IMPROVEMENT OF THE DESIGN OF HYDRAULIC TRANSPORT DEVICES FOR THE TRANSPORT OF HYDRO ABRASIVE MEDIUM

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ABSTRACT

The hydro transport equipment of mountain-concentrating industrial complexes has the low use reliability, an insufficient working resource because of an intensive hydro abrasive wear of working surfaces of pipe ducts and the pumping equipment, deficiencies of constructions of some nodes of soil pumps and their maintenance. The considerable hydro abrasive wear of a basic element of a construction of the soil pump - the impellor, calls additional disturbing dynamic forces that leads to heightened vibration of the aggregate and, hence, to its premature exit out of operation. To questions of influence of a hydro abrasive wear of the impellor of soil pumps on life expectancy of their installations and their resource the insufficient attention, till now, was paid. The assaying of development of a cavitation damage of details of a flowing part of soil pumps is made, measures of lowering of a cavitation at the expense of favorable conditions of receipt of a fluid in the pump and lowering vacuum metric suction lift are planned. Cavitation influence is offered also series of actions of the technological and constructive decision, lowering harmful. Materials for manufacture of details of the centrifugal soil pump, by the possessing high operation qualities, a having high resource of operation are selected and analysed. These alloys have displayed a high corrosion stability because of the high contents in them of chrome. Paths of perfecting of a construction of details of the centrifugal soil pump are planned, allowing to raise a resource of their operation, to create the automized system of diagnosing of a condition of a construction as a whole.

Keywords: the soil pump, the driving wheel, hydro abrasive deterioration, the measuring stand.

INTRODUCTION

Ground pumps are mass units for the transport of crushed ore in aqueous media. The formed water abrasive medium has a high destructive capacity, so that the ground pumps, due to the intensive wear of working parts, have a low service life [1–3].

Service life of parts of the pump-armored disk, impeller, does not exceed 20 days of work, after which it is necessary to stop the pump and carry out repair work to replace worn parts. That requires considerable losses of working time of the basic equipment of concentrating manufacture and a large volume of spare parts [2].

Therefore, the research aimed at developing a new ground pump design, with an increased service life, is relevant.

The analysis of the problem of operation of ground pumps has shown that ground pumps at the enterprises of mining and processing manufacture do not meet the requirements on reliability and power consumption indicators. The main drawback of ground pumps is the low service life of parts of the pump flow part due to the action of hydro abrasive and cavitation wear [1, 2].

Therefore, as a result of the research of mechanical and cavitation wear of impeller parts, the development of a new design of the ground pump with high resources of work is an urgent task.

MATERIALS AND METHODS

Theoretical analysis.

The works of a number of foreign and Russian sources [3–7], design and technological decisions in creation of effective ground pumps which consists in the following are analyzed:

– increased disc thickness in the area of maximum wear and through holes;

– the presence of an elastic band in the flow channel, which may fluctuate;

– the presence of grooves in the impeller blades, arranged in a certain order;

– use of a protective coating of high hardness material in the form of shells;

– formation of local turbulent flows, displacement of laminar flows from the periphery to the flow axis;

– reduced vibration due to intermediate supports;

– a way to reduce hydrodynamic friction by exposing the boundary layer of liquid or gas to an alternating electromagnetic field;

– changing the pipeline design from the inside – presence of longitudinal ribs with cylindrical segments fixed on them in order to reduce aerodynamic friction resistance and reduce the thickness of the boundary layer;

– replaceable wear ring installed in the rotating pump assembly;

– the presence of resistant and wear-resistant rings, in order to hold the liquid film between them, as a result – reduced wear when the impeller rotates.

However, these measures did not solve the problem of increasing the service life of ground pumps and replacement of worn-out parts, which takes a long time. The reason for this may be objective difficulties associated with the lack of original solutions of constructive and technological nature, which makes appropriate research impractical.

An option to overcome these difficulties may be that ground pumps are used in mass production, and the limits of ground pump improvement also depend on the hydrodynamic design parameters of the pulp movement in hydro abrasive media.

All this makes it possible to assert that it is expedient to conduct a study on the improvement of the impeller and armored disk design as the most important loaded parts of the pump.

From the works, on the theme of hydro abrasive media transportation, it is possible to allocate researches where the condition of systems of hydro transport of some concentrating factories is analyzed. In work [3] it is shown that in connection with obsolescence of the technological equipment the main reason of failures in work of hydro transport of tails is insufficient reliability of pump units due to which there are up to 79 % of failures of the equipment.

In works [4, 5] extensive researches of hydro abrasive wear in industrial and laboratory conditions in which the theoretical analysis of process of wear is combined with laboratory researches and pilot tests are resulted.

Of great interest for further study of the process of hydro abrasive wear are also theoretical and experimental studies carried out by the authors [6].

When working on hydraulic mixtures with small solid inclusions, the slot seals located at the inlet side of the impeller and the working surfaces of the blades and their inlet areas are wearing out most quickly.

Thus, all these types of wear lead to the destruction of the pump operating elements, deterioration of performance characteristics. Therefore, the improvement of the pump components design, providing the increase of wear resistance and regulation of the pump unit operation mode, are actual.

The aim of the study is to substantiate the process of water-abrasive wear of ground pumps, to outline the ways of its reduction.

To achieve this aim, the following objectives are accomplished:

– to analyze the problems of ground pumps operation;

– to develop constructive measures to increase the service life of the ground pump and its parts;

– to conduct pilot tests of ground pumps.

Experimental part. Pumps wear out due to the contact of solid particles moving in the liquid with the walls of the pump flow channels. The impeller separates the particles by their particle size. Larger particles, whose trajectories are coarser than the liquid current lines, do not fall on the working surface of the blades at all. The blade flows only through the flow of small solids suspended in it.

The process of water-abrasive wear of pumps is a consequence of the total effect of all types of destruction: abrasive, cavitation, erosion and corrosion.

As a result of water-abrasive wear, impellers, armored discs and pump housings (snails) are most often replaced at mining and processing plants.

Non-ferrous metallurgical enterprises have adopted a classification of hydro-mixtures, according to which they are divided into four categories depending on the properties of solid particles (Table 1).

Table 1 - Classification of hydro mixtures adopted by non-ferrous metallurgical enterprises

Hydro mixture category	Mass concentration of solids, % inclusive	Particle hardness on the Mohs scale	Particle size, mm	Hydrogen index, *pH*
I	Up to 25	Less than 2 2…3 3…4 4…5	More than 8 8…3 3…1 1 and less	6…8
II	25 to 35	Less than 3 3…4 4…5 5…6	More than 8 8…3 3…1 1 and less	6…8
III	35 to 45	Less than 4 4…5 5…6 6…7	More than 8 8…3 3…1 1 and less	6…8
IV	45 to 65	Not regulated	Not regulated	6…10

The main parameters of the hydraulic mixtures flows characterize their physical and mechanical properties and the conditions of the steady flow in the pump. The main physical and mechanical properties of hydro-mixtures include: solid content (volume S or mass S_1); specific gravity γ, kN/m^3; pseudo viscosity μ, N·s/m^2 (for dispersed or finely dispersed mixtures).

In terms of the predominant content of solid particles of a certain particle size class, the following main types of hydro-mixtures can be identified:

– colloidal (atypical) – with a particle size of up to 1 µm;

– structural (hydrosols) – particle size 1–50 µm;

– fine – particle size 50–150 µm, obtained in the processes of sedimentation and grinding;

– coarse dispersion – particle size from 100 µm to 2 mm, obtained in the processes of sedimentation and grinding;

– heterogeneous coarse dispersions – particle size greater than 1.5–2 mm;

– polydisperse – particles of various sizes obtained in the processes of sludge accumulation, dispersion, crushing or crushing.

Surfaces are destroyed by continuous impacts transported by a stream of particulate matter to the surface of the component. At the moment of impact, the deformation of the material in the flow of the part is transformed.

Countless collisions of the solids transported by the flow with the surface of the part, even if they cause only elastic deformations of the material, also lead to the eventual destruction of the surface due to fatigue phenomena of the metal. The liquid medium has a de-strengthening effect, thus accelerating the process of fatigue failure.

As a result of modeling the process of pumping units operation, using multifactor experiment and computer programs Excel planning and processing of experimental data, the equations of regression allowing to determine:

– specific power consumption from the volume of processed abrasive material, $y = 2E - 07x^4 - 2e - 05x^3 + 0.0027x^2 + 0.0283x + 0.1875$, $R^2 = 0.9994$;

– pump feed rate from the volume of abrasive material processed, $y = -0.0002x^3 - 0.0051x^2 - 0.4655x + 602.21$, $R^2 = 0.9993$;

– pump head from the volume of abrasive material processed, $y = -1E - 05x^3 + 0.0005x^2 - 0.001x + 43.97$, $R^2 = 0.9982$.

Regression equations of pump units operation processes are shown in Fig. 1–3, which allows to make corresponding calculations.

Hydro abrasive wear of the ground pump impeller and other parts of the pump is the main reason for the reduction of the service life of the pump itself and the entire hydraulic transport system. The development of hydro abrasive wear of the impeller's impeller surfaces is accompanied by a change in the vibration spectrum at the main support units of the pumping unit. Excess oscillations of the pump casing are transferred to the support units, which can support significant alternating dynamic loads, leading to their destruction.

If the actual Q_A flow and H_A pressure of the pump unit, as defined at operating point A, do not meet the specified conditions, the operating mode of the installation changes:

1) Throttling by means of a regulator. When it is partially closed, the hydraulic losses in the pipeline increase by the value h_o. The required head of the pumping unit increases (Fig. 4, *a*):

$$H_{pipes} = H_F + K_C Q^2 + h_0 = H_F + K_C^{'} Q^2, \quad (2)$$

where $K_C^{'}$ – network resistance coefficient with additional throttling. The working point will move to the point *B*. The pump supply will be reduced.

The method is simple in execution, but accompanied by power losses:

$$N_I = \rho g h_0 \frac{Q_B}{\eta_B} \quad (3)$$

2) By bypassing a part of the liquid (Q_{per}) from the pressure line to the suction (or tank) through the bypass line.

3) Changing the characteristics of the pump itself, e. g. changing the pump shaft speed (Fig. 5, *b)*;

Speed control can be achieved by using a DC motor, combustion engine or turbines.

4) Changing the characteristics of the pump itself by turning the impeller, i.e. reducing the output diameter ($D_2^1 < D_2$). The geometric similarity of the wheels is broken, the conversion formulas are semi-empirical:

$$\frac{Q}{Q^{'}} = \left(\frac{D_2}{D_2^{'}}\right)^x ; \frac{H}{H^{'}} = \left(\frac{D_2}{D_2^{'}}\right)^y ; \frac{N}{N^{'}} = \left(\frac{D_2}{D_2^{'}}\right)^z \quad (4)$$

where *Q'*, *H'*, *N'* are pump parameters after turning.

Thus, the production of the impeller as a composite impeller makes it possible to process the internal curvilinear impellers. And also to cover them before assemblage with the special covering protecting them from corrosion, cavitation and hydro abrasive deterioration that is difficult to carry out in the closed wheel. Restoration of the protective coating and replacement of worn-out parts will reduce the cost of purchasing pump spare parts and extend the life of the pump until overhaul.

The armoured disc is a characteristic feature of the Discs class. Parts in this class must be manufactured to the required shape and dimensional accuracy of the outer, inner and end faces of rotation. The part under consideration is rigid enough, has convenient base surfaces and does not cause any technological difficulties in its manufacture.

On the inner surface of the case 1 there is a similar replaceable armour plate 14, which is connected to the case with the help of screws. Water is also supplied to the gap between the removable armour plate 14 and the impeller. A cuff is installed in the lower part of the replacement armoured personnel carrier.

At designing of pumps consider a number of features of their work, for reduction of abrasive action of particles details of pumps carry out from wear proof materials, and thickness of walls of the case, disks, blades and other details choose taking into account deterioration.

The main requirement and reliability is the service life of the ground pump. The main part of spare parts are impellers – up to 50 %, armored discs account for 25 %, branches and other parts 25 %.

In order to significantly reduce the wear and tear of hydraulic abrasive mixtures, it is proposed to apply fundamentally new approaches:

1) Create a vibration effect on the transporting device.

2) Create vibration impact directly on the transported mixture.

Vibratory impact on the mixture causes a significant decrease in the viscosity of the mixture, breaks the bonds between the particles of the mixture and sharply reduces the contact interaction of the mixture particles with the working bodies and bodies of transporting devices. As a result, abrasive wear and tear of conveying devices is reduced and the service life of pumps is increased accordingly.

The vibration parameters monitoring, regulated by the industry and international standards, is based on the statistical data on slurry pumps failures at the mining and processing plants. That is, in the process of operation, it is possible to predict the residual life of pumping units, as a function of water-abrasive wear of the impeller.

In addition to the vibrating effect on the conveyed mixture, the vibrating effect of the pump mass caused by the rotor unbalance should be reduced, resulting in intensive wear and tear on the shaft bearings.

The first includes such means of protection as dynamic balancing, antiphase synchronization, changing the nature of disturbing influences, changing the structural elements of the source of excitation, changing the frequency of vibrations, etc. They are used, as a rule, at the stage of designing and manufacturing of equipment.

Vibration isolation is carried out by means of introduction into the vibrating system of additional elastic bonding, which prevents the transmission of vibrations from the machine – the source of vibration – to the base or adjacent elements of the structure. This elastic connection can also be used to weaken the transmission of vibrations from the base to the person, or to the protected unit.

Vibration isolation is achieved by installing the units on special elastic devices (supports) with low rigidity.

The effectiveness of vibration isolation is evaluated by the transfer coefficient, which has a physical meaning of the ratio of force acting on the base in the presence of elastic bonds to the force acting in the case of rigid bonds. The smaller the ratio, the better the vibration isolation. Good vibration isolation is achieved with *KP*=1/8–1/15 [6].

The transfer coefficient can be calculated using the formula:

$$K_P = \frac{1}{\left(\frac{f}{f_0}\right)^2 - 1}; \qquad (5)$$

where f is the frequency of disturbing force; f_0 is the natural frequency of the system on vibration isolators. The optimal ratio between f and f_0 is 3...4.

For vibration isolation of machines with vertical perturbation force, 3 types of vibration isolating supports are used: rubber, spring and combined.

Installation of machines on spring shock absorbers is more effective than on rubber shock absorbers, as it provides lower natural frequencies of vibrating mechanism vibration.

The disadvantage of rubber shock absorbers is that they do not last long, as they become stiffer over time and after 5. They must be replaced after 7 years. In addition, they cannot be used to obtain very low intrinsic system frequencies, which are necessary for slow-moving units, due to the inevitable overload of gaskets, which significantly reduce their service life.

At designing of details of ground pumps it is necessary to accept thickness of a rubber layer not less than 12–15 mm. Fig. 10 shows the dependence of rubber layer wear rate on its thickness.

Weakening the vibration level:

$$\Delta L_u = 20\lg\frac{1}{KP}, \qquad (6)$$

where the *KP* is the transmission factor.

With the operation of the ground pump, in the hydraulic transport system, with the given kinematic characteristics of the pumped pulp, the spectrum of vibration parameters changes. Gradually the amplitude of vibrations in radial and axial directions increases. Each moment of time, the ground pump working process, corresponds to its own values of vibration characteristics, i.e.

$$T = k_B \bar{V}^n, \qquad (7)$$

where k_B is the proportionality coefficient, $\bar{V}$ is the root-mean-square value of the vibration velocity, mm/s.

The energy required to move a unit of liquid weight from the receiving tank to the pressure tank, or the required head of the pumping unit:

$$H_{pipes} = h_r + \frac{(p''-p')}{(pg)} + \sum h_n = H_r + K_C Q^2, \qquad (8)$$

The vibration of the pumping units increases significantly with the increase of hydro-abrasive wear, with the maximum vibration movements taking place on the support bearings in the frequency band from 8–12 Hz. The development of vibration processes is directly related to the loss of weight of the ground pump impeller due to water-abrasive wear.

For measurement of the received vibration the measuring stand presented in Fig.1 is developed, including the system of gauges, measuring means.

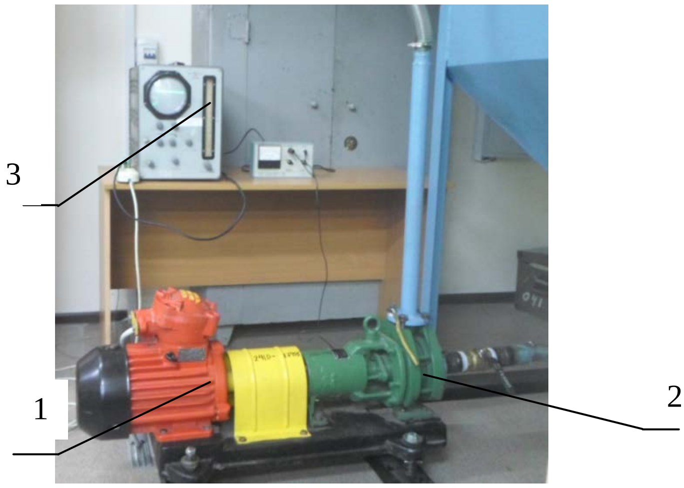

Fig. 1. Installation measuring system: 1 – electric motor, 2 – pump, 3 – vibrometer

Measuring instruments:
– Vibrometer VIP-UHL 4.2;
– working range of parts 10–100 Hz;
– measuring range:
a) The actual vibration velocity values of 01–100 mm/sec;
b) Vibration range – 01–1000 microns;
– limits of measuring ranges:
a) vibration resistance 1, 3, 10, 30, ...100 mm/sec;
b) vibration displacement 10, 30, 100, 300, 1000 microns;
– relative transverse conversion factor of the transducer does not exceed 10 %;
– the basic relative error of vibration measurement under normal conditions is not used to:
a) 25 % when measuring the vibration range of 10–20 Hz;
b) 15 % when measuring the vibration velocity in the private range of 20–1000 Hz;
– normal operating conditions:
a) the ambient temperature is 20 plus, –5 °C;
b) relative humidity – 65±15 %;
c) atmospheric pressure – 100±4 kpa;
– Scales electronic with accuracy to 5 g;
– A caliper with a measurement limit from 0 to 500 mm with an accuracy of 0,05 mm.

The centrifugal ground pump was tested on a hydro-mixture with 45 % of solid particles within 72 hours.

The entire pump design is evaluated for vibrations when the transducer (e. g. vibration displacement, vibration velocity or acceleration transducer) is placed at a specific point in the pump or on a mechanical part of a measuring stand that is mechanically connected to the pump parts.

The accumulated data is analyzed to find one or more parameters that are used to characterize vibration. These data can be used to determine the quality of the pump and its condition. The measurement process can be represented schematically as shown in Fig.1. Table 2 presents comparative characteristics of wear-resistant alloys for manufacturing parts of centrifugal pumps operating under abrasion conditions.

Table 2 - Characteristics of wear-resistant alloys

Mark of alloy	Hardness, HRC	Wear resistance coefficient of steel 25	Processability factor
300Ch12M5	59–62	7.0	1.0
300Ch12M3Mo	61–62	8.5	–
300Ch12Mo	28–33	3.3	4.5
300Ch16MoT	60–61	10.0	4
300Ch28N2	47–55	7.3	1.0
ICCh28N2	35–50	5.0	2.0
250Ch25T	53–60	7.0	1.0

The ICCh28N2 alloy, which is widely used in pumping, is hard to machine on metal-cutting machines. It can be ground only with low cutting speed (8–10 m/min), and it is impossible to cut threads on parts made of this alloy and chisel key grooves at all.

At the request of VNIIINedra the impellers were tested cast of M13Ch2F steel. Service life of these impellers was 3 times longer in relation to the impellers cast from 55F steel.

Two grades of medium carbon low-alloy steels are recommended for industrial testing:

– chromium-manganese chromium-nickel (40ChMNF) and

– chromium-nickel- tungsten-vanadium (35ChN1TVF).

RESULTS AND DISCUSSION

The obtained results of the ground pump research are based on the real methods of solutions, both theoretical and experimental.

A distinctive feature of the proposed methods is the improvement of design and technological parameters of pumping units operation for transportation of pulp containing media in their originality and uniqueness.

The proposed development of ground pump parts, namely the impeller and armour wheel, to increase the service life of the pumping unit is obvious and requires industrial application. These design developments were claimed and inventions were received (Fig. 7, 8) [19, 20].

The pilot test resulted in positive results of the ground pump performance evaluation. Regression equations of pump units operation processes are presented in Fig. 2–4 that allows to make corresponding calculations.

The design decisions were made at the level of invention issued by the RSE "National Institute of Intellectual Property" of the Ministry of Justice of the Republic of Kazakhstan.

The limitations of this study are the high percentage of waterjet media transported, which limits the service life of the pumping units, which is the subject of further research.

Promising directions of further research can be the development of 3D technology for manufacturing the main parts of ground pumps: snail, impeller, armored disk, housing, with pre-determined requirements of high wear resistance. Also it is necessary to carry out research on physical influence on a transported material and the pump unit by elastic, wave influences.

The process of operation of a centrifugal ground pump for the transportation of hydro abrasive mixture in the enrichment plant was studied.

Kazakhstan extracts a large amount of ore materials that are processed in order to extract valuable metals from them. In the process of processing rocks, the latter, in accordance with the technological process, are transported by centrifugal ground pumps. Thousands of ground pumps are used in the production process, their service life is very low, so the research of the operation of the centrifugal ground pump in order to increase its service life is an actual problem of mining and construction production.

The solution of the technological and structural task to increase the service life of the centrifugal ground pump, development of new design of ground pumps with increased service life will allow to increase the production capacity, reduce overhaul cycles and the number of spare parts.

The carried out researches is continuation of scientific research works of faculty "Standardization, certification and technology of mechanical engineering" and, now, is a theme of the doctoral dissertation of the applicant of faculty.

CONCLUSION

1. The analysis of the processes of water-abrasive wear and cavitation erosion of the working parts of ground pumps, the reasons for their appearance, the nature of wear and methods of their prevention, as a change in the modes of their operation, and design solutions. On the basis of the analysis of wear of parts of the ground pump flowing part, the advanced designs of the prefabricated armored disk with a replaceable disk, and the compound impeller with the improved indicators of wear resistance and maintainability are developed, allowing to increase their service life, to reduce expenses on purchase of spare parts, to reduce the repair period. The influence of the ground pump parts wear on its operating parameters is determined, the dependence of the pump head and flow rate on the volume of the pumped hydroabrosion mixture is established;

2. The influence of the hydraulic mixture characteristics and flow parameters on the ground pump wear has been established, analytical and experimental dependences of the pump working parts wear – armour wheel and impeller – on the hydraulic mixture density and solid particles particle size have been found;

3. The main directions for increasing the service life of wearing parts, the choice of high-strength steel and wear-resistant coatings are defined. It also improves pump design and assesses the effect of physical fields on the transported material and pump unit. A laboratory experimental unit for laboratory tests has been developed: modes of operation of the pumping unit; the service life of the pumping unit in the conditions of water-abrasive wear of the ground pump has been determined. The basis for monitoring vibration parameters regulated by industry and international standards is statistical data on ground pump failures at mining and processing plants, which allows to predict the residual life of pumping units as a function of water-abrasive wear of the impeller.

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