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Analysis of the pattern between the mass of the plunger and the translational motion maximum frequency of the working body of the electromagnetic action differential pump

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The article deals with the frequency of translational movement of the working body. The frequency is limited by the mass of the plunger. The operation of a differential pump of electromagnetic action and the design of a vibrating pump are described. The description of constructive structures of working bodies of the differential pump of electromagnetic action is presented. The characteristics of the differential pump indicate the kinematic parameters on which the maximum frequency of the working body depends. The article describes in detail the interaction between the working body and the solenoid of the differential pump. The influence of mass on the working bodies, the influence of geometric features on the mass of the plunger, and the frequency of translational motion are stated. The characteristics of working bodies made of different materials are presented and described in detail. This generally made it possible to analyse the design of the plunger of the differential pump of electromagnetic action. Due to the careful choice of material, as well as the design features of the working body of the differential pump its productivity is increased successfully.

Keywords: mass of the plunger, mathematical justification, maximum frequency.

Аналіз закономірності між масою плунжера та максимальною частотою поступального руху робочого органу диференційного насоса електромагнітної дії

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В статті йде мова про коливальні рухи плунжера диференційного насосу електромагнітної дії, які залежать від багатьох чинників, зокрема струм, що проходить крізь котушку насоса, геометричні розміри котушки (ширина та діаметр дроту з якого виготовлено котушку), матеріал з якого виготовлено дріт, активний опір котушки, реактивний опір соленоїда, опір оздоблювального матеріалу що перекачується який залежить від густини оздоблювального матеріалу та площі поперечного перерізу циліндра диференційного насоса, опір робочої та компенсаційної пружин диференційного насоса що безпосередньо пов'язано з діаметром дроту з якого виготовлено робочу та компенсаційну пружини, внутрішнім діаметром самих пружин та матеріалом з якого виготовлено дріт, сила тертя що в свою чергу залежить від матеріалу з якого виготовлено плунжер та циліндр диференційного насоса та степені механічного обробітку. Частота обмежена масою плунжера. Охарактеризована робота диференційного насоса електромагнітної дії та описана конструкція вібраційного насоса. Представлено опис конструктивних будов робочих органів диференційного насоса електромагнітної дії. Характеристика роботи диференційного насоса вказує на кінематичні параметри, від яких залежить максимальна частота робочого органу. В статті детально описано взаємодію робочого органу та соленоїда диференційного насоса. Констатовано вплив маси на робочі органи, вплив геометричних особливостей на величину маси плунжера та частоту поступального руху. Від вибору матеріалу, з якого можна виготовити робочий орган, залежить маса плунжера і максимальна частота робочого органу. Проведено детальний опис всіх процесів, котрі відбуваються в робочому органі. Представлені та детально описані характеристики робочих органів, які виготовлені з різних матеріалів. Це загалом дало можливість аналізувати конструкцію плунжера диференційного насоса електромагнітної дії. За рахунок ретельного вибору матеріалу, а також конструкційних особливостей робочого органу диференційного насоса вдалося збільшити його продуктивність.

Ключові слова: маса плунжера, математичне обґрунтування, максимальна частота.

Introduction

The acute problem of existing pumps is high metal and electricity consumption and low productivity. This is due to the large mass of working bodies. This article offers plungers for a differential pump made of different materials. When calculating the performance of the pumps, the geometric dimensions of the working bodies, the density of the material, and their weight were taken into account. The analysis was conducted in order to create a differential pump, the design of which is devoid of the above disadvantages.

Review of the research sources and publications

The operational characteristics of the differential pump of electromagnetic action are obtained experimentally. Kinematic data are determined theoretically. The main purpose of these studies is to increase the energy efficiency of the differential pump. In addition, the results of experimental tests of the pump affect the design of the differential pump. This problem is covered in [12 – 14]. This is especially true of the need to obtain reliable statistical parameters of the pump performance required to increase the pumping of the finishing material. This is described in numerous publications of the scientific school “Creation of theoretical foundations for calculation, design, and implementation of effective means of complex mechanization of finishing works in construction” of the National University “Yuri Kondratyuk Poltava Polytechnic” [1].

Definition of unsolved aspects of the problem

Nowadays, in the construction of pumping devices there is a need to manufacture transport mechanisms, which would consume a small number of consumables at maximum productivity and with minimum electricity consumption. It is also important to ensure maximum service life. The urgent task is to create a differential pump of electromagnetic action, capable of operating economically, i.e. to ensure maximum efficiency while consuming minimum power as a result of achieving high stability.

With an extraordinary variety of differential pumping systems of electromagnetic action, their internal versatility is diverse. The introduction of the required quality of the differential pump of electromagnetic action, which consumes a small amount of electricity, is a painful problem that is important for the development of pumping.

Problem statement

The main task of the article is to argue the results of studies of the two-way differential pump of electromagnetic action created for pumping the finishing material. A review of the literature on this topic and research has shown that the plunger has energy losses due to friction between the working body and the cylinder of the differential pump, the resistance of the working spring, and the resistance of the finishing material which reduces pump performance. The reason for the resistance of the finishing material is its density, the reason for the resistance of the working spring is its stiffness, and the sliding of the plunger is the reason for friction forces. The above-mentioned parameters are minimized. In order to make a differential pump with higher productivity, the following tasks are solved:

– during the manufacture of the working body from different materials, the performance of the pump was increased with equivalent power consumption;

– in order to increase the retraction force of the coil, its width was reduced;

– in order to find the optimal operation of the differential pump in which the pump will consume a small amount of electricity at high performance a three-dimensional graph called the kinematic characteristics of the differential pump was built.

Basic material and results

An alternating voltage is applied to the coil winding, under the action of which a single-phase current system flows in the windings. Since the winding in the differential pump of electromagnetic action is placed parallel to the working body, as in a symmetrical system the current in the winding has a phase shift with voltage, in such a winding a translational magnetic field is created. The translational magnetic field, crossing the plunger, induces an electromotive force in it. Under the action of this force, current flows in the working body, which distorts the magnetic field of the solenoid, increasing its energy [9-11, 15, 16]. This leads to an electromagnetic force, under the action of which the plunger begins to move (for a simpler explanation, we can refer to the Ampere force acting on the working body located in the magnetic field of the coil). In order for EMF to occur in the plunger, it is necessary that the speed of the working body differs from the speed of change of the poles of the coil.

The frequency of translational movement of the plunger (asynchronous frequency) is always less than the frequency applied to the solenoid, i.e. the working body of the differential pump always lags behind the coil. This phenomenon can be explained as follows: if the working body moves with the frequency of the translational field, this field does not penetrate the plunger. In the latter, there is no EMF and no currents, which means that the translational motion on the working body is zero. Thus, the actuator of the differential plunger in principle cannot move with synchronous frequency.

The relative difference between the speed of the plunger and the rate of change of the polarity of the coil is called a slide. The nominal slide is usually 2 – 8%.

At a frequency of 50 Hz, this speed can be different depending on the number of pole pairs of the coil ($p = 1$; $p = 2$; $p = 3$, etc.). To achieve a higher speed of translational movement of the magnetic field, the solenoid of the differential pump is fed with a high-frequency current. The speed of translational movement of the working body of the differential pump is regulated by changing the frequency of the supply current, or by changing the number of pairs of poles of the coil (step adjustment), as well as by changing the slide. The slide is changed by means of the active resistance, which is introduced into the secondary circuit of the differential pump, cascade circuits, or by changing the voltage applied to the coil of the differential pump of electromagnetic action.

Thus, the process of asynchrony between the working body and the magnetic field of the coil is due to the phenomenon of sliding, which is primarily determined and depends on: the frequency of the coil and the speed of the working body.

Seven working bodies of a differential pump are considered, each of which has had a different structure (Fig. 1-7) or was made of different materials (Fig. 8-14). Each plunger has its own weight depending on the density of the material and its size.

In the mathematical description of the sliding process of the working body, it is considered as a physical body having a mass of a certain value. Examine the case when the plunger is in the extreme right position. Knowing the kinematic values of the coil, the force of movement of the plunger to the left is determined [6]

$$\vec{F} = B \cdot \frac{w}{X_L} \cdot l \cdot \sin\alpha , \quad (1)$$

where B – magnetic induction T;
w – current frequency Hz;
X_L – reactance of the coil, Ohm;
l – wire length, m;
α – the angle between the direction of magnetic induction and current, grad.

During the movement of the plunger to the left, there are forces that are directed against the movement of the working body. One of such forces is the resistance force of the finishing material

$$\vec{F} = \rho \cdot g \cdot V , \quad (2)$$

where ρ – density of finishing material, kg/m^3;
V – the volume of compressed finishing material, m^3.

The next force that opposes the plunger movement to the left is the force of the working spring, the action of which is revealed by Hooke's law

$$\vec{F}_{sp} = -k \cdot \Delta l , \quad (3)$$

where k – the coefficient of stiffness of the working spring, N/m;
Δl – elongation of the working spring, m.

If the mass of the working body and the elongation coefficient of the working spring are experimentally determined, it becomes possible to know the stiffness coefficient, which in turn makes it possible to determine the force of the working spring

$$k = mg / l , \quad (4)$$

where m – plunger mass, g;
Δl – elongation of the working spring, m.

If the mass of the working body is experimentally determined, it also becomes possible to know the reaction of the support, which in turn makes it possible to determine the force of friction

$$N = m \cdot g , \quad (5)$$

where m – plunger mass, g.

The third and last force that opposes the movement of the working body is the friction force that occurs during the movement of the plunger on both sides and in both cases, it is opposite to the movement of the plunger

$$\vec{F}_{sp} = S \cdot N , \quad (6)$$

where S – the coefficient of sliding of the plunger;
N – support reaction.

Thus, taking into account the value of the plunger mass m, current frequency f and the number of pole pairs p the maximum frequency of the working body is determined [5]

$$n = \frac{f \cdot 50 \cdot p}{m}(1 - S) , \quad (7)$$

where f – frequency of alternating current of a power supply, Hz;
m – the mass of the working body, g;
p – the number of pole pairs;
S – the coefficient of sliding of the plunger.

Table 1 shows the kinematic dependence of the mass of the working bodies and the maximum frequency of the plungers and the friction force [2, 3, 4, 7, 8]. The table is structured by the mass of the plungers. The weight of the working body and the friction force are inversely proportional to the frequency of the plunger. The weight of the plunger and the diameter of the working body are directly proportional.

The numbers in the table (1, 2, 3, 4, 5, 6, 7) show the movement of the plungers in Fig. 6, 7, 3, 1, 2, 5, 4 depending on the frequency of the magnetic field caused by the solenoid.

According to № 1 the working body (Fig. 6) at a frequency from 0 to 45.1 Hz moves synchronously. From 45.1 Hz to 50 Hz it moves asynchronously. According to № 2 the working body (Fig. 7) at a frequency from 0 to 28 Hz moves synchronously. From 28 Hz to 50 Hz it moves asynchronously. According to № 3 plunger (Fig. 3) at a frequency from 0 to 6 Hz moves synchronously. From 6 Hz to 50 Hz it moves asynchronously. According to № 4 the working body (Fig. 1) at a frequency from 0 to 32.4 Hz moves synchronously. From 32.4 Hz to 50 Hz it moves asynchronously. According to № 5 the plunger (Fig. 2) moves synchronously at a frequency from 0 to 10 Hz. From 10 Hz to 50 Hz it moves asynchronously. According to № 6 the plunger (Fig. 5) at a frequency of 0 to 7 Hz moves with the magnetic field of the coil equally. From 7 Hz to 50 Hz it moves separately. According to № 7 the working body (Fig. 4) at a frequency of 0 to 1.4 Hz moves synchronously. From 1.4 Hz to 50 Hz it moves asynchronously.

The graphs shown in Fig. 15 demonstrate the pattern between the mass of the plunger and the frequency of change of the magnetic field of the coil of the differential pump [17, 18, 19, 20]. As can be seen from the graphs at a constant mass of the working body, the frequency gradually increases. The plunger № 4 has a maximum mass. Working body № 6 has a minimum mass. The masses of the plungers № 2, 4, 7 are different. This is due to the different density of materials of the working bodies. Plungers № 1, 2 have different masses. This is due to the different size of the working bodies. In addition, the working bodies № 2, 4, 5, despite the different masses, have the same frequency. This is due to the same diameter of the plungers.


Figure 1 – Plunger with a diameter of 22,8 mm


Figure 2 – Working body with a diameter of 29,8 mm


Figure 3 – Working body with a diameter of 22,8 mm


Figure 4 – Plunger with an important diameter of 29,8 mm


Figure 5 – Plunger with a diameter of 29,8 mm


Figure 6 – Plunger with a thickness of 22,8 mm

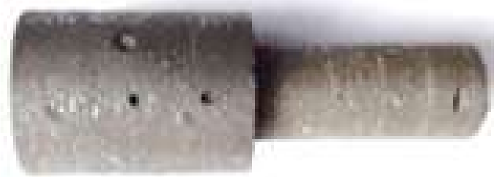
Figure 7 – Plunger with a thickness of 29,8 mm

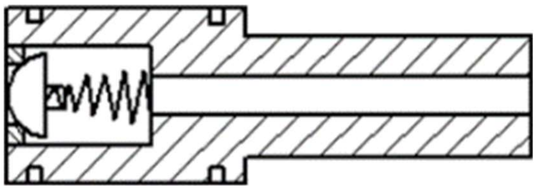
Figure 8 – Woking body made of steel

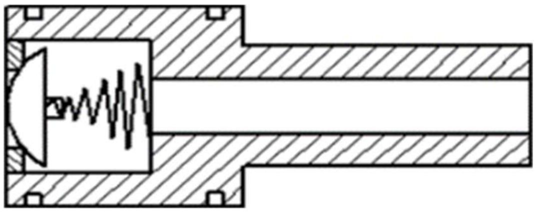
Figure 9 – Working body made of cast iron

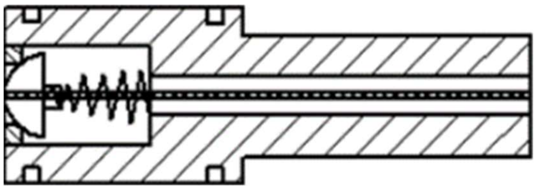
Figure 10 – Working body made of steel (separate)

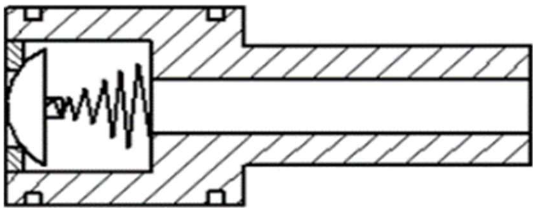
Figure 11 – Plunger made of steel

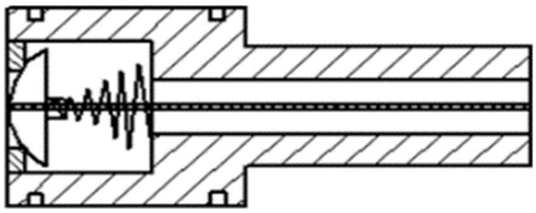
Figure 12 – Plunger made of steel (split)

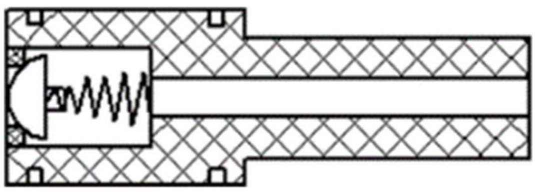
Figure 13 – Plunger made of ground iron

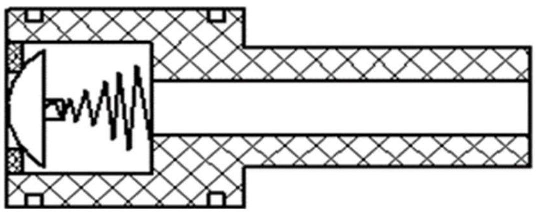
Figure 14 – Plunger made by powder metallurgy method

Table 1 – Kinematic characteristics of the working bodies

No	Name of the plunger	Plunger mass *m*, g	Maximum plunger frequency *f*, Hz	Friction force $\vec{F}$, N
1	Plunger made of iron sawdust with a diameter 22,8 mm	51	45,1	0,26
2	Plunger made of iron sawdust with a diameter 29,8 mm	83	28	9,6
3	Working body made of steel (split) with a diameter of 22,8 mm	128	6	1
4	Working body made of steel with a diameter of 22,8 mm	137	32,4	0,5
5	Working body made of cast iron with a diameter of 29,8 mm	192	10	9,7
6	Plunger made of steel (split) with a diameter of 29,8 mm	210	7	5
7	Plunger made of steel with a diameter of 29,8 mm	215	1,4	2,5

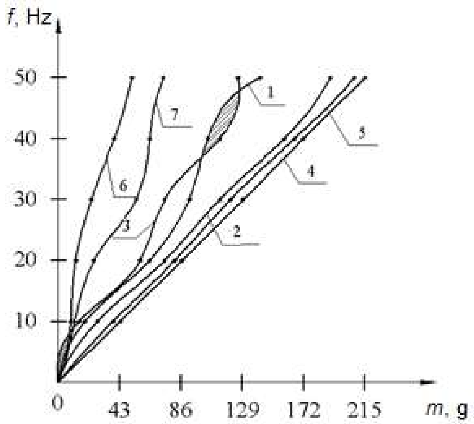

Figure 15 – Graphical dependences of the mass of the plunger on the network frequency

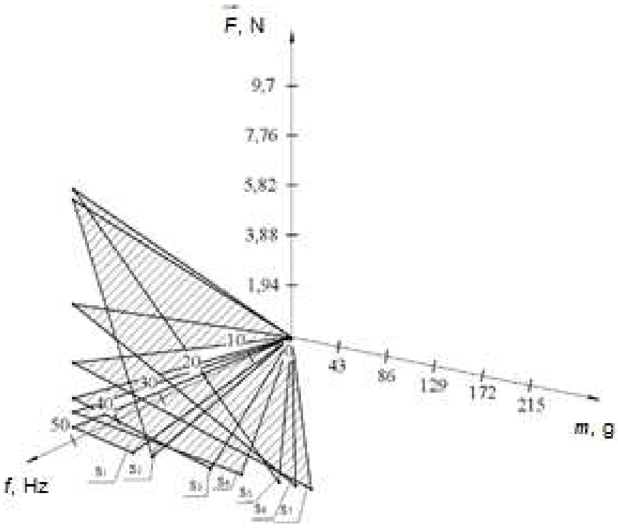

Figure 16 – Three-dimensional graphical dependences of the network frequency of the working body and the friction force

The three-dimensional graph (Fig. 16) shows the mass of the plunger on the abscissa axis, the friction force on the ordinate axis, and the frequency of the feed coil of the differential pump on the applicate axis. According to experimental data, graphs are constructed, and each graph corresponds to the working body. These graphs form areas bounded with curves, these areas correspond to the maximum values of the frequency of the plungers.

Conclusions

During the experiments, the results of studies of the two-way differential pump of electromagnetic action are examined. Research has shown that in the plunger there are energy losses due to the resistance of the finishing material, the working spring, and friction between the working body and the cylinder of the differential pump, which leads to a decrease in pump performance. The reason for the friction force is the sliding of the plunger, the reason for the resistance of the working spring is stiffness, and the reason for the resistance of the finishing material is its density.

The following parameters were minimized by choosing the working body with a minimum mass. In order to manufacture a differential pump of higher efficiency, the following tasks are solved:

– reducing the width of the coil from 10 cm to 3 cm led to an increase in the retraction force from 40 N to 167 N;

– the differential pump plunger with a diameter of 22,8 mm, made by powder metallurgy with a filler of epoxy glue (weight 51g, maximum frequency 45.1 Hz, friction force 0.26 N) has an optimal mode of operation.

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