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Mathematical modeling of a hydraulic drive for leveling the support table of a robotic drilling platform

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Abstract. The principle of moving a hydraulic drilling platform is described. To study the dynamics of transient response processes of hydraulic drive for leveling, a mathematical model was created. The structural diagrams of mathematical models of the actuator and hydraulic control valve are given. The time dependences of the spool positions of the hydraulic control valve and the hydraulic cylinder rod are presented. The dependences of pressure changes in the rod and piston cavities of the hydraulic cylinder are presented.

1 Introduction

Nowadays, there are works around the world to create various extreme robotics tools for various industries. Traditionally, these are mobile robots with a single manipulator mounted on a moving platform with a wheeled or caterpillar propulsion. Their wide distribution is due to the simplicity of not only a mechanical design, but also a control system that does not require the use of complex algorithms. However, the functionality of such robots is much less than that of robots with several manipulators, as well as robots with a wheel-walking propulsion [1–4].

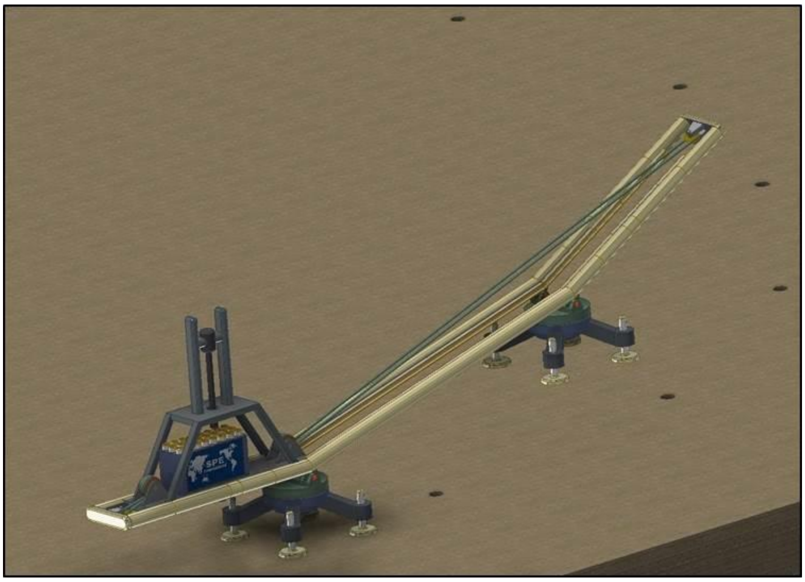

Fig. 1.3D model of a robotic drilling platform.

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To carry out geological exploration works on the seabed, it is proposed to use a robotic drilling platform with a stepper mover (utility model patent No. 166446 “Walking drilling rig”, utility model priority: 07/04/2016) (Fig. 1). The unit includes a farm, supports with platforms, hydraulic cylinders of supports, hydraulic cylinders of the supports of the supporting table, working body, control system. The load-bearing frame is made of two parallel pipes with long carriages and is equipped with eyelets pivotally connected to the support platforms, while the ends of the pipes are rigidly connected by bridging beams with blocks placed on them. The working body is made in the form of a trolley with rollers connected with the long carriages of the farm, with a drilling rig rigidly fixed on it and two draw-works equipped with flexible traction elements covering blocks of bridging beams, one end of which is fixed on the winch drum of draw-works and the other on the trolley of working body [5–6].

2 Methods

Description and principle of operation:

There are 3 groups of hydraulic actuators:

1st group. Basic hydraulic cylinders of a drilling platform;

2nd group. Hydraulic cylinders for leveling the support table;

3rd group. The hydraulic motor rotates the load-bearing frame relative to the support table. Of interest is a group of cylinders for maintaining the the support table horizontally (Fig. 2).

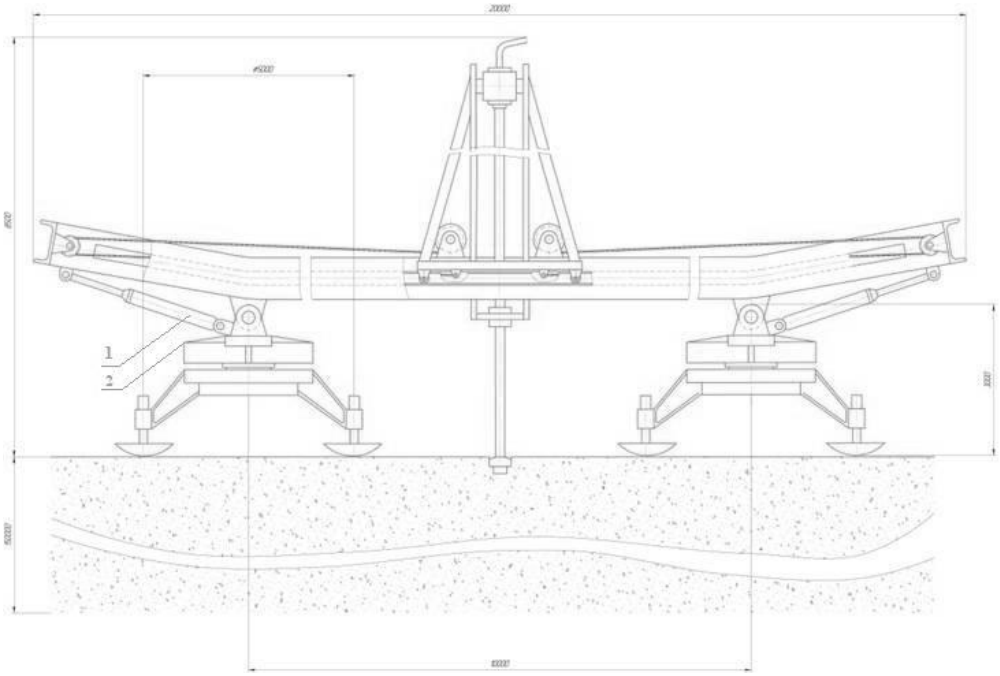

Fig. 2. Schematic construction of a robotic drilling platform.

Where: 1 — hydraulic cylinder for leveling the support table; 2 — supporting table.

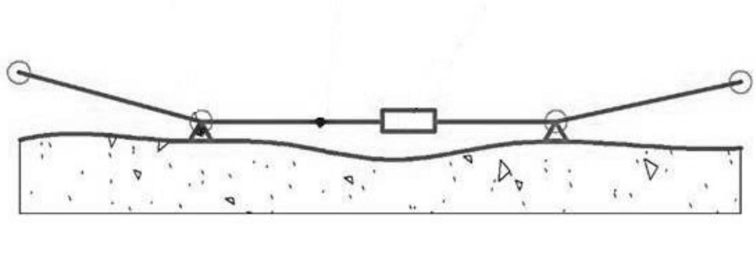

Fig. 3. Drilling platform in neutral position.

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When the platform is in the neutral position (Fig. 3), the working body (drilling assembly) is capable to drill the geological exploration wells. Then the draw-works is turned and the platform with the counterweight moves to the cantilever section along the long carriages, for example, from left to right. The frame will rotate around the horizontal axis of the right support table by an angle of 12 degrees and raise the left support up (Fig. 4). Then, the frame will be rotated using a hydraulic drive (Fig. 5) around the vertical axis by an angle of 20 degrees. [7–10].

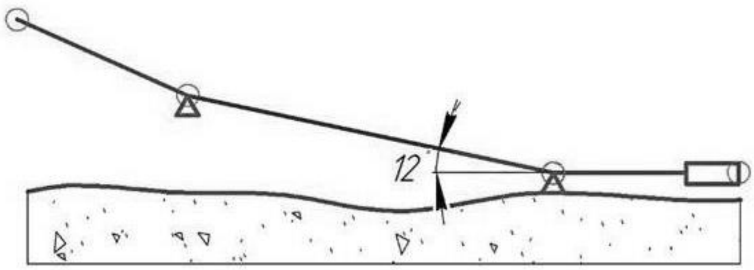

Fig. 4. Change in the center of mass of the system.

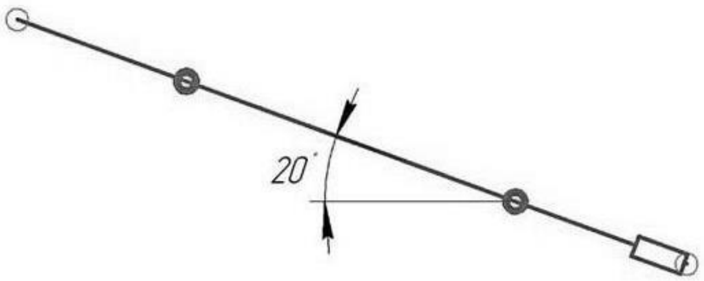

Fig.5. Rotation around the vertical axis

The process is repeated. The drilling assembly with a counterweight returns to its middle position and the left support table is brought down. Extended to the middle position, the rods of the support hydraulic cylinders at various times touch the bottom surface. The downward movement of the support table occurs until each of the hydraulic cylinders has touched the bottom surface and the pressure changes in the piston cavities of the hydraulic cylinders become equal to each other.

During downward movement of the left support table and equalization of pressure changes in the piston cavities of the hydraulic cylinders, the forces act on the table from the side of the cylinders for leveling (Fig. 6), which do not allow it to deviate from the horizon. To study the dynamics of transient response processes in the hydraulic drive for leveling(Fig. 7), its mathematical model was created.

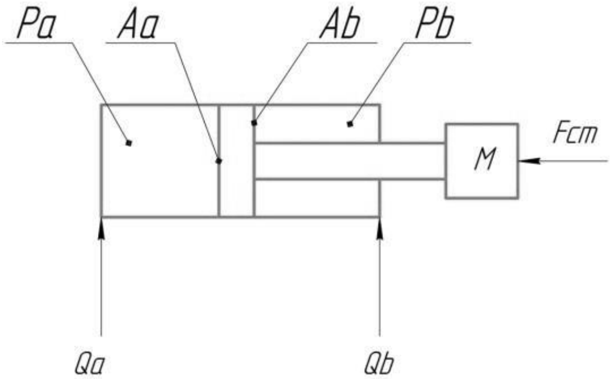

Fig. 6. The design scheme

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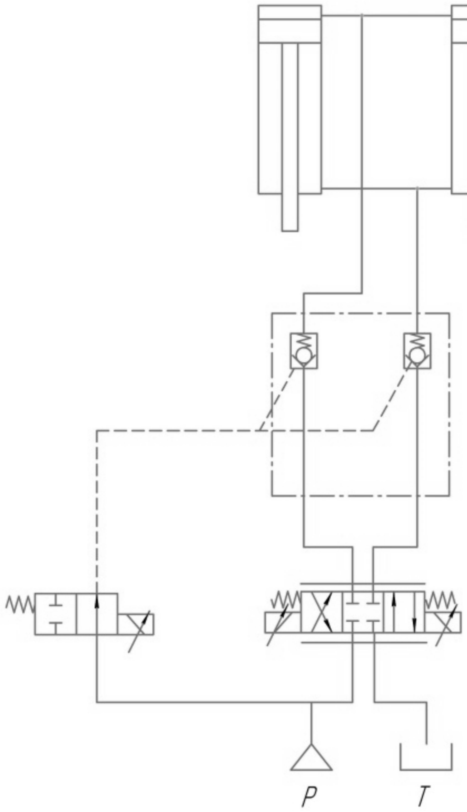

Fig. 7. The scheme of hydraulic drive for leveling the support table

The equation of motion is written:

$$M = p_A A_A l - p_B A_B l - bxl - F_{cm} l_{cm}$$

The pressure in the cavities is written taking into account the fluid compressibility:

$$p_A = \frac{E}{V_A}\left(Q_A - A_A x\right)$$

$$p_B = \frac{E}{V_B}\left(Q_B - A_B x\right)$$

A block diagram is drawn down (Fig. 8).

At the input, the flow rates QA and QB have to be given, the force F must also be indicated. The forces developed by the hydraulic cylinder, the arms of the forces, the areas of the piston and rod cavities of the hydraulic cylinder must be written.

3 Mathematical model of the control valve

A hydraulic control valve 4/3 model with a closed center is created and a variant of its design scheme is shown in the Fig. 9.

A cylindrical spool with three fillets is inserted into the barrel with the bores. Supply pressure is supplied to the central cavity, and the extreme ones are connected to the drain. The cavity between the fillets of the spool can be connected to the corresponding cavities of the hydraulic cylinder. The edges of the spool form throttling slots with the barrel bores, the areas of which depend on the displacement of the spool. [11]

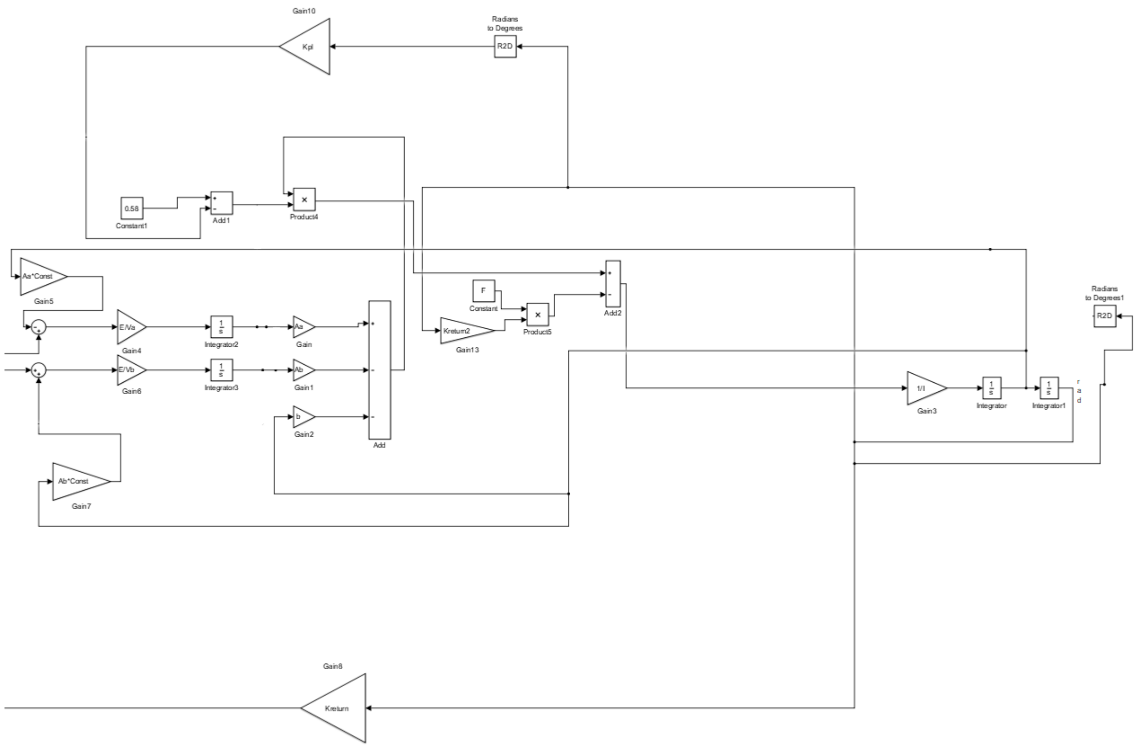

Fig.8. Structural scheme of mathematical model of actuator

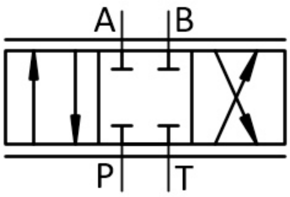

Fig.9. The scheme of hydraulic control valve 4/3 model with a closed center

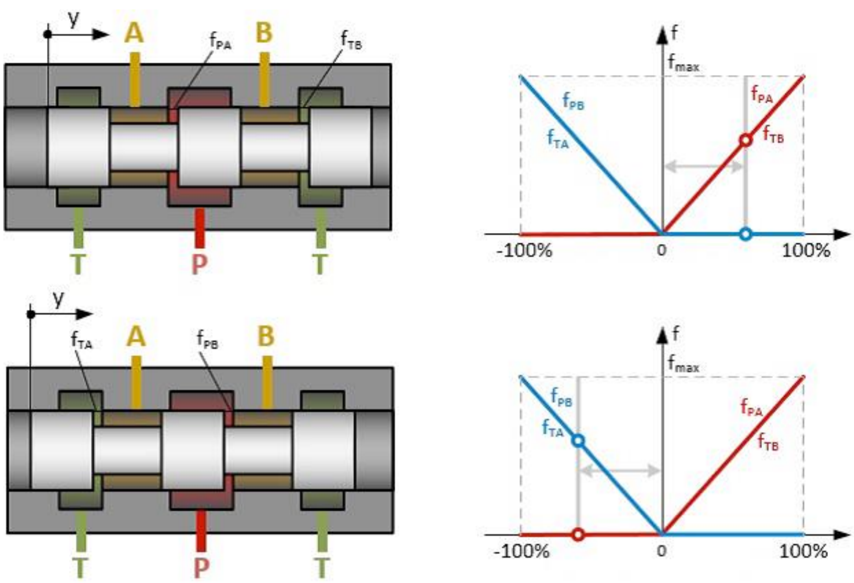

Fig. 10. The change in the opening area of the slot of hydraulic control valve

TA — connects the cavity A with drain;
PA — connects the cavity P with line A;
PB — connects the cavity P with line B;
TB — connects the cavity with a drain.

The dependence of the change in the opening area of the slot is shown in Fig. 10.

As in the case of the hydraulic cylinder model, all flow rates are movingt in one direction. The sign of flow rate will be determined based on the sign of the differential pressure. The formulas for the costs are:

$$Q_{PA} = \mu_S f_{PA} \sqrt{\frac{2}{\rho}\left|p_n - p_A\right|} \cdot sign(p_n - p_A);$$

$$Q_{PB} = \mu_S f_{PB} \sqrt{\frac{2}{\rho}\left|p_n - p_B\right|} \cdot sign(p_n - p_B);$$

$$Q_{TB} = \mu_S f_{TB} \sqrt{\frac{2}{\rho}\left|p_T - p_B\right|} \cdot sign(p_T - p_B);$$

$$Q_{TA} = \mu_S f_{TA} \sqrt{\frac{2}{\rho}\left|p_T - p_A\right|} \cdot sign(p_T - p_A).$$

To find all the necessary flow rates coming in or out of the control valve, it is necessary to algebraically add the corresponding components [8]:

$$Q_A = Q_{PA} + Q_{TA};$$
$$Q_B = Q_{PB} + Q_{TB};$$
$$Q_P = Q_{PA} + Q_{PB};$$
$$Q_T = Q_{TB} + Q_{TA}.$$

The structural scheme of the mathematical model of the control valve is shown in Fig. 11:

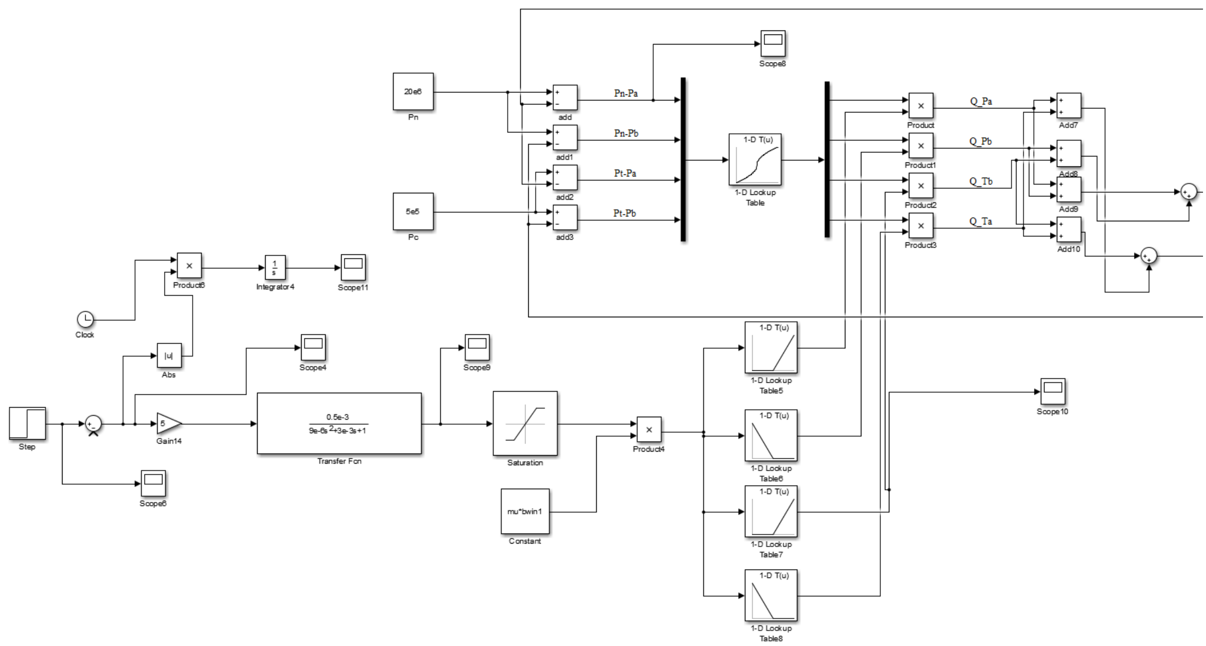

Fig.11. The structural scheme of the mathematical model of the control valve

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4 Results

When the maximum electric signal is applied to the inlet of the hydraulic control valve, the spool will displace by 1 mm (Fig. 12). Figure 13 shows the dependence of the position of the rod of the hydraulic cylinder on time. The pressures in the rod and piston cavities of the hydraulic cylinder are shown in Fig. 14.

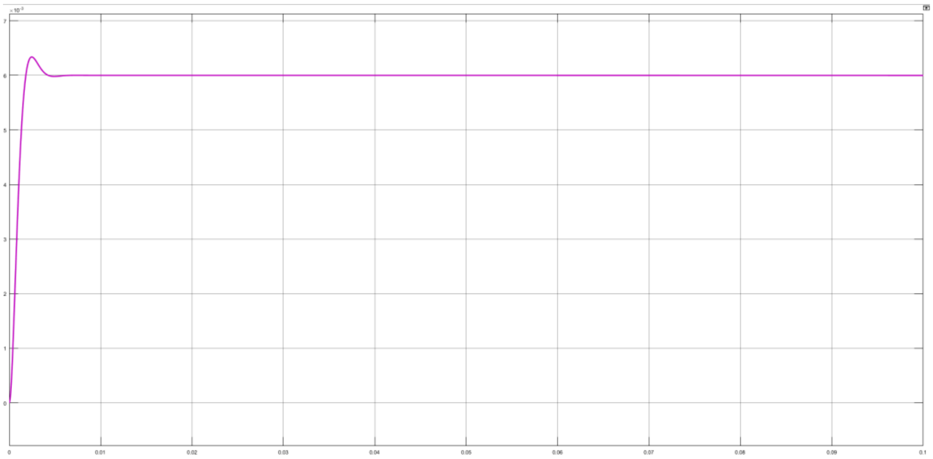

Fig.12. The displacement of the control valve spool

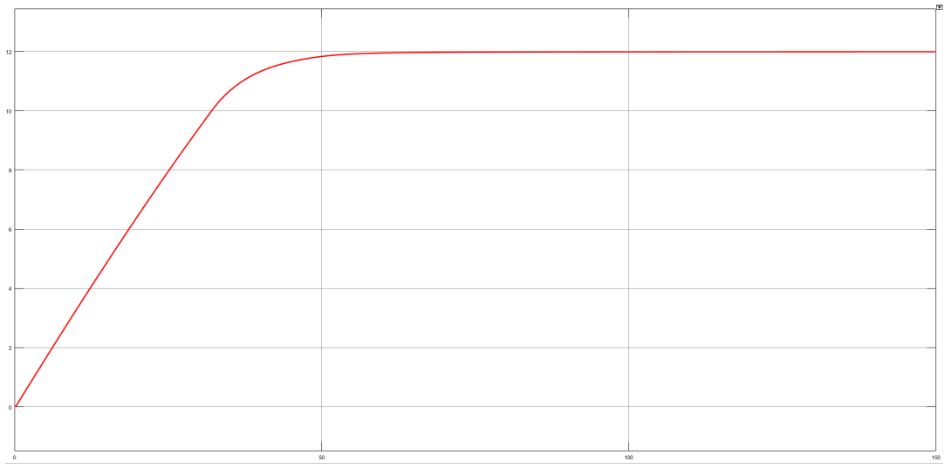

Fig.13. The extension of the rod in the hydraulic cylinder

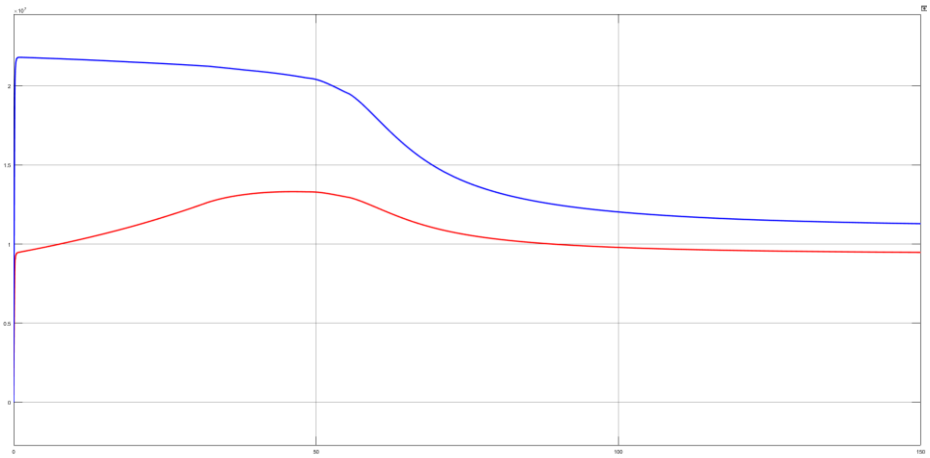

Fig.14. Pressure in the cavities of the hydraulic cylinder

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