Improvement of Dynamic Characteristics of Membrane Magneto Hydraulic Pusher Using Mathematical Modeling

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Abstract: The work offers a new original design of the membrane magneto hydraulic pusher, which includes the body performed in the form of interconnected hydrocylinders of different diameters. A piston rod placed in the small-diameter hydrocylinder is performed with an opportunity of connection with actuating mechanism, while electromagnet armature placed in the large-diameter hydrocylynder located inside the direct current electromagnet coil is rigidly coupled with a rigidly fixed membrane. The space above membrane is connected with an under-piston area of the rod through armature and core holes, at that an above-piston rod area is connected with the area under membrane by pipe and regulating valve. The above-membrane area is connected by unilateral valve with the above-piston area of the rod and under-membrane area. The upper part of the armature is ended by mutually perpendicular projections with an opportunity of adjoining the electromagnet core that provides implementation of the conclusion drawn using mathematical modeling – the reasonability of reduction of adjoining area between armature and core for improvement of dynamic characteristics.

***Keywords**: Membrane, Magneto Hydraulic Pusher, Armature, Core, Power Fluid.*

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I. INTRODUCTION

A membrane magneto hydraulic pusher is used in such branches of industry, in which the electric process transformation into mechanical ones, in particular, into rectilinear translation is needed. It may be used as the brake drive of lifting-and-shifting machines.

For releasing the brakes of hoisting machines or mechanisms the electric energy is delivered both to the actuating mechanism drive and to their brake drive. In case of using magneto hydraulic pusher (MHP) as the brake gear, when the electric energy is delivered to the pusher, its rod lifts from the lowermost position to the uppermost one. In this moment, release of brake takes place and actuating mechanism starts to execute the engineering process. Based on this fact, it is desirable to make the rod lift time as small as possible, since the smallness of rod lift time of pushers used in machines and mechanisms is one of the main determining factors of enhancement of their reliable operation, productivity and durability.

MHP's rod lift time depends on the amount of pusher's electromagnet armature attraction time and the nature of this time change depends on both electromagnetic characteristics of the electromagnet, and on those mechanical or hydraulic resistances¸which are predermined by constructional features of MHP.

II. BASIC PART

Right after electric energy delivery to the pusher of MHP of any design, MHP electromagnet switches on and the electromagnet armature (in membrane MHP) or armature-piston (in membraneless MHP) when completely attracting to the electromagnet core, displaces a liquid located between them, delivers it to the under-piston area of MHP's rod and lifts the rod by a value of working stroke.

In case of complete attraction of armature or armature-piston they adjoin the plain ring face of the core by the upper plain ring end surface and remain in this position until the electricity is cut off from the MHP.

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When two plain surfaces approach each other in the direction of the normal, the resisting force of liquid displacement located between these two surfaces increases with the reduction of the thickness value of interfacial layer (the layer placed between the surfaces), and in case of small thickness of this layer the liquid displacement resisting force increases insomuch that reduces the encroaching speed of these two surfaces.

The same process takes place in MHP of any design, when the electromagnet armature or armature-piston attracts to the electromagnet core. With the decrease of clearance size between them during their attraction by flat faces the value of displacement resisting force for a liquid located between them is getting higher, thereby the velocity of armature (armature-piston) attraction to the core reduces that increases the rod lift time.

The equation describing the distribution of liquid pressure P located between armature and core during their attraction has a following form in the pre-existing membrane MHPs [1].

$$\frac{d}{d\rho}\left(\rho\frac{dP}{d\rho}\right) = \frac{12\mu}{h^3}\cdot\frac{dh}{dt}\rho, \qquad (1)$$

where μ is oil viscosity, P – pressure, t – movement time during armature attraction, h – armature stroke value, ρ – polar radius.

If one solves the problem for the equation (1) with the following boundary conditions.

$$\begin{cases} P|_{\rho=r} = P_o \\ P|_{\rho=R} = P_o' \end{cases} \qquad (2)$$

where P_o is a pressure in the hydrosystem.

ρ is a polar radius, while r and R are the small and major radiuses of the ring, then [2]

$$P = \frac{3\mu h'}{h^3}\left[(\rho^2 - r^2) + \frac{(R^2 - r^2)(ln\rho/r)}{\ln(r/R)}\right] + P_0 \qquad (3)$$

Integrating of (3) over the given ring gives us a resistance force.

$$F = \frac{3\pi\mu h' r^4}{2h^3}\left\{\left(\frac{R}{r}\right)^4 - 1 - \frac{\left[\left(\frac{R}{r}\right)^2 - 1\right]^2}{\ln(r/R)}\right\} + \pi P_o(R^2 - r^2) \qquad (4)$$

If one determines dt from (4) and afterwards integrates it from t_o to t_1, bearing in mind that when changing time from t_o to t_1, the armature will shift from h_o to h_1, so we get the ratio between time and armature stroke.

$$\Delta t = t_1 - t_o = \frac{3\pi\mu\left[\frac{1}{h_1^2} - \frac{1}{h_0^2}\right]\cdot[R^4 - r^4 - ((R^2 - r^2)/\ln(R/r)^2)]}{4[F - P_o\pi(R^2 - r^2)]} \qquad (5)$$

Based on formulas (4) and (5), reduction of armature abutment area to the core leads to decrease of F and Δt.

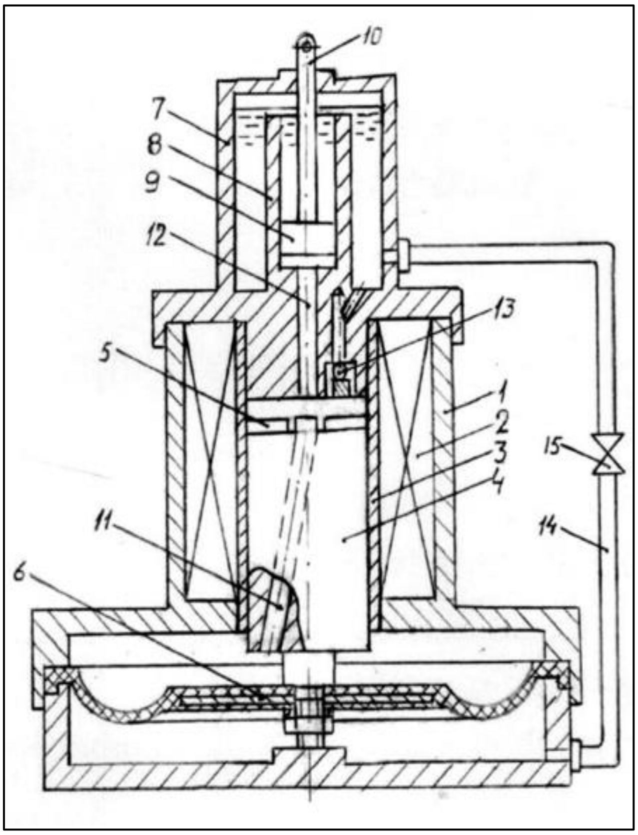

Fig 1 Membrane Magneto Hydraulic Pusher

Taking the all above-mentioned into account, we have developed the membrane MHP [3] (Fig. 1), which includes the body 1 performed in the form of interconnected hydrocylinders of the different diameter, at that, a rod 10 of piston 9 placed in the small-diameter hydrocylinder is performed with an opportunity of connection with actuating mechanism, while electromagnet armature 4 located in the large-diameter hydrocylynder situated inside the direct current electromagnet coil 2 is rigidly coupled with a membrane 6 rigidly fixed in the body, and the space above membrane is connected with an under-piston area 9 of the rod through armature 11 and core 12 holes, at that the above-piston area of the rod is connected with the under-membrane area by a pipe 14 and regulating valve 15, while the above-membrane area is connected by unilateral valve 13 with the above-piston area of the rod and under-membrane area, at this the upper part of the armature is ended by mutually perpendicular projections 5, with an opportunity of adjoining the electromagnet core.

When switching on the pusher, a current feeds direct current electromagnet coil 2 of the pusher, an armature 4 attracts to electromagnet core and starts upward stroke, and a membrane 6, while lifting up along with it, creates excessive

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pressure in its upper area and a working liquid through holes 11 and 12 is pumped in the under-piston area 9. As soon as the excessive pressure is created in the under-piston area 9, a piston along with a tappet rod rigidly bound with it lifts up by the distance equal to its working stroke. At that time, a valve 13 is plugged and doesn't let a working liquid to enter an tank 7, and a working liquid by means of branch pipe 14 and regulating valve 15 from tank 7 is soaked by a membrane 6 in the area below it. While attracting to the electromagnet core, armature 4 by means of projections 5 adjoins the flat face of a core. That is why, a working liquid is extruded on that small area of projection 5 only, by which an armature 4 adjoins the the core face and, respectively, liquid extrusion resistance force value is so small that is unable to reduce the lift speed of armature 4 and tappet rod 10 and lifting time of tappet rod 10 reduces. I.e. an armature 4 adjoins the core and tappet rod is in the uppermost operating position. The pusher remains in this position until electromagnet core of the pusher is not powered off.

If the end face of armature will have projections of l high and S area, then $\Delta t \rightarrow t_{min}$, when $S \rightarrow 0$. Though reduction of S will cause inadmissible increase in bearing stress σ_b and compression stress σ_c at the contact surface of projection and core face, especially in case of expectable impact between them.

That is why, as the optimum time of surfaces approximation one should consider the time, in case of which the following conditions are fulfilled.

$$\sigma_c = [\sigma_c]$$

And

$$\sigma_b = [\sigma_b]$$

Where $[\sigma_c]$ and $[\sigma_b]$ denote acceptable values of compression stress and bearing stress, respectively.

Calculation has to be made for projection material, which will be prepared from nonmagnetic material no less strong than the core material.

During impact event, the following data must be taken as the initial ones:

- ✓ Area S and height l of projection;
- ✓ Initial impact speed

$$V_i = \frac{2(h_1 - h_o) + V\Delta t}{\Delta t},$$

Using the calculated formula (5), in order to simplify calculation, a slowdown on the way from h_o to h_1 is considered as constant. V corresponds to h_o thickness and is determined by piston-armature motion law, prior to onset of slowdown caused by extruded oil resistance.

- ✓ Elasticity module E and acceptable compression stress $[\sigma_c]$ according to projection material.

Based on these data we calculate Poisson's ratio

$$\varepsilon = \frac{[\sigma_c]}{E}$$

And compression of projeciton of this elactic deformation.

$$\Delta l = l\varepsilon$$

For the impact first stage period τ.

If we consider elastic strain rate as uniformly decelerated from V_i to 0, we will be able to determine a time first.

$$\tau = \frac{2\Delta l}{V_i},$$

And afterwards – respective deceleration of armature.

$$\alpha = \frac{V_i}{\tau} = \frac{V_i^2}{2\Delta l},$$

Which gives us an impact force.

$$P_i = ma,$$

Where m is an armature mass.

Now we can check strength conditions.

$$\sigma_c = \frac{P_i}{S} \leq [\sigma_c]$$

And

$$\sigma_b = \frac{P_i}{S} \leq [\sigma_b]$$

If some of them is not satisfied we must change an active area of projection.

III. CONCLUSIONS

So, the use of the offered membrane MHP as the drive gear of machines and equipment enhances their efficiency, reliability and durability. This result is achieved thanks to the fact that the upper part of the armature is ended with the mutually perpendicular projections, that makes adjoining the electromagnet core possible, at that in the moment of adjoining by the projections the working liquid is displaced only to that small area of projections, by which the armature adjoins the flat end of the core, respectively the liquid displacement resisting force is so small that it is no more able to reduce the armature and piston lifting speed, and the rod lift time reduces. When the armature adjoins the core, the rod is in the uppermost working position, where the pusher

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remains until the electricity is cut off from the electromagnetic coil of the pusher.

REFERENCES

[1]. O.S. Ezikashvili and S.G. Bitsadze. Magneto hydraulic pusher. Authorship certificate №582188, USSR, 1977.

[2]. R. Bitsadze and S. Bitsadze. Determination of some dynamic characteristics of membrane magneto hydraulic pushers using mathematical modeling, International Journal of Innovative Science and Research Technology, vol.10, Issue 2, India, 2025, pp.1901-1904.

[3]. Bitsadze and R. Bitsadze. Magneto hydraulic pusher. Patent of invention P2022 7337B, National Intellectual Property of Georgia, 20-10-2022.