration of the positioning motor

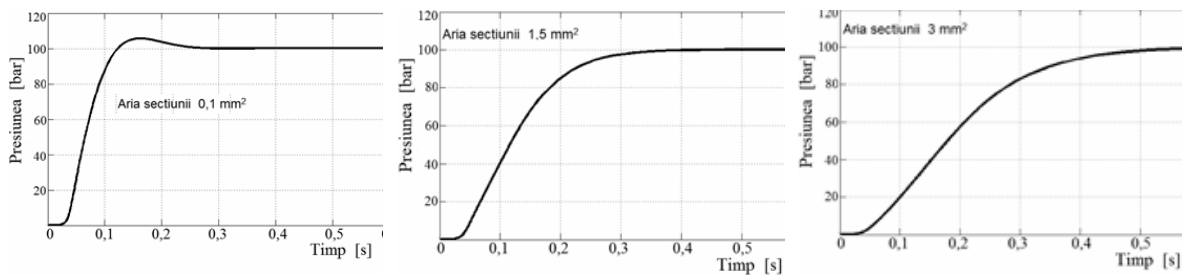


Fig. 8 Influence of the load variations

4. Conclusions

The static and dynamic performances of the system investigated:

- ✓ Stability - well-damped.
- ✓ Rapidity - response time less than 0.5 s.
- ✓ Precision - stationary error under 2.5%.

show that it can be used to adjust the variable displacement pumps considering the performances required by industrial applications

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