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Specifying the technical state limit value of the pump pulp without disassembling

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The northern part of the territory of the Republic of Sakha (Yakutia) is rich in vast deposits of diamonds. These deposits are developed by the mining company "Almazy Anabara", which is engaged in the extraction of diamonds at seasonal processing plants using various technological equipment. One of the key types of equipment is the pulp pump of a foreign company "KETO". The work of pulp pumps of this company in the enrichment of diamond-containing raw materials is accompanied by intensive hydroabrasive wear of their impellers, the service life of which usually does not exceed three months.

In practice, untimely replacement of a worn impeller can lead to emergency breakdowns of sealing elements and bearings, which is explained by super-permissible deflections of the shaft of pumping equipment arising from a significant unbalance of the rotor.

The main cause of breakdown of slurry pumps at "Almazy Anabara" seasonal processing plants is the inability to quickly identify their ultimate technical condition, the key sign of which is the maximum wear of the impeller.

The seasonal beneficiation plants of "Almazy Anabara" currently need a simple and at the same time reliable diagnostic sign of pulp pumps reaching their ultimate technical state, the identification of which can be quickly performed without disassembling and using complex equipment, which is very important when operating pumping equipment in short wash season on the Far North.

***Key words*:** impeller pumps; wear; impeller; shaft deformation; failures

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Introduction. The northern part of the territory of the Republic of Sakha (Yakutia) is rich in alluvial diamondiferous deposits. These deposits are developed by the mining company "Almazy Anabara" (a subsidiary of DMC "ALROSA").

Diamonds are mined from sands extracted from deposits at seasonal processing plants (SPPs) using various technological equipment operating on the principle of gravitational enrichment of a mineral in water. The transportation of hydraulic mixtures formed during the mixing of water and sand is mainly carried out by "KETO" slurry (gravel and sand) pumps (Fig.1).

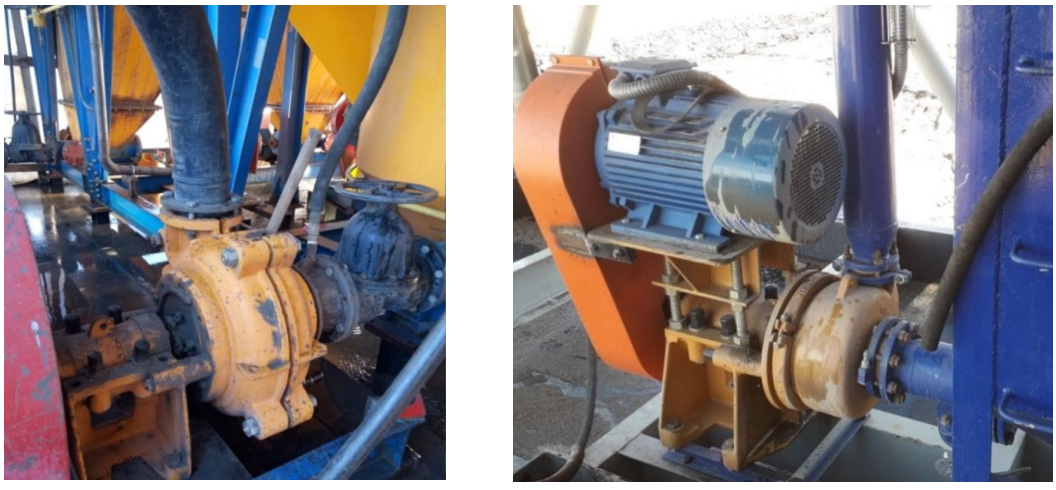


Fig.1. "KETO" pulp pumps during operation. Mine Mayat, June 2018

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Fig.2. Consequences of the operation of "KETO" slurry pumps on hydraulic mixtures

According to workers in a number of SPPs, the operation of these pumps on hydraulic mixtures is accompanied by intensive hydroabrasive wear of their impellers, the service life of which is 1-3 months. (Fig.2).

Practice shows that untimely replacement of a worn impeller of a pulp pump can lead to emergency breakdowns of its sealing elements and bearings. Unscheduled failures of these parts are explained by super-permissible deflections (deformations) of the pump shaft that arise due to a significant unbalance of the rotor due to wear of the impeller [1-9].

The main cause of emergency breakdowns of slurry pumps at the "Almazy Anabara" SF plant is the fact that the current system of technical maintenance and repair (MR) of pumping equipment does not allow to quickly identify its ultimate technical condition, the key sign of which is that the impeller reaches its maximum wear.

At present, "Almazy Anabara" is practicing a hybrid maintenance and repair strategy for SPP pumping equipment, combining a scheduled preventive maintenance (SPM) strategy and an actual condition maintenance (ACM) strategy.

The first MR strategy should be understood as the monthly decommissioning of pumping equipment for detailed visual inspections with complete disassembly. The low efficiency of such planned activities is dictated by two objective reasons:

1. In "KETO" pumps, during operation, worn parts are replaced not only with original (factory) parts, but also with interchangeable "Warman" parts. Despite the almost complete interchangeability of the details of the pulp pumps of these companies, their wear resistance, and hence their durability, vary. Thus, it is clear that the limiting technical state of slurry pumps can occur after a relatively different operating time.

2. Interviews with the maintenance staff of a number of SPPs indicate that the installation of threaded impellers for "KETO" and "Warman" pulp pumps is accompanied by systematic damage (microcracks, deformations, chips, etc.) due to excessive tightening. This is a consequence of the relatively low qualification of staff.

The essence of the ACM strategy of any technological equipment is to carry out repair work only if at least one of the operational parameters characterizing its technical condition reaches its maximum level.

In the conditions of the SPP of "Almazy Anabara" company, such a priority diagnostic parameter at present is the speed of the pump motor. Practice shows that slurry pumps are usually decommissioned if the nominal speed of their motors increases by 15 %. According to numerous observations of the operation of pulp pumps, an increase in the initial motor speed of 15 % is usually accompanied by strong vibration in the pump, which indicates serious violations in its operation.

Due to the fact that a much lower level of vibration is characteristic for breakdowns of the pumping equipment of the SPP, it is not correct enough to take into account the diagnostic sign under consideration.

The lack of vibration monitoring tools in the equipment of pulp pumps SPP, which is the most common method in the production of operational diagnostics of the actual technical condition of various equipment, is explained in the papers [1, 2, 10, 11, 12]. Workers at the SPP are accepted only under a short-term employment contract, without a guarantee of employment for the next washing season. Therefore, training in the basics of vibration diagnostics of SPP workers changing

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every year is unlikely to bring tangible results. In addition, equipping all the pumping equipment available at the SPP with vibration equipment is quite expensive from financial point of view.

In the literary source [1] it is noted that when the pressure of the pulp pump is reduced by 25 % or more, it must be immediately decommissioned for major repairs.

The change in the pressure of any centrifugal pump is most easily monitored using a pressure gauge mounted on the discharge line, since there is a very high correlation between the pressure and the pressure at the pump outlet.

However, it is not to be forgotten that the pressure drop due to hydroabrasive wear of the impeller of a centrifugal pump also inevitably leads to a decrease in its performance. In turn, a decrease in the performance of the centrifugal pump Q leads to a decrease in the working speed of the pumped hydraulic mixture [13]:

$$\upsilon = \frac{4Q}{3600\pi D^2}, \quad (1)$$

where D – slurry pipe inner diameter.

When the working speed of the slurry drops below the critical level of mechanical impurities deposition, the initial stage of siltation of the slurry pipelines begins. Settled sludge increases the roughness of the flow section of the slurry pipeline, and due to the increase in hydraulic losses in the pipe, there is a further decrease in pressure and performance of the pulp pump. The deterioration of the hydraulic characteristics of the pulp pump leads to an increase in the thickness of the layer of settled sludge in the slurry pipeline. Thus, for a very short period of operation of pumping equipment on hydraulic mixtures, complete clogging of its discharge slurry line may occur. Therefore, monitoring the technical condition of the pump through its outlet pressure under hydraulic mixtures may be accompanied by serious errors due to the gradual siltation of the slurry pipeline.

In practice, the slurry piping of the pumping equipment of SPP of “Almazy Anabara” practically never silts. This is because the pressure of the slurry pumps practically does not change over time. Constant maintenance of the nominal pressure of the pulp pump provides the greatest degree of efficiency of enrichment of diamond-containing raw materials in heavy-medium hydrocyclones. Even a slight deviation of pressure in one direction or another can seriously affect the efficiency of enrichment.

Maintaining for a relatively long period of time the nominal pressure of the pulp pump under conditions of intensive hydroabrasive wear of the impeller is ensured by gradually increasing the number of revolutions of its electric motor. Thus, it is advisable to diagnose the limiting technical state of a pulp pump precisely by the frequency of rotation of its electric motor.

The purpose of this study is to establish and further substantiate the maximum allowable increase in the nominal speed of a pulp pump electric motor operating in conditions of intense hydroabrasive wear.

Methology. According to R.Hooke’s law, the strains ε of most elastic bodies (including shafts) are directly proportional to the stresses arising in them:

$$\sigma = E\varepsilon, \quad (2)$$

where E – Young's modulus.

From this it follows that super-permissible deformations of the pulp pump shaft will occur only when the actual stresses concentrated in it exceed the maximum permissible mark.

According to the source [14], the shafts of centrifugal pumps are not safe to operate in the event of an stress σ_{max} increase of 1,8 times and even more:

$$K_v = \frac{\sigma_{lim}}{\sigma_{max}} = 1.8, \quad (3)$$

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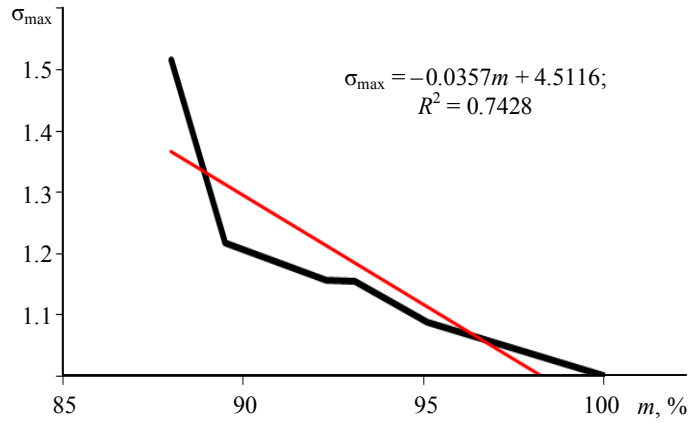


Fig. 3. Linear dependence $\sigma_{max} = f(m)$ and its approximation in linear function, R^2 – confidence coefficient

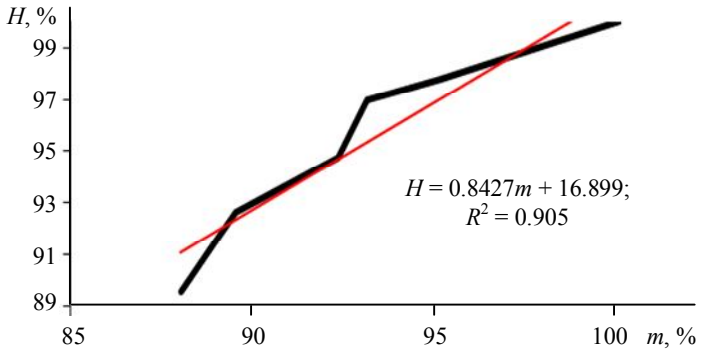


Fig. 4. Linear dependence $H = f(m)$ and its approximation linear function

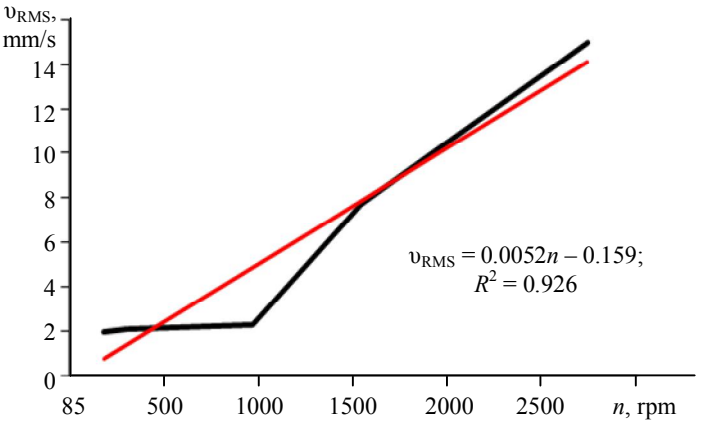


Fig.5. The linear dependence of υ_{RMS} from n and its approximation by a linear function

where K_v – pump shaft safety factor; σ_{lim}, σ_{max} – endurance limit and maximum equivalent stress in the shaft structure during pump operation.

Calculations by the empirical formula obtained by the authors by approximating the experimental relationship between the linear trend σ_{max} and the metal consumption of the impeller m of the K8/18 model centrifugal pump (which is almost identical in design to pulp pumps), it is shown that the stresses arising in the seat of the pulp pump shaft under the impeller (the most loaded shaft location) reached the limit value in the case, if m = 76 % (Fig.3) [15]. Under the unit along the σ_{max} axis of the graph, the maximum equivalent voltage is taken, which occurs in the most loaded place of the simulator pump shaft when it is working with a new impeller (m = 100 %).

Thus, the risk of unplanned failures of bearings and sealing elements of slurry pumps used at “Almazy Anabara” s seasonal concentration plants will increase significantly if the initial impeller mass of the pump decreases by 24 % or more.

The calculations according to the second empirical formula derived by the authors (Fig.4) show, that the impeller reaches m value of 76 % by the metal consumption if the current head H of the pulp pump is 81 % of the nominal value.

In other words, if the nominal pressure of the pulp pump is reduced by 19 % or more, it is recommended that it be decommissioned for the purpose of performing an audit [16].

The pressure of the pulp pump increases by 19 % with an increase in the number of revolutions of its electric motor by 9 %:

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2, \quad (4)$$

where H_1, H_2 – the current and nominal pressure of a centrifugal pump respectively; n_1, n_2 – the current and rated speed of the centrifugal pump motor respectively.

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Based on this, it can be concluded that an increase in the nominal speed of the electric motor by 9 % (in our case from 2340 to 2551 rpm) can be considered a reliable diagnostic sign that the pulp pump has reached its maximum technical condition.

An increase in the number of revolutions of the electric motor during the operation of the pulp pump with a worn impeller can lead to greater shaft loading due to an increase in the vibration level of the pump rotor. Subsequently, this may adversely affect its reliability.

Calculations using the empirical formula (Fig.5), derived on the basis of the processing by methods of mathematical statistics of experimental studies that were carried out on a drilling machine (simulates an electric pump unit) with an unbalanced working body (simulates a worn impeller), showed that the increase in speed n from 2340 up to 2551 rpm on the rms value (RMS) of the vibration velocity υ_{RMS} of the rotor of the pulp pump will practically not affect.

Conclusions. Based on the results of the research conducted by the authors, an operational diagnostic sign was established and justified for the pulp pump to reach its maximum technical state, which can be quickly identified without disassembling the pump and using complex equipment, which is very important during the short washing season on the Far North.

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