Solution Pressure Pulsations into the Pipeline Size Determination in Dependence on Constructive Parameters of Valve Units of Mortar Pump

Bogdan Korobko, Inna Khomenko, Mykola Shapoval, and Viktor Virchenko

Abstract The article considers a single-piston mortar pump with electromechanical drive, ball suction and spring-loaded discharge valves, a special insert in the suction chamber and a compensator of increased volume.

The analysis of the influence of hydrodynamic pressure on the valve balls is carried out taking into account all the design parameters of the hydraulic part of the mortar pump.

The mechanisms of action of the hydrodynamic pressure force on the ball from the side of its solution flow on the valve ball due to such factors as the cumulative flow of the solution through the hole in the valve seat are established; the influence of normal and tangential stresses that occur in the surface layer on the surface of the valve ball and occur when the solution has a structured viscosity.

Keywords Single-piston mortar pump with combined compensator of increased volume · Suction chamber · Suction and discharge valves · Volumetric efficiency · Mobility of the solution

1 Introduction

The main directions of development of mortar structures development are analyzed and analytical analysis of single-piston mortar pump with combined compensator of increased volume is carried out. Introduction of a mortar in the design, namely the installation of a special insert, which should ensure a decrease in back leaks through the suction valve, which will ensure the growth of the volumetric efficiency of the mortar and reduce the level of the solution pulsation. Also, the use of an elastic element in the supercharger valve should have a positive effect on reducing inverse leaks through the injection valve due to the increase in the rate of lowering of the ball,

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especially when pumping solutions of reduced mobility P 7–9 cm. From less to a minimum pulsation of the pressure of the solution during its pumping will positively affect the quality of finishing work, both in the use of m in conjunction with plaster stations or as part of mobile small plaster units.

Therefore, it is necessary for theorists to investigate the process and in the hydraulic part of a single-piston mortar pump with a combined compensator of increased volume.

The analysis of the latest sources of research indicates the inability to investigate the interaction of the pumped medium with valve nodes, taking into account structural changes in the suction chamber of the mortar pump a, which will affect the reduction of the degree of pulsations of the pressure supply of the solution [1–8]. Therefore, the analytical research of the hydrodynamic effect of the cumulative jet of the solution on the elements of the hydraulic part of the mortar pump becomes relevant [9–15].

Highlight parts of a common problem that have not been solved before. It is necessary to analyze the effect and interaction of hydrodynamic pressure force on the ball of valves from the cumulative flow of the solution.

Setting a Task. To increase the level of volumetric efficiency and reduce the level of pressure pulsations of the solution during pumping, it is necessary to use a hydraulic drive in a single-piston mortar pump and with a combined compensator of increased volume.

The Purpose and Objectives of the Study. The purpose of this work is to increase the level of volumetric efficiency and reduce the level of pressure level of the single-piston mortar solution with a combined compensator of the increased volume due to the use of a special insertion in the suction chamber and further reducing its harmful volume.

To achieve a certain goal, the following tasks must be solved:

1. Theoretical investigation the forces in the influence of the structured environment on the ball valve.
2. Install with chem in the effect of hydrodynamic forces on the injection and suction valves of single-piston mortar pump.
3. Carry out the operation of the ball valve of the mortar based on the established dynamic model, which makes it possible to determine the law of movement of the valve ball during operation, depending on the law of movement of the working body of the valve node design, and the properties of the pumped solution

The object of research is the processes occurring in the hydraulic part of the single-piston mortar pump, and with a combined compensator of increased volume during the transportation of mortars through the pipeline.

The subject of research is a single-piston mortar pump with a combined compensator of increased volume.

Research Methods. When conducting researches, I used the basic provisions of hydraulics, hydrodynamics, methods of mathematical physics, physical and mathematical modeling by methods of applied mechanics, computer programming of Microsoft Office, Compass 3D, MathCAD 14.

The results of the study. Theoretically, the influence of the solution pumped into the elements of the hydraulic part of the mortar was investigated on the basis of the laws of hydrodynamics, taking into account the rheological properties of the solution, the pressure of the solution supply and when using a combined compensator of increased volume. The effect of the operation of the mortar valves on the technical characteristics of productivity and volumetric efficiency has been established.

The Main Material. The analysis of the work of the mortar pump a (Fig. 1), which was developed at the National University "Poltava Yuri Kondratyuk Polytechnic" indicates a more thorough study of the interaction of the pumped medium with valve nodes, which directly affects the level of technical characteristics of the mortar pump with electromechanical drive, which has established itself as a reliable and highly efficient volumetric machine. But pumping solutions with a solution of reduced mobility P7-8 cm does not occur at a degree of pressure pulsations near the level $\delta \geq 25\%$.

To determine the number of pulsations of the pressure of the solution into the pipeline from the design parameters of the valve components of the mortar, it is

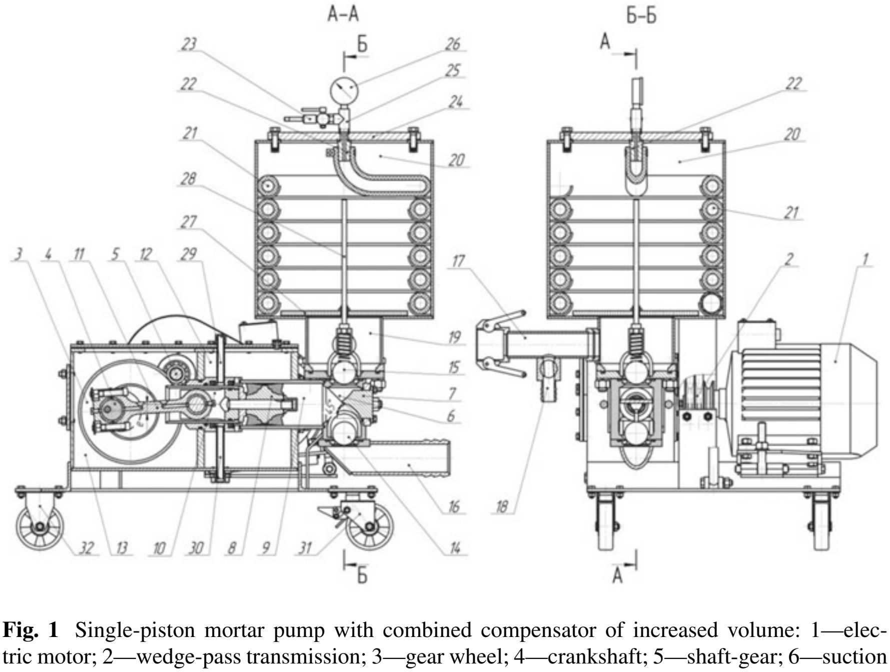

Fig. 1 Single-piston mortar pump with combined compensator of increased volume: 1—electric motor; 2—wedge-pass transmission; 3—gear wheel; 4—crankshaft; 5—shaft-gear; 6—suction chamber; 7—special cylindrical insert; 8—piston; 9—working cylinder; 10—slider; 11—rod; 12—chamber; 13—gearbox body; 14, 15—suction and suction suspended ball valves; 16, 17—suction and injection nozzles; 18—pressure reduction valve; 19—supercharger; 20—cylindrical chamber; 21—locked chamber; 22—fitting of air pumping unit; 23—nipple; 24—cover; 25—crane; 26—pressure gauge; 27—float-limiter; 28—guide rod; 29, 30—channel nozzles; 31, 32—pair of wheels

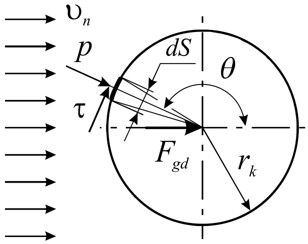

Fig. 2 Design diagram of the influence of the valve ball on the flow of structured liquid

necessary to analyze the effect of hydrodynamic pressure on the valve balls, taking into account all the design parameters of the hydraulic part of the mortar.

The effect of the solution on the valve ball is characterized by the effect of hydrodynamic pressure on the ball from its flow. This effect occurs due to the following factors: the cumulative flow of the solution through a hole in the valve saddle; influence of normal and tangent stresses that occur in the surface layer on the surface of the valve ball and occur when a solution has structured viscosity.

So, to determine the strength of the hydrodynamic effect F_{gd} on the ball, dependence is made [3]

$$F_{gd} = F_s + F_t \tag{1}$$

where F_s—effort of frontal resistance from the cumulative jet of the solution in the hole of the valve saddle; F_t—side friction force that occurs during the flow of the ball by a structured liquid.

At the time of lowering the ball in a statically stationary solution, the force of the frontal pressure on the ball F_s from the side of the cumulative jet and side friction, as well as during the flow of the F_t structured liquid of the valve balls in a limited volume space has the same nature (see Fig. 2) [3, 8].

Therefore, the force of the influence of the structured medium on the ball valve can be presented as a component of the elementary forces of pressures and grated Ion the parts of the surface of the ball [3, 8]

$$\begin{aligned} F_{gd} &= \int_0^{\pi} \left(-\frac{3}{2} \cdot \frac{\upsilon_p \cdot \mu}{r_k} \cos\theta\right) \cdot \cos\theta \cdot 2 \cdot \pi \cdot r_k^2 \cdot \sin\theta d\theta \\ &+ \int_0^{\pi} \left(\tau_0 + \frac{3}{2} \cdot \frac{\upsilon_p \cdot \mu}{r_k} \sin\theta\right) \sin\theta \cdot 2 \cdot \pi \cdot r_k^2 \cdot \sin\theta d\theta \\ &= 2 \cdot \pi \cdot \upsilon_p \cdot r_k \cdot \mu + 4 \cdot \pi \cdot \upsilon_p \cdot r_k \cdot \mu + \pi^2 \cdot r_k^2 \cdot \tau_0 \end{aligned} \tag{2}$$

After simplification will look like

$$F_{gd} = 6 \cdot \pi \cdot \upsilon_p \cdot r_k \cdot \mu + \pi^2 \cdot r_k^2 \cdot \tau_0 \tag{3}$$

The frontal resistance of the ball of the solution flow and the resistance of the surface friction of the ball when the mortar stream moves are defined as components of dependence (2). Both components of the ball movement resistance are determined by the flow rate υ_n, the structured viscosity of the liquid μ and the geometric parameter of the ball, namely the radius r_k. From the dependence (2) it can be seen that a much greater effect carries out friction resistance compared to the frontal resistance, and the third addition of the amount means the total force required to shift the valve ball relative to the solution, which in turn creates a static resistance of its movement caused by the presence of tension τ_0, and does not depend on the two components of the structured viscosity μ of the solution and the velocity of relative movement. Addiction is the solution to the inseparability problem of the Naive-Stokes mass when the ball interacts with a structured liquid.

To determine the values of hydrodynamic force, it is necessary to determine the rheological parameters μ and τ_0 of environment. Based on the expressions (2) (3), it is possible to develop analytical dependences to determine the characteristics of the structured solution by studying the lowering of the ball under the action of gravity, as well as to assess the hydrodynamic effect of the solution flow on the valve ball during its operation in the limited round-valve space of the working chamber.

Taking into account the design features of the valve node, namely: the presence of a saddle under the ball, the limitations of the round-valve chamber, the pressure force F_s acting on the ball from the cumulative jet can be considered equivalent to the average velocity of the jet of the solution, which makes the infusion from the saddle hole, and the resistance force on the surface of the ball F_t is equivalent to the average velocity of the solution jet in the medial cross section of the ball (see Fig. 3). The static effect of the resistance of the ball's interaction with the solution (see formulas (3) (4), can be considered independent of the nature of the flow movement.

Provided that at the beginning of the tear of the ball from the saddle its speed υ_k relative to the solution is close to zero, then the expression (3) taking into account $\upsilon_k = \upsilon_p$ will look like [3, 8]

$$F_\tau = \pi^2 \cdot r_k^2 \cdot \tau_0 \tag{4}$$

Where

$$\tau_0 = \frac{F_\tau}{\pi^2 \cdot r_k^2} \tag{5}$$

The value of the force F_τ is defined as the difference between the external force F_0 at which the ball moves and the Archimedes force F_A

$$F_A = \frac{4}{3} \cdot \pi \cdot r_k^3 \cdot g \cdot \rho \tag{6}$$

where ρ—density of the solution under investigation, kg/m^3; g—acceleration of free fall, m/s^2.

The value of the structured viscosity of the soluble mixture μ is determined by the dependence [3, 7], obtained on the basis of the expression (3)

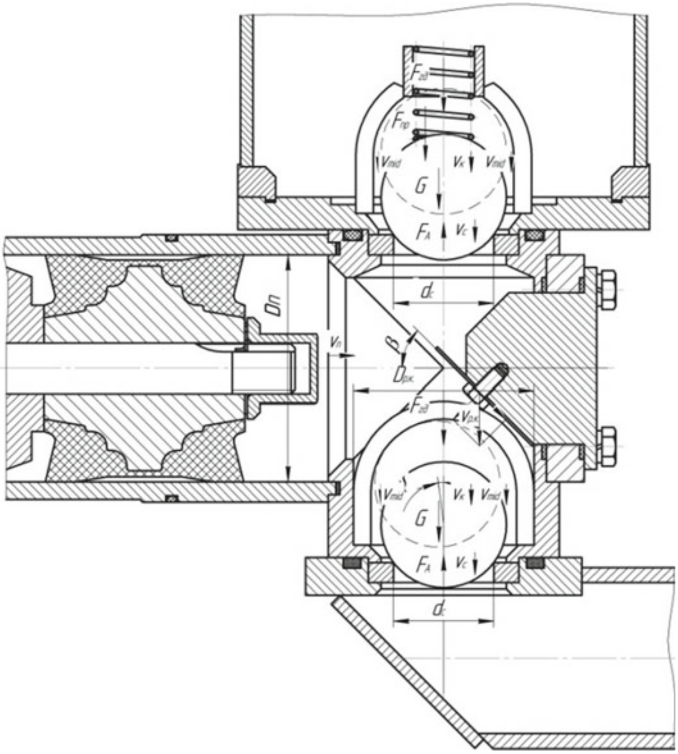

Fig. 3 Scheme of influence of hydrodynamic forces on the injection and suction patch of single-piston mortar

$$\mu = \frac{F_\eta - \pi^2 \cdot r_k^2 \cdot \tau_0}{6 \cdot \pi \cdot \upsilon_k \cdot r_k} \tag{7}$$

By dependence, the (6) marginal stress of the shift τ_0, taking into account the influence of the Archimedes force, will take the form

$$\tau_0 = \frac{F_0 - \frac{4}{3} \cdot \pi \cdot r_k^3 \cdot g \cdot \rho}{\pi^2 \cdot r_k^2} \tag{8}$$

where $F_A = \frac{4}{3} \cdot \pi \cdot r_k^3 \cdot g \cdot \rho$—is the component of the force of Archimedes, which has an effect on the ball.

The value of the structured viscosity of the solution, taking into account the effect on the ball of the Archimedes force valve [3, 8] will be determined by dependence (3) will look like

$$\mu = \frac{F_\mu - \frac{4}{3} \cdot \pi \cdot r_k^3 \cdot g \cdot \rho - \pi^2 \cdot r_k^2 \cdot \tau_0}{6 \cdot \pi \cdot \upsilon_k \cdot r_k} \tag{9}$$

where F_μ—resistance to lowering the ball from the solution, H; υ_k—speed of movement of the ball in a statically stationary solution, m/s; r_k– radius of the ball, m.

Obtained mathematical dependences (8) (9) which allow describing the nature of the interaction of the flow with the elements of the hydraulic part of the mortar (piston working organ, valve nodes, working chamber) is determined on the basis of experimental determination of parameters F_0, F_μ and υ_k the movement of the valve ball radius r_k in the solution and calculate the values of the maximum shear stress τ_0 and the coefficient of structured viscosity of the solution μ.

Based on dependence (2), and assumptions given, on the design parameters of the valve nodes and the characteristics of the solution flow, the dependence of the hydrodynamic pressure force will look like

$$F_{gd} = C_r \cdot \pi \cdot \mu \cdot r_{kl} \cdot \upsilon_s + C_\tau \cdot \pi \cdot \mu \cdot r_{kl} \cdot \upsilon_{mid} + \pi^2 \cdot r_{kl}^2 \cdot \tau_0 \tag{10}$$

where r_{kl}—the radius of the valve ball, m; υ_s—the speed of the jet of the solution coming out of the hole of the saddle, m/s; υ_{mid}—flow rate of solution in copper cross section, m/s; μ—coefficient characterizing the structured viscosity of the solution, Pa · s;—extreme shear stress of the solution, Pa; C_r, C_τ—odds of frontal pressure and grater resistance of the valve ball.

It should be noted that when the ball is fully flown around in the volume of the absorbent chambers, the entered coefficients have a value corresponding to: $C_r = 2C_\tau = 4$ (2).

The nature of the change in the pressure force of the cumulative jet on the ball valve is determined by the coefficient C_r and depends on the following parameters: the diameter of the ball, the diameter of the saddle hole, the height of the lifting of the ball. The coefficient C_τ of expression (10) characterizes the influence of a limited flow that the surface of the ball and is determined by the design parameters of the valve space. The coefficients C_r and C_τ were determined experimentally during the study of the process of interaction of the ball with the solution in a confined space using constructive and physical modeling [4].

During the operation of the valve, the speeds of the jet of the solution are redistributed in the characteristic cross section of the valve node. This process is characterized by the Law of Westphalia [1, 6], according to which, during the movement of the ball in the direction of the jet solution, the flow of the solution through the saddle hole is greater than the consumption of the solution through the valve slit (Fig. 3).

$$Q_s = Q_{shch} + Q_{kl} \tag{11}$$

where Q_s—solution consumption through the hole in the valve saddle, m^3/s; Q_{shch}—solution consumption through the valve slot, m^3/s; $Q_{кл}$—loss of the solution occupying the sub-space, m^3/s.

The law of inseparability of the flow indicates that the consumption of the solution in the medial cross section Q_{mid} is equal to the consumption of the solution through the gap, so the dependence is based on the expression (11)

$$Q_s = Q_{mid} + Q_{kl}. \tag{12}$$

Accordingly, the consumption of the solution of the included nodes that make up, are determined by the dependences of the (11) (12)

$$Q_s = \upsilon_s \cdot S_s; \;\; Q_{shch} = \upsilon_{shch} \cdot S_{shch}; \;\; Q_{mid} = \upsilon_{mid} \cdot S_{mid}, \tag{13}$$

where S_s, S_{shch}, S_{mid}—area of cross-sectional holes: saddles, crevices and middle, respectively, m^2; υ_s, υ_{shch}, υ_{mid}—average speeds of soluble flow: in the hole of the saddle, crevices and medial cross section, respectively, m/s.

The consumption of the solution covering the sub-space during the lifting of the ball can be approximately determined by dependence

$$Q_{kl} = \upsilon_{kl} \cdot S_s \tag{14}$$

where υ_{kl}—the speed of movement of the valve ball, m/s.

Since the consumption of the solution through the saddle hole is proportional to the consumption of the solution in the suction chamber $Q_{v.k.}$, therefore, dependence is made

$$Q_s = Q_{v.k} = \frac{1}{\cos\beta} \cdot \upsilon_p \cdot \frac{D_p^2}{d_s^2} \cdot S_p \tag{15}$$

where υ_p—piston velocity, m/s; S_p—area of the contact part of the piston with solution, m^2; β—angle of inclination of special insertion.

When opening the valve, the ball moves in the direction of the stream, respectively, the relative flow rate of the ball will decrease by the value of its velocity, that is, the dependence (10) will look like

$$F_{gd} = C_p \cdot \pi \cdot \mu \cdot r_{kl} \cdot (\upsilon_s - \upsilon_{kl}) + C_\tau \cdot \pi \cdot \mu \cdot r_{kl} \cdot (\upsilon_{mid} - \upsilon_{kl}) + \pi^2 \cdot r_{kl}^2 \cdot \tau_0 \tag{16}$$

Given that speeds $\upsilon_s = \upsilon_p \cdot \frac{1}{\cos\beta} \cdot \frac{S_p}{S_s}$, and $\upsilon_{mid} = \frac{\upsilon_p \cdot S_p - \upsilon_{kl} \cdot S_s}{S_{mid}} \cdot \frac{1}{\cos\beta}$ (see (11)–(15)), determine the strength of hydrodynamic pressure can be by dependence

$$\begin{aligned} F_{gd} = C_r \cdot \pi \cdot \mu \cdot r_{kl} \cdot \left(\upsilon_p \cdot \frac{S_p}{S_s} \cdot \frac{1}{\cos\beta} - \upsilon_{kl} \right) + C_\tau \cdot \pi \cdot \mu \cdot r_{kl} \\ \times \left(\frac{\upsilon_p \cdot S_p - \upsilon_{kl} \cdot S_s}{S_{mid}} \cdot \frac{1}{\cos\beta} - \upsilon_{kl} \right) + \pi^2 \cdot r_{kl}^2 \cdot \tau_0 \end{aligned} \tag{17}$$

By marking the current height of the ball above the saddle with a variable coordinate x, the dependence will look like

$$F_{gd} = C_r \cdot \pi \cdot \mu \cdot r_{kl} \cdot \left(\upsilon_p \cdot \frac{S_p}{S_s} \cdot \frac{1}{\cos\beta} - \dot{x} \right) + C_\tau \cdot \pi \cdot \mu \cdot r_{kl} \times \left(\frac{\upsilon_p \cdot S_p - \dot{x} \cdot S_s}{S_{mid}} \cdot \frac{1}{\cos\beta} - \dot{x} \right) + \pi^2 \cdot r_{kl}^2 \cdot \tau_0 \quad (18)$$

where $\dot{x}$—the first derivative coordinates of the position of the ball x while moving over the saddle, which determines its speed of movement, namely υ_{kl}; S_s—area of the passing hole of the saddle.

Figure 3 shows the scheme of influence of hydrodynamic forces on the injection and suction valves.

It is worth noting that the movement of the valve ball affects not only the level of inverse consumption of the solution, but determines the resistance to the movement of the current solution, the suction ability or level of vacuum in the working chamber and the degree of its filling in the suction tact.

The process of hydraulic interaction and the balance of forces acting on the ball valve during the operation of the suction valve can be described according to Newton's law

$$m_{kl} \cdot \ddot{x} = -F_{gd} - G + FA \quad (19)$$

The direction of force F_{gd} is determined by the vector of the flow rate of the solution υ_r in the near-detached space.

Dependences (18) and (19) indicate that the hydrodynamic force F_{gd} is directly proportional to the flow rate of the solution and is determined depending on the speed $\vec{\upsilon}_p$ of movement of the piston, and depends on the position of the ball, the geometric dimensions of the valve node and the characteristics of the solution. In general, force F_{gd} can be represented as a function from the rheological parameters of the solution and the design parameters of the valve nodes

$$F_{gd} = f\left(x_{kl}, \dot{x}_{kl}, \upsilon_p, \mu, \tau_0, r_{kl}, r_s, D_{nkl}\right) \quad (20)$$

Where x_{kl} is the coordinate of the path that determines the instantaneous position of the ball above the saddle; $\dot{x}_{kl}$—instantaneous speed of the ball (υ_{kl}) in position x_{kl}; υ_p—piston speed; μ, τ_0—extreme shear stress, depending on its mobility; r_{kl}, r_s—radius of the ball and the hole of the saddle; D_{nkl}—diameter of the round-the-circle cavity.

Given dependencies (6) (20), an expression (19) can be represented as a differential dependency

$$m_{kl} \cdot \ddot{x}_{kl} = -F_{gd}\left(x_{kl}, \dot{x}_{kl}, \upsilon_p, \mu, \tau_0, r_{kl}, r_s, D_{nkl}\right) - mkl \cdot g + \frac{4}{3} \cdot \pi \cdot r_{kl}^3 \cdot g \cdot \rho \quad (21)$$

Permanently

$$m_{kl}\cdot\ddot{x}_{kl}=-\left(\begin{array}{l}C_r\cdot\pi\cdot\mu\cdot r_{kl}\cdot\left(\upsilon_p\cdot\dfrac{S_p}{S_s}\cdot\dfrac{1}{\cos\beta}-\dot{x}\right)+C_\tau\cdot\pi\cdot\mu\cdot r_{kl}\times\\ \times\left(\dfrac{\upsilon_p\cdot S_p-\dot{x}\cdot S_s}{S_{mid}}\cdot\dfrac{1}{\cos\beta}-\dot{x}\right)+\pi^2\cdot r_{kl}^2\cdot\tau_0\end{array}\right) \tag{22}$$
$$-m_{kl}\cdot g+\frac{4}{3}\cdot\pi\cdot r_{kl}^3\cdot g\cdot\rho$$

When considering the opening of the valve, the initial condition is that it corresponds to the lower part of the ball. When closing the valve, the initial condition is (the upper position of the ball) $x_{kl}(t_0) = 0$ $(m_{kl}\cdot\ddot{x}_{kl} < 0)$ $x_{kl}(t_0) = 0$.

During the operation of the supercharging valve, the process of hydraulic interaction differs from the previous case in that the ball is affected by a column of solution from the combined compensator and the effect of the force of the elastic element, the balance of forces acting on the ball, has the form

$$m_{kl}\cdot\ddot{x} = -F_{gd} - G - F_{pr} + F_A \tag{23}$$

Resistance force of the elastic element acting on the valve ball

$$F_{pr1} = \frac{G_m\cdot d_{pr}^4\cdot f_1}{8\cdot D_0^3\cdot n_{pr}}\cdot\frac{1}{\chi_{op}} = \frac{G_m\cdot d_{pr}^4\cdot(H_0-H_1)}{8\cdot\left(D_1-d_{pr}\right)^3\cdot n_{pr}}\cdot\frac{1}{\chi_{on}} \tag{24}$$

where G_m is the material shear module (pressure that causes deformation by 1 mm), MPa; d_{pr}—spring fiber diameter, mm; D_0—average diameter of the spring, mm; D_1– outer diameter of the spring, mm; H_0—spring length in free condition, mm; H_1—spring stroke length at the length of the pressure valve ball, mm; f_1—change in the length of the spring when compressed by the ball of the supercharger valve; n_{pr}– the number of spring coins; χ_{op}– spring movement resistance coefficient depending on the density of the pumped medium.

Taking into account the law Hutton and Archimedes (6), (20) and (24) the expression (23) can be written in the form of a differential equation

$$\begin{aligned}m_{kl}\cdot\ddot{x}_{kl} &= -F_{gd}(x_{kl},\ddot{x}_{kl},\upsilon_n,\mu,\tau_0,r_{kl},r_c,D_{nkl}) - m_{kl}\cdot g\\ &-\frac{G_m\cdot d_{pr}^4\cdot(H_0-H_1)}{8\cdot\left(D_1-d_{pr}\right)^3\cdot n_{pr}}\cdot\frac{1}{\chi_{op}}+\frac{4}{3}\cdot\pi\cdot r_{kl}^3\cdot g\cdot\rho\end{aligned} \tag{25}$$

And finally, in expanded form

$$m_{kl} \cdot \ddot{x}_{kl} = -\left(\begin{array}{l} C_r \cdot \pi \cdot \mu \cdot r_{kl} \cdot \left(\upsilon_p \cdot \dfrac{S_p}{S_s} - \dot{x} \right) + C_\tau \cdot \pi \cdot \mu \cdot r_{kl} \times \\ \times \left(\dfrac{\upsilon_p \cdot S_p - \dot{x} \cdot S_s}{S_{mid}} - \dot{x} \right) + \pi^2 \cdot r_{kl}^2 \cdot \tau_0 \end{array} \right) - m_{kl} \cdot g - \frac{G_m \cdot d_{pr}^4 \cdot (H_0 - H_1)}{8 \cdot (D_1 - d_{pr})^3 \cdot n_{pr}} \cdot \frac{1}{\chi_{op}} + \frac{4}{3} \cdot \pi \cdot r_{kl}^3 \cdot g \cdot \rho. \tag{26}$$

It can be assumed that the influence of the law of movement of the working body of the pump occurs with a double nature, namely, establishes the value of the piston stroke for the period of time and time of closing the valve, which directly determines the volume of reverse flow of the solution. That is, the establishment of the law of movement of the working body requires rational decisions for the period of time of lowering the valve ball and the speed of movement during this period.

Analysis of the operation of the ball valve of the mortar based on the established dynamic model, which makes it possible to determine the law of movement of the valve ball during operation, depending on the law of movement of the working body of the valve node design, and the properties of the pumped solution. Theoretically, it is necessary to evaluate the interaction of the law of movement of the working body and the development of the suction and injection valves and the consumption of the solution during closing.

The solution of the differential equation presented makes it possible to obtain the law of movement of the valve ball as a function

$$x_{kl}(t) = f\left(m_{kl}, r_{kl}, r_s, D_{nkl}, \upsilon_p(t), \mu, \tau_0, \rho, t\right) \tag{27}$$

which makes it possible to establish the dependence of the nature of the movement of the ball with the time t and design parameters of the valve $(m_{kl}, r_{kl}, r_s, D_{nkl})$, the law of movement of the working body $\left(\upsilon_p(t)\right)$ and the rheological properties of the pumped solution (μ, τ_0, ρ).

The initial movement of the ball with a diameter of 50 mm in a solution with a mobility of P10 cm was carried out with a total weight of 510 g, that is, the force of the initial shift H. $F_0 = 9, 81 \cdot 0, 51 = 5$.

In Fig. 2 4 the dependences of the movement of the pump and suction valve of the mortar depending on the mobility of the pumped solution and taking into account (Table 1) the rheological parameters of building solutions of varying mobility, the strength of the ball's shift in solutions and its speed of initial movement in solutions are given.

Dependences (Fig. 4) indicate that the triggering of the suction and suction valves occurs faster depending on the mobility of the solution, which is explained by the increasing resistance of movement with a decrease in mobility, as well as the closure

Table 1 Rheological properties and power parameters of sand solutions of different mobility to determine the laws of movement of pump and suction valves

Personality solution, cm	Density ρ, kg/m^3	Limit (law) displacement, Pa τ_0	Factor structured viscosity, Pass $\mu \cdot$	Efforts movement, N F_1	Movement speed, m/s υ_0
P8	2100	736,27	35,86	15,3	0,74
P10	2000	602,39	18,58	11,75	1,06
P12	1900	431,24	10,24	7,86	1,2

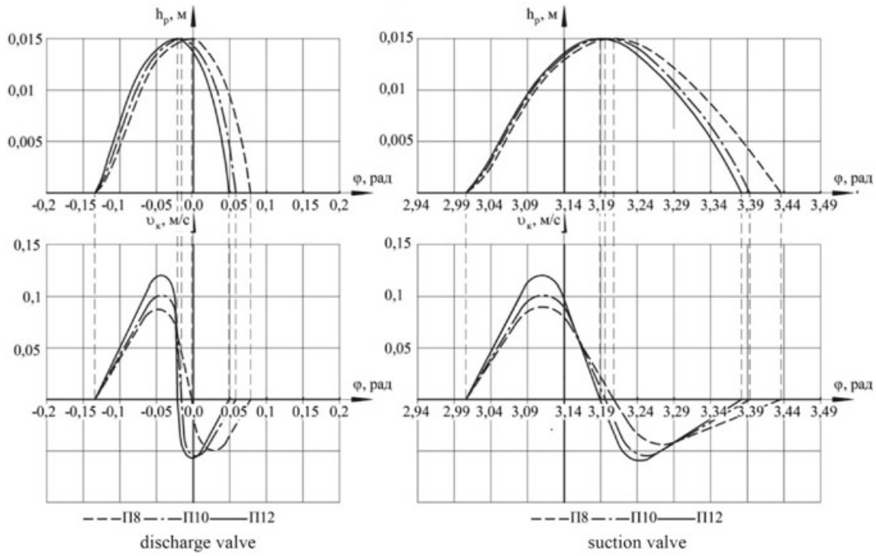

Fig. 4 Dependences of the movement of the pump and suction valve of the single-piston mortar with a combined compensator of increased volume depending on the mobility of the solution:

of valves in the mortar with a combined pressure pulsation compensator, respectively, by more than 1.35° and 0.96° rotation of the crane and filter.

It is worth paying attention to the fact that the faster operation of the valve balls in the mortar with a combined compensator of increased volume affects not only the reduction of the reverse leaks of the solution, but determines the resistance to the promotion of the flow of the solution depending on the installation of a special insertion in the suction chamber, the level of vacuum in it and the degree of its filling in the suction tide, which significantly affects the reduction of the degree of pulsation and increase in volume.

Next, it is necessary to determine the maximum shear τ_0 stress and the value of the structured viscosity of the solution with mobility P10.

$$\tau_0 = \frac{F_0 - \frac{4}{3}\cdot\pi\cdot r_k^3\cdot g\cdot\rho}{\pi^2\cdot r_k^2} = \frac{5-\frac{4}{3}\cdot 3{,}14\cdot 0{,}025^3\cdot 9{,}81\cdot 2000}{3{,}14^2\cdot 0{,}025^2} = 602{,}39\ \text{Pa}$$

$$\mu = \frac{F_\eta - \frac{4}{3}\cdot\pi\cdot r_k^3\cdot g\cdot\rho - \pi^2\cdot r_k^2\cdot\tau_0}{6\cdot\pi\cdot\upsilon_k\cdot r_k} =$$

$$= \frac{11{,}75-\frac{4}{3}\cdot 3{,}14\cdot 0{,}025^3\cdot 9{,}81\cdot 2000 - 3{,}14\cdot 0{,}025^2\cdot 602{,}39}{6\cdot 3{,}14\cdot 1{,}06\cdot 0{,}025} = 5{,}92\ \mathit{Па}\cdot c.$$

Determining the law of movement of the valve ball will determine the time of its movement from height h to saddle and estimate the number of inverse leaks ΔV during the closure of the valve

$$\Delta V = S_b\cdot\frac{1}{\cos\psi}\cdot S_p(\varphi_z) \tag{28}$$

where $S_б$is the size of the area of the side around the valve opening surface depending on the lifting height of the ball $S_б = f\left(h\right)$, m^2; ψ—the angle of change in the trajectory of the valve ball, which arises as a result of the tank force of the influence of the working body.

Mass of consumption mortar through the saddle of the suction valve determine based on the preliminary analysis dependence

$$\begin{aligned}\Delta Q_{vs.kl} &= \rho\cdot\upsilon_{r.k.}\cdot S_p - \rho\cdot\upsilon_s\cdot S_b = \rho\cdot\upsilon_p\cdot\frac{1}{cos\beta}\cdot\frac{D_p^2}{d_{r.k}^2}\cdot S_p \\ &-\rho\cdot\upsilon_p\cdot\frac{1}{cos\beta}\cdot\frac{D_p^2}{d_s^2}S_b\end{aligned} \tag{29}$$

After the transformations, we have

$$\begin{aligned}\Delta Q_{vs.kl} &= \frac{\pi\cdot\rho\cdot D_p^4}{cos\beta}\cdot\left(R\cdot\sin\varphi - \frac{\left(R\cdot\sin\varphi - e\right)\cdot R\cdot cos\varphi}{\sqrt{l^2-\left(R\cdot\sin\varphi-e\right)^2}}\right)\cdot \\ &\cdot\left(\frac{D_p^2}{4\cdot d_{r.k}^2} - \frac{R_k}{d_s^2}\cdot\frac{h^2+2\cdot h\cdot\sqrt{R_k^2-r_s^2}}{\sqrt{r_s^2+\left(h+\sqrt{R_k^2-r_s^2}\right)^2}}\right),\end{aligned} \tag{30}$$

where $S_p(\varphi_z)$—moving the piston during the period of time of lowering the valve ball to the saddle, which is characterized by the law of movement of the working body, m; φ_z—the angle of rotation of the cradle during the t lowering of the valve ball to the saddle.

The dependence (28) can be explained by the fact that during the lowering of the valve ball, the piston will move at a certain distance $S_p(\varphi_z)$ and during this movement will change the volume of the pump suction chamber. It is clear that the simultaneous opening of both valves is impossible, both in the suction and injection tactics of the solution through any valve that is currently closed, the solution flows in the form of reverse leaks and fills the change in volume in the suction chamber.

Under conditions and if the speed of the working body is constant, dependency can be used to determine the magnitude of inverse leaks through the supercharger valve

$$\Delta Q_{nagn.\,kl} = \frac{\pi \cdot d_k^2 \cdot h_r}{4} - V_k + Q_K \tag{31}$$

where d_k is the diameter of the cylindrical part in the suction chamber, m; h_r—lifting path, which the ball passes along with the solution, m; V_k—volume displacing the lower mideal part of the valve ball, $V_k = \pi \cdot h_{k.s.}^2 \cdot \left(R_k - \frac{h_{k.s.}}{3}\right)$, m^3; $h_{k.s.}$—height of ball copper; R_k—flap ball radius; Q_B—a sublimation “dead” volume, which joins the reverse leaks under the Law of Westphalia, m^3, $Q_K = \frac{\pi}{4} \cdot h \cdot \left(D_{kl}^2 - d_s^2\right)$.

Received after conversions

$$\Delta Q_{nagn.\,kl} = \frac{\pi \cdot d_k^2 \cdot h_r}{4} - \pi \cdot h_{k.s.}^2 \cdot \left(R_k - \frac{h_{k.s.}}{3}\right) + \frac{\pi}{4} \cdot h \cdot \left(D_{kl}^2 - d_s^2\right) \tag{32}$$

The established law of movement of the valve ball allows you to determine the time of its lowering in height h to the saddle and set quantitatively the values of the inverse leaks ΔV_{kl} during the closing of the valve at different mobilities of the solution

$$\Delta V_{kl} = F_p \cdot S_p(\varphi_{kl}) \tag{33}$$

where $F_p = \frac{\pi}{2} \cdot D_p^2$—piston area; $S_p(\varphi_{kl})$—part of the movement of the piston for a certain period of time, during which the valve ball is lowered to the saddle, which is characterized by the law of movement of the working body, m; φ_{kl}—the angle of rotation of the cradles during the lowering t of the valve ball.

The path h_r, the valve balls that it passes along with the flow of the solution can be represented by dependence

$$h_r = h - h_t \tag{34}$$

where h—the lifting height of the valve ball to its limiter, m;

h_t—lifting height of the ball, which it passes through the resistance of the solution under the action of gravity, m.

Also, the path h_r can be associated with the diameter and stroke of the piston with this dependence

$$h_r = \frac{D_p^2}{d_k^2} \cdot S_p(\varphi_z) \tag{35}$$

where φ_z is the angle of rotation of the cradle, the value, which coincides with the moment of lowering the valve ball to the saddle, rad.

The lifting height of the ball h_t can be expressed as the product of the speed of lifting at a time

$$h_t = \upsilon_t \cdot t \tag{36}$$

where υ_t—the speed of movement of the valve ball in solution, m/s;

t—the time of the valve ball being sedittered for closing, s.

Lowering the valve ball t can be associated with the angle of rotation φ_z of the cradles with dependence

$$t = \frac{60}{n} \cdot \frac{\varphi_z}{2\pi} = \frac{30 \cdot \varphi_z}{\pi \cdot n} \tag{37}$$

where n—is the number of revolutions of the cradly wasps, s^{-1}.

Then, through expressions (36) and (37), dependency (34) will look like

$$h_r = h - \upsilon_t \cdot \frac{30 \cdot \varphi_z}{\pi \cdot n} \tag{38}$$

To find the closing angle φ_z, you must compare the (35) and (38) expressions. The resulting dependency will look like

$$h - \upsilon_t \cdot \frac{30 \cdot \varphi_z}{\pi \cdot n} - \frac{D_p^2}{d_k^2} \cdot \left(R \cdot (1 - \cos\varphi_z) - \left[l - \sqrt{l^2 - (R \cdot \sin\varphi_z - e)^2} \right] \right) = 0 \tag{39}$$

Conducts direct calculations to determine the value of the angle of rotation of the cradle analytical way in an analytical way φ_z in a cumbersome and inconvenient way (39), so it is more advisable to use the software of computer mathematics Mathcad 15 to get numerical values.

Substantive to the value of the angle φ_z before dependence (38), we obtain the value of the valve ball path h_r, which the valve ball passes along with the flow of the soluble mixture—0.015 m, and substantive finally gives us the value of the volume of leaks $\Delta V_{vs.kl}$ in the injection rate of 0.041 m^3.

Having integrating the dependence of the leakage rate through the valve socket from the beginning of the coordinates to the closing angle of the valve φ_z, you can also find the volume of leaks (excluding values V_{kl} and Q_B).

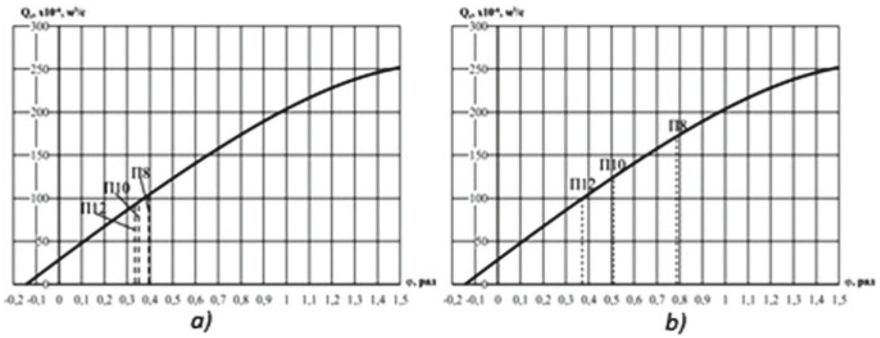

Fig. 5 Dependence of the loss of the soluble mixture through the saddle of the supercharger **a** and the suction **b** valves of the soluble pump with a combined compensator of increased volume depending on the angle of rotation of the cradle when pumping solutions with mobility P8, P10, P12

The loss of the volume of the soluble mixture $\left(\mathrm{m}^3/\mathrm{s}\right)$ through the valve saddle is determined as the product of the speed of the working organ $\upsilon_p(\varphi)$ on the area of the valve saddle passing hole and the counting of piston and saddle areas $\frac{D_p^2}{d_s^2}$, which determines their difference.

$$\Delta V_{kl} = \upsilon_p(\varphi) \cdot \frac{\pi \cdot d_s^2}{4} \cdot \frac{D_p^2}{d_s^2} = \upsilon_p(\varphi) \cdot \frac{\pi \cdot D_p^2}{4} \tag{40}$$

Finally, the volume of leaks through the suction and injection valves in the injection rate is determined depending on the suction and injection rate

$$\begin{gathered}
0 \le \varphi \le \pi,\ \Delta V_{vs.kl} = \frac{\pi \cdot D_n^2}{4} \cdot \int\limits_0^{\varphi_z} \left(R \cdot \sin\varphi - \frac{\left(R \cdot \sin\varphi - e\right) \cdot R \cdot cos\varphi}{\sqrt{l^2 - \left(R \cdot \sin\varphi - e\right)^2}} \right) d\varphi - \\
- \pi \left(R_k - \sqrt{R_k^2 - r_s^2} \right)^2 \cdot \left(R_k - \frac{R_k - \sqrt{R_k^2 - r_s^2}}{3} \right) + Q_B \\
\pi \le \varphi \le 2\pi,\ \Delta V_{ng.kl} = \frac{\pi \cdot D_p^2}{4} \cdot \int\limits_0^{\varphi_z} \left(R \cdot \sin\varphi - \frac{\left(R \cdot \sin\varphi - e\right) \cdot R \cdot cos\varphi}{\sqrt{l^2 - \left(R \cdot \sin\varphi - e\right)^2}} \right) d\varphi - \\
- \pi \left(R_k - \sqrt{R_k^2 - r_s^2} \right)^2 \cdot \left(R_k - \frac{R_k - \sqrt{R_k^2 - r_s^2}}{3} \right) + Q_K - \Delta V_{pr},
\end{gathered} \tag{41}$$

where Q_K—the volume of the solution in the cylindrical compensator chamber, which affects the valve; ΔV_{pr}—reduction of volume from the elastic element of the valve.

Based on dependencies (34), (37), (38), (39), (41) and theoretical studies [5] on determining the rational height of lifting the valve ball in Table 2 and Fig. 6 is given with the allergy of the degree of pressure pulsations when pumping solutions of varying mobility depending on the lifting height of the suction and injection valve.

Dependences (Fig. 6) indicate that the degree of pulsations when pumping solutions with mobility P8-12 cm in the mortar will be reduced to the minimum values when setting the ball lifting limiters in the range of 12.5–17.5 mm, both for the suction and for the injection valves.

This is due to the rational sub-valve space, which is equal to 1260 mm^2 suction and supercharger valves, which provide high suction capacity and filling of the suction chamber and ensuring quick operation.

Table 2 The value of the pulsation level taking into account various factors

Number of double moves of piston , min n^{-1}	Average feed pressure , MPa p_{cp}	Volume of compensator , dm $V_{комп}$ ^{3}	Mobility of solution, P, cm	Lifting height of suction and suction valve , h mm	δ , %
Mortar pump with combined compensator of increased volume					
150	2,0	47	8	5	36,54
				10	18,22
				15	12,81
				20	15,12
				25	25,32
				30	38,09
			10	5	31,03
				10	12,05
				15	6,93
				20	10,04
				25	20,89
				30	34,61
			12	5	29,03
				10	10,04
				15	5,10
				20	8,13
				25	18,22
				30	33,23

*In gray, rational heights of lifting of suction and supercharger valves and minimum levels of pulsation degree are determined

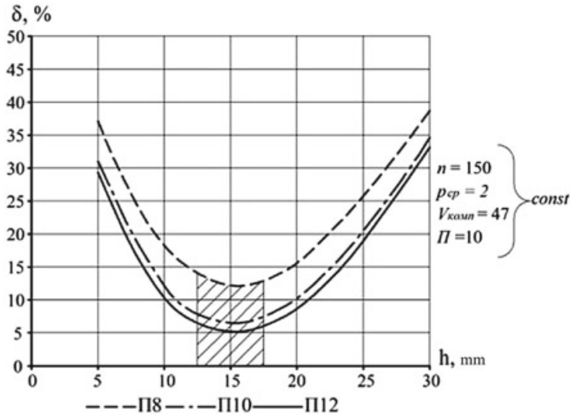

Fig. 6 Dependence of the degree of pulsations of the pressure of the solution and on the lifting height of the suction and suction valves

Increasing the lifting height of the valve ball $h = 15$ mm will lead to an increase in the degree of pressure pulsations as a result of an increase in inverse leaks due to the delay in lowering the valve ball, especially at reduced mobilities of the solution.

2 Conclusions

According to the results of studies, it can be seen that the speed of operation of the suction and supercharger valves is significantly influenced by the mobility of the solution, this is especially noticeable when pumping solutions P8 cm.

The height of the lifting of the valve ball mm according to the results of studies and $h = 15$ the level of pulsation of pressure of the pumped solution is considered rational.

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