Features of the Use of a Universal Hose Concrete Pump in the Construction Site

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Abstract. The design of a hose concrete pump with a hydraulic drive is described, its versatility makes it possible to use it with pipelines with diameters of 32, 50 and 75 mm. The advantages of a new pump over existing structures are shown. Dependencies have been found to determine its main indicators: productivity and capacity. The reliability of a concrete pump of a new design is grounded.

1. Introduction
In modern construction in the construction of buildings and structures from monolithic reinforced concrete, as well as during repairs and reconstruction of existing construction sites, equipment for carrying out work using wet shotcreting is widely used.

The process of wet shotcreting is carried out with the help of such machines as mortar pumps, mortar-concrete pumps, concrete pumps. The most efficient is operation of these machines with the use of a hydraulic drive, which allows for wide regulation of the operating modes.

In conditions of construction sites, along with two-piston concrete pumps with a hydraulic drive, non-piston hose-type concrete pumps can be successfully used, which have a number of advantages over piston pumps: compact design with a simplified principal scheme, reduced metal capacity, and lower power consumption for similar performance [1].

2. Analysis of research and publications
The results of studies of the principle of action of hose pumps, the possibilities of their operation with a decrease in pulsations of liquid at the pump outlet are known [2, 3]. However, in this paper, a pump without a hydraulic drive is considered. The research of concrete pumps with hydraulic drive is also covered in a number of works in which the issues of supply of concrete mixtures are considered taking into account their rheological properties and dimensions of a transport main line [4-6]. The problem of uneven feeding of concrete mixes by a concrete pump into the pipeline, which depends on the parameters of a concrete pump is not considered in this source. Questions of fluctuations in the flow of fluid and optimization of its parameters are presented in [7, 8], where these problems are considered with respect to peristaltic micro-pumps. As in the above sources, the materials of the paper do not carry the problems of pulsations in the flow of a concrete mixture pumped by a hose concrete pump.
The results of research of the operating conditions of concrete pumps with the use of elastic pipelines with the absence of self-oscillations in them are known [9].

The first experience of using a two-piston continuous-flow mortar-concrete pump for manufacture of reinforced concrete structures and products of complex geometric shapes under the conditions of a construction site by the wet-shotcreting method in case of off-shuttering concreting is of interest. [10-12] The experience of using the wet-shotcreting method for erecting monolithic dome homes [13] which effectively use non-piston hose concrete pumps is of interest. There are known hose pumps that have a housing with a support element radially arc-like in the longitudinal section, where the arcuate elastic hose and the rotor with rollers move in a circle and squeeze the construction mixture out of the hose [14-16].

However, it should be noted that currently insufficient attention is paid to creation of new and improvement of the existing designs of such machines. There are no in-depth studies of the operating conditions for hose-type concrete pumps in order to increase the service life of these pumps.

Considering the above, a new design of a universal hose concrete pump is proposed, which is aimed at solving the problem of creating reliable machines for the conditions of a construction site.

Objective of research is to create a universal, non-piston hose concrete pump of increased reliability, which is equipped with a hydraulic drive and can be used for working with pipelines with diameters of 32, 50 and 75 mm.

3. Research results

A universal non-piston hose concrete pump has been designed, the scheme and general appearance of which are shown in Fig.1 [17].

![Figure 1. Universal non-piston hose concrete pump of a new design with a hydraulic drive.](image)

1 – hydraulic motor; 2 – electric motor; 3 – hydraulic pump; 4 – hydraulic distributor; 5 – tank with hydraulic oil; 6 – concrete pump frame; 7 – concrete pump housing; 8 – housing cover; 9 – rotor; 10 – pressure rollers; 11 – flexible hose; 12 – hydraulic capacity regulator; 13 – conical plug.
pivottally connected rotor traverses allows, if necessary, to adjust the concrete pump to the required capacity by changing the center-to-center distance between the rotor axes and the rollers, depending on the diameter of the flexible hose.

The main indicators of the efficient operation of the universal hose concrete pump are the capacity and installed power.

The performance of a universal hose concrete pump of a new design solution is determined according to the dependence:

\[ P_{\text{tech}} = 3600 \cdot S_{\text{hose}} \cdot v_{\text{av}} \cdot k_1 \cdot k_2 \cdot k_3, \quad (1) \]

where \( S_{\text{hose}} \) - cross-sectional area of the hose in the concrete pump housing, \( m^2 \); \( v_{\text{av}} \) - average speed of the concrete mix on a flexible hose, \( m/s \); \( k_1 \) - coefficient that takes into account the gradual buildup of the force created by the pressure rollers of the rotor, which compress the hose outside of the working part of the pump; \( k_2 \) - coefficient that takes into account reliability of the hose part of the pump, taking into account the stresses arising in it and the breaking state; \( k_3 \) - coefficient that takes into account the conditions for the mixture to be delivered by a concrete pump via a flexible hose taking into account its properties.

The average speed of the mixture through a flexible hose inside the pump housing with a hydraulic drive is determined as:

\[ v_{\text{av}} = \frac{(\tau_{\text{shear}} - \tau_0)}{4\mu} (r_{\text{hose}} + r_{\text{hose}}), \quad (2) \]

where \( \tau_{\text{shear}} \) - shear stress of the concrete mixture on the inner wall of the hose; \( \tau_0 \) - ultimate shear stress; \( \mu \) - dynamic viscosity of the concrete mixture; \( r_{\text{hose}} \) - radius along the end surface of the hose, which is compressed by the action of the side roller; \( r_{\text{hose}} \) - radius along the end surface of the hose, which is compressed under the action of the central roller.

The power required to feed the concrete mixture with a universal hose concrete pump into the transport pipeline of a certain length, along which this mixture is delivered to the working nozzle during shotcreting operations, is determined as:

\[ P_{\text{tot}} = P_1 + P_2, \quad (3) \]

where \( P_1 \) - power used to feed the mixture into the transport pipeline with a universal hose concrete pump; \( P_2 \) - the same, for the process of transportation of the mixture through the pipeline, determined respectively by the formulas

\[ P_1 = \frac{3.45 \cdot (G_{\text{mix}} \cdot k_{fr} + G_{\text{rot}} \cdot k_{rol.fr}) \cdot n \cdot R_{av}}{30 \cdot 1000 \cdot \eta_{cp}}, \quad (4) \]

\[ P_2 = \frac{S_{\text{hose}} \cdot \Delta p \cdot v_{\text{av}} \cdot k_{\text{length}}}{1000 \eta_{h}}, \quad (5) \]

where \( G_{\text{mix}} \) - weight of a concrete mixture under the influence of pressure rollers; \( k_{fr} \) - coefficient of friction, which arises as a result of a wall effect between the inner wall of a flexible hose and a concrete mixture during its movement; \( G_{\text{rot}} \) - weight of the rotor with rollers; \( k_{rol.fr} \) - rolling friction coefficient of rollers over the hose surface; \( r_{rol} \) - radius of pressure rollers; \( n \) - rotor speed; \( R_{av} \) - average distance between the rotor axis and the end surface of the roller, equal to \( R_{av} = (R_1 + R_2)/2 \) (here \( R_1 \) - distance from the rotor axis to the end surface of the roller; \( R_2 \) - distance from the rotor axis to the end surface of the lateral surface roller); \( S_{\text{hose}} \) - cross-sectional area of the transport pipeline; \( \Delta p \) - pressure drop at the ends of the transport pipeline; \( v_{\text{av}} \) - average speed of mixture movement through the pipeline; \( k_{\text{length}} \) - coefficient, taking into account the length of the transport pipeline; \( \eta_{h} \) - hydraulic losses in the transport pipeline (\( \eta_{h} = 0.95 [9] \)).

The efficiency of the concrete pump is determined by the formula [9]:

\[ \eta_{h} \]
\[ \eta_{cp} = \eta_{en} \cdot \eta_{mech} \cdot \eta_{vol}, \quad (6) \]

where \( \eta_{en} \) – engine efficiency; \( \eta_{mech} \) – mechanical efficiency; \( \eta_{vol} = \frac{Q_{act}}{Q_{theor}} \) – volumetric efficiency (here – \( Q_{act} \) – actual supply of the concrete mixture; \( Q_{theor} \) – calculated consumption of the mixture when fed with a hose concrete pump).

The reliability of the universal hose concrete pump is affected by the dynamic characteristics [17], in particular, the moments of start-up and braking of its high-torque hydraulic motor. For this purpose, the reliability factor of the new concrete pump \( k_{r1} \) was determined, which is compared with the reliability coefficient of the existing concrete pumps \( k_{r2} \).

For the concrete pump of the developed design \( k_{r1} \) is determined as:

\[ k_{r1} = \frac{G_1 + G_2 + G_3}{G_1 + G_3} = 1.43, \quad (7) \]

where \( G_1 \) – weight of the concrete mixture in the deformed hose under the pressing of additional rollers 1; \( G_2 \) – weight of the concrete mixture in the deformed hose under the pressure of central rollers of the rotor 2; \( G_3 \) – weight of the concrete mixture located in the gap between the inner walls of the maximally deformed hose under the pressure of central rollers 2. Deformation of the hose is determined at its length \( L_{p1} \) (Fig. 2).

![Figure 2. Design scheme of the working body of a concrete pump (a rotor with rollers)
1 - additional pressure rollers; 2 - central pressure rollers.](image)

For a traditional hose concrete pump with only central rollers [18]:

\[ k_{r2} = \frac{G}{G - G_3} = 1.02, \quad (8) \]

where \( G \) – total weight of the concrete mixture, which moves along the hose under the pressure of rollers.

To determine reliability of the machines under consideration, it is necessary to calculate the operating cycles for each of the concrete pumps (new and current) according to the dependence:

\[ z_c = \frac{3600 \cdot T \cdot k_{r1}}{T_1 + T_2}, \quad (9) \]

where \( k_{r1} \) – coefficient of reliability of a corresponding concrete pump (\( k_{r1} = 1.43; \ k_{r2} = 1.02 \)); \( T \) – duration of failure-free operation of the concrete pump [19]; \( T_1 \) – the same, acceleration of the rotor of the concrete pump; \( T_2 \) – the same, braking of the rotor of the concrete pump.

Calculation of the working cycles of the proposed design of the concrete pump and operating machines showed that the service life of the new pump is 25% higher than that of modern hose concrete pumps.

The efficiency of the hose concrete pumps is also largely dependent on the conditions for the stable supply of concrete mixtures to the transport main line. At the same time, the evaluation of the
operation of machines can be carried out according to the coefficient of unevenness of the mixture feeding [20].

For hose-type concrete pumps, this coefficient is determined by:

- with a hydraulic drive

\[
\delta_{cp,h} = \frac{4(d_{hose}\pi n R^* - k_{eq} h_g \sqrt{\frac{2\Delta p_p}{\rho_0}})}{d_{hose} (v_1 + v_2)} = 1.093;
\]  

(10)

- with a mechanical drive

\[
\delta_{cp,m} = \frac{4(d_{hose}\pi n R^* - k_{eq} h_g \sqrt{\frac{2\Delta p_p}{\rho_0}})}{d_{hose} v_1} = 1.286,
\]  

(11)

where \(d_{hose}\) – diameter of the hose in the concrete pump housing; \(R^*\) – distance between the axis of the rotor and the axis of the central roller; \(k_{eq}\) – equivalent coefficient that takes into account consumption of the mixture when rotor rollers are sequentially applied to the hose; \(h_g\) – gap height, which is formed between the inner walls of the maximally deformed hose under the influence of the central roller; \(\Delta p_p\) – pressure drop in the pump; \(\rho_0\) – average density of the concrete mixture; \(v_1\) – speed of the concrete mixture movement along the hose in the concrete pump housing (\(v_1 = 2\pi n_{hose}\)).

Determination of the coefficients \(\delta_{cp,h}\) and \(\delta_{cp,m}\) according to the formulas (10 and (11) shows that when a hydraulic drive of a concrete pump is pulsed, the pulsation of the mixture is 15% less in the pipeline than in the case of a mechanical drive, which indicates a more favorable operating conditions for a machine, and so most, increase the service life of the working hose of the concrete pump.

4. Conclusions

The design of a new universal non-piston hose concrete pump with a hydraulic drive is considered. Dependencies are obtained to determine the basic performance of a new hose concrete pump: capacity and power. The efficiency of a new hose concrete pump is substantiated by determination of reliability coefficients and unevenness of the mixture feeding. The developed design of the concrete pump has increased reliability in comparison with operating machines.

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