Simulation of parameters of hydraulic drive with volumetric type controller

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Abstract. The article presents a mathematical model of volumetric type hydraulic drive controller that allows to calculate the parameters of forward and reverse motion. According to the results of simulation static characteristics of rod’s speed and the force of the hydraulic cylinder rod were built and the influence of the angle of swash plate of the controller at the characteristics profile is shown. The results analysis showed that the proposed controller allows steplessly adjust the speed of hydraulic cylinder’s rod motion and the force developed on the rod without the use of flow throttling.

Increase of fuel price and tightening of ecological requirements make the problem of increasing of earthmovers’ energy efficiency more and more actual.

Nowadays one of the ways to increase energy efficiency is using the combined power unit with volumetric hydraulic drive. It is characterized by high rate of power density and smooth control of operating parameters.

Traditionally hydraulic drive contains a pump with several hydraulic actuators as well as directional and regulating equipment. Nowadays it is spreading the electric and hydraulic drive with hydraulic actuators controlled by valves with proportional solenoids [1]. The drive is controlled by using of throttle regulator installed in series or in parallel that causes the increase of energy cost.

There is the variant of using the volumetric type controller operating as axial-piston hydraulic machine. In combination with control system it allows to recover energy when lowering the working bodies of the earthmover, improve it’s handling and increase efficiency of the entire power unit.

The use of the adjustable volumetric flow divider operating as axial-piston hydraulic machine in hydraulic transmission of mobile machines is considered in the work [2]. The use of gear-type volumetric flow divider is shown in the work [3].

This article is devoted to the modeling of processes in the volumetric hydraulic drive with the volumetric type controller that take place when working body of earthmover is moving.

When the earthmover’s working body is lifted by hydraulic cylinder the first and the second sections of the volumetric type controller operate in a pump mode and the third section operates in a hydraulic motor mode. Thereby the pressure generated in the pressure chamber of the hydraulic cylinder is higher than the pressure generated by the pump. When the earthmover’s working body is lowered the pump’s flow and pressure are not required, so the operating modes are changed allowing to use the hydraulic cylinder as a pump.
For calculation of required pump delivery at a known speed of the output link of hydraulic actuator (direct problem) and calculation of the speed of the output link of hydraulic actuator for a known pump delivery (inverse problem) we use the balance of the input and output flows of the volumetric type controller (fig. 1):

\[ Q_n + Q_d = Q_{II} + Q_{III}, \quad (1) \]

where \( Q_n \) – pump delivery, \( m^3/s \); \( Q_d \) – drain flow from the first section, \( m^3/s \); \( Q_{II} \) – the second section’s inlet flow rate, \( m^3/s \); \( Q_{III} \) – the third section’s inlet flow rate, \( m^3/s \).

We consider that according [4] the average flow rate of axial-piston hydraulic machine is defined as

\[ Q_{\varphi} = D \cdot \tan(\gamma) \cdot S \cdot n \cdot z \cdot \eta, \quad (2) \]

for the section operating in a pump mode and

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for the section operating in a motor mode and that the shafts of the controller’s sections’ shafts are rigidly connected so their rotation frequency is the same. Here \( D \) – the diameter of the pistons’ axes in the cylinder block, m; \( S \) – piston’s area, \( m^2 \); \( n \) – controller’s shaft rotation frequency, rps; \( z \) – number of pistons in the cylinder block; \( \gamma \) – the angle of the controller’s sections swash plates; \( \eta \) – volumetric efficiency of hydraulic machine (fig. 1).

The resulting system of equations allows to determine the speed of movement of the cylinder rod for various angles of controller’s swash plates at a given pump delivery.

For calculation of required pump pressure at a known external force load on hydraulic actuator (direct problem) and calculation of the load at a known pump pressure (inverse problem) we use the balance of forces on the hydraulic actuator, as well as the balance of moments on the shafts of controller’s sections operating in a motor mode –

\[ M_{II} = D_{III} \cdot \tan(\gamma_{III}) \cdot S_{III} \cdot z_{III} \cdot (p_n - p) \cdot \eta \]  

or in a pump mode –

\[ M_{III} = D_{III} \cdot \tan(\gamma_{III}) \cdot S_{III} \cdot z_{III} \cdot (p_n - \sigma) \cdot \eta \]  

After mathematical transformations provided that the sections I and II have the same dimensions we finally obtain the equations (2-5) representing a mathematical model of the proposed controller:

\[ F = S_n \cdot (p_n - \sigma \cdot p_B) \cdot \eta \]  

\[ n = \frac{Q_n}{D_{III} \cdot \tan(\gamma_{III}) \cdot S_{III} \cdot z_{III} \cdot \eta \cdot \sigma} \]  

\[ \nu = D_{II} \cdot \tan(\gamma_{II}) \cdot S_{II} \cdot n \cdot z_{II} \cdot \eta \]  

For the mathematical simulation of changes in the value of the cylinder rod’s effort \( F \) and its speed \( \nu \) at various angles \( \gamma \) of controller sections’ swash plates we use the software complex «MathCad v.15». We also define the following terms and conditions:
The sections I and II have pistons’ area $S_i = 3.14 \, \text{cm}^2$ and the diameters of the pistons’ axes in the cylinder block $D_i = 100 \, \text{mm}$;

- all sections have the same highest control angle $\gamma_i = 30^\circ$;

- the pressure in the return line of the cylinder $p_B$ and the outlet pressure of section III $p$ are zero;

- pump delivery $Q_n = 110 \, \text{l/min}$, pump pressure $P_n = 6.3 \, \text{MPa}$;

- diameter of cylinder’s rod $d_w = 80 \, \text{mm}$;

- volumetric and mechanical efficiency of hydraulic machines are averaged.

The simulation result is represented as dependence of the force on the cylinder’s rod $F_w$ from the angle $\gamma$ (fig. 2) and dependence of the cylinder’s rod extension speed $v_w$ from the angle $\gamma$ (fig. 3).

Figure 2 shows that the proposed controller allows to change the force on the cylinder’s rod $F_w$ towards larger values at a constant given pump pressure $P_n$ through the variation of the angle $\gamma$. At small values of the angle of the sections’ swash plates $\gamma$ the force $F_w$ sharply increases so it is necessary to provide the protection of the system from overload.

Dependence on the figure 3 shows that the proposed volumetric type controller allows to steplessly adjust the cylinder’s rod speed $v_w$ and the force on the cylinder’s rod without throttling the flow at a constant given pump delivery.

Thus, the use of the proposed volumetric type controller in earthmover’s hydraulic drive allows to adjust value of the force generated by hydraulic actuators without increasing the pump pressure and steplessly adjust the speed of the output unit without throttling the flow of hydraulic fluid. This will extend the range of regulation of power and speed characteristics that will significantly improve the earthmover’s handling without increasing the power plant capacity.

References

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