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Vibration-based Diagnostics of Slurry Pump Technical State

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Abstract

Background/Objectives: This study is an attempt to prove the dependence of the slurry pump life on the vibration parameters for developing the diagnostics algorithm and express-method to evaluate the operating state of the slurry pump in the hydraulic transportation system. **Methods/Statistical Analysis:** It is expedient to evaluate technical state of the pumping equipment by parametric diagnostic methods based on the measurement of hydrodynamic parameters of the slurry pump workflow. The pump vibration characteristics were measured with Prufnechnik portable diagnostic system using autonomous encoders Vibscanners. The dependence of the slurry pump life on the vibration parameters is proved theoretically and experimentally and it is shown that the operating life of the pump is an exponential function of the preset root-mean-square value of the vibration velocity. **Findings:** Most parametric diagnostic methods are based on specifications on the respective equipment. The important factor is that these characteristics are obtained by factory tests on water pumps. Therefore, when this equipment is operated for slurry pumping, it will be immediately show deviation of the basic hydraulic parameters from the factory performance. During operation, characteristics of the equipment may also vary. This may be determined by many factors, the main of which is the hydroabrasive wear, which is associated with features of the pumped medium. Data analysis of operating slurry pumps at the processing facilities and reasons of their failures leads to the conclusion that among all the factors determining operating life of slurry pumps hydroabrasive wear of the impeller has the greatest impact. The experiments and statistical data show that with the increase in the hydraulic abrasion of the impeller considerable dynamic loads occur associated with the misbalance at the driving shaft due to the low-frequency vibrations received by the bearing units. These factors result in the slurry pump lower pressure. These results suggest giving a more accurate evaluation of the technical state of the pumping equipment based on the measurement of hydrodynamic parameters of the slurry pump workflow. **Improvements:** Engineers designing hydraulic transportation systems will be able to obtain more complete idea of the vibration-based diagnostics of slurry pumps used for pulp-pumping, which will enable to increase operating life of pumping equipment applying these data.

Keywords: Energy Consumption, Express-Diagnostics, Hydrotransport, Hydroabrasive Wear, Slurry Pump, Technical State

1. Introduction

The problem of the hydrotransport system reliability at the dressing plants of Russia is one of the most urgent now. The issues of the process equipment technical state and of improving its reliability are the subject matter of many scientific and research studies. Up to now, several lines of research in the sphere of improving the reliability and of evaluating the technical state of the ore-tailing hydraulic transportation systems have been formulated. As an example, the book by[1] on the theory of designing the complex systems with the preset reliability parameters can be mentioned. In that study, considerable attention is paid to the process equipment operation in ore-dressing plants and in mining and processing industrial complexes. Also, notable is the book by[2], who introduced such idea as "mixing effect" into the practice of defining the degree of reliability, which is quite important for the hydraulic transportation systems. The methods of investigating the quantitative indicators of the hydrotransport system

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reliability have been expostulated in works by[3]. In the study by[4] the parameters characterizing the slurry pumps reliability have been considered together with the methods of optimizing the quality of the pump-house operation. In the study[5] the issues of the slurry pumps technical state and of the diagnostics and monitoring methods are discussed profoundly.

For the purposes of this study, the most interesting line of research is that dedicated to studying the parameters, predetermined by the hydroabasive wear of the hydraulic transportation equipment and of the slurry pumps. This interest has been, to a large degree, stipulated by the fact that the methods of the hydrotransport system and the slurry pump diagnostics are closely related to the alterations in the slurry pump technical state occurring in the course of operation, which is directly associated with the degree and the intensity of the hydroabrasive wear at the pump elements, particularly, at the impeller. A considerable contribution to studying the process of hydroabrasive wear has been made in the works by[5] who carried out extensive investigations both in laboratories and in the industrial field conditions in the sphere of coal and stowing slurry transportation with the hydraulic transportation pipelines. The author highlights that the wear at the walls of the pipelines and at the elements of the pumps is a result of the hard particles affecting the slurry restricting surfaces, which leads to the surface abrasion as a result of friction and sliding forces. Similar models of the hydroabrasive wear have been considered in works by[6–12].

2. Quotient of the Slurry Pump Technical State

Insufficient reliability of the pumping equipment is a considerable drawback to the operation. This reason accounts for up to 80% of accidents and failures, one third of which is caused by the slurry pumps. The results of observing the reasons for failures at the parts of the slurry pumps at Almalyk Dressing Plant are shown in Table 1.

The data from Table 1 show that the most loaded elements of a slurry pump, which are most likely to go wrong, are represented by its internal flow section parts, such as impeller, casing, front cover, which are in permanent contact with the pumped medium. Analyzing the data on the slurry pumps operation at the dressing plants and the data on the failure reasons enables a conclusion that hydroabrasive wear at the impeller is the factor that affects the slurry pump life most drastically among other factors influencing the operation. The experiments and the statistics prove that with the increase in the hydraulic abrasion of the impeller considerable dynamic loads occur, associated with the misbalance at the driving shaft due to the low-frequency vibrations received by the bearing units. Those factors result in the slurry pump lower pressure. The practice shows that when the operating pressure decreases down to 0.75 as compared to theoretical value ($0.75H_{theor}$) the pump is either in need of a major overhaul or has to be replaced completely. As of today, it is safe to say that at the pump-houses of the hydraulic transportation systems there is no systematic process in place to evaluate the technical state of the slurry pumps. The operation life of a piece of equipment is determined by the preset amount of service hours; and then this part is to be replaced by a new analog. For example, the service life of the impellers, under different slurry pump operational conditions, does not exceed 780–900 hours of continuous operation. This approach, under the conditions of constantly alternating operational modes of the pump houses, with different volumes, concentrations and physical and mechanical properties of the transported medium, affecting the rate of the hydroabrasive wear of the slurry pump elements, proves to be neither precise nor effective. In determining the operational modes of the pumps, the technical state of their elements is not taken into account; at the same time, the precision of predetermining the parameters of the pumping equipment operation is the prerequisite for solving the issue of optimizing the parameters of the slurry hydraulic transportation and of improving the operational life of the slurry pumps.

Table 1. Reasons for slurry pump failures

Reasons for failures	Average % of failures in slurry pump parts and units								
	10	20	30	40	50	60	70	80	90
1 Parts wear									
front covers									•
impeller								•	
volute diffuser									•
valves								•	
2 Imperfect design of units									
poor support units			•						
imperfect impeller fixings		•							
3 Deficiency in operation and control practice									
insufficient bearing lubrication	•								

In this regard, the efforts dedicated to developing reliable and valid methods for predetermining the operational modes, and, in the first place, the methods for the pumping equipment diagnostics and operational control, acquire special significance.

It is practicable to evaluate the technical state of the pumping equipment using the methods of parametric diagnostics, based on measuring the hydrodynamic parameters of the slurry pump operation process.

It should also be noted that the majority of the parametric diagnostics methods rely on the rated (documented) characteristics of the relevant process units. An important factor is the fact that those data are obtained in the course of factory trials, when the pumps are tested with water. Consequently, when this equipment is put in operation to pump the slurry, the deviation of the basic hydraulic parameters from those obtained by the manufacturer will be observed immediately. In the course of operation the characteristics of the unit may alter as well. This can be stipulated by many factors, the most important among which being represented by hydroabrasive wear of the equipment due to the peculiar features of the pumped medium. Therefore, to evaluate the actual state of the process unit, it seems convenient that the idea of the slurry pump technical state quotient should be introduced.

Relative head pressure in the pump operating with slurry is $\frac{H_h}{H_w}$, where H_h is the head pressure of the pump operating with slurry; H_w is the head pressure of the pump operating with water. According to[6,12] this correlation can be presented as an empiric dependency as follows:

$$\frac{H_h}{H_w} = 1 - \frac{\rho_h - \rho_w}{\rho_h}\beta\alpha \tag{1}$$

where ρ_w is the density of water; ρ_h is the density of pulp; β is the quotient, accounting for the effect of the pump dimensions on the value of hydraulic losses.

As the diffuser value *Re* increases, the hydraulic losses become lower; it should be assumed that at $\mathrm{Re} > 1200000 \quad \beta = 0.6$, at $\mathrm{Re} < 1200000 \quad \beta = 800/\sqrt{\mathrm{Re}}$.

Quotient α in Formula (1) is determined according to the formula as follows:

$$\alpha = 0,4\frac{gH_w r_1^2}{u^2 r_m D_g}\left[100\left(\frac{r_2^3}{D_R r_m}\sqrt{0,5}\right)^{-1,4} - 1\right] \tag{2}$$

where r_1 is the impeller radius; r_m is the average radius of the diffuser; D_g is the hydraulic diameter of the diffuser in the calculated section; r_2 is the outer radius of the diffuser in operational section; u is the circumferential velocity of the impeller.

Actual relative head pressure can be considered as a hydromechanical quotient of the slurry pump flow section technical state k_{tsh}, accounting for hydromechanical losses at the impeller and at the diffuser.

$$k_{tsh} = 1 - \frac{\Delta\rho}{\rho_h}\beta\alpha, \tag{3}$$

The relative head pressure can also be expressed as follows:

$$\frac{H_h}{H_w} = \frac{Q_w}{Q_h}\cdot\frac{\eta_{h.m}}{\eta_{w.m}} \tag{4}$$

This equation can be considered as the mechanical quotient of the slurry pump technical state:

$$k_{tsm} = \frac{Q_w}{Q_h}\cdot\frac{\eta_{h.m}}{\eta_{w.m}} \tag{5}$$

The total value of the slurry pump technical state quotient will be equal to the product of the hydromechanical technical state Quotient (3) by the mechanical technical state Quotient (5), i.e.,

$$K_{ts} = k_{tsm}\cdot k_{tsh} = \frac{Q_w}{Q_h}\cdot\frac{\eta_{h.m}}{\eta_{w.m}}\cdot\left(1 - \frac{\Delta\rho}{\rho_h}\beta\alpha\right) \tag{6}$$

The value of the technical state quotient changes from one to some minimum value in the course of the impeller operation. The maximum value of K_{ts} corresponds to the slurry pump operation with rated (nominal) parameters, which are in conformity with the factory characteristics obtained when the pump was tested by manufacturer and which are specified in the technical documents for this particular pump.

The technical state quotient is a generalized characteristic of the slurry pump and it can be adopted as a criterion of the normal operational life of a hydraulic transportation system. Considerable decrease in value K_{ts} testifies of the mechanical wear of the slurry pump operational elements and of the increased hydromechanical losses in the operational channels of the flow section. Figure 1 represents the characteristic dependency of the technical state quotient K_{ts} of the slurry pump type GrT 8000/71 at Katchkanarskiy Dressing Plant on the time of operation taking into account the current maintenance repairs. The maximum admissible value of the technical state quotient for a slurry pump is assumed as 0.8, and then the pump should go under repair.

As is clear from the figure, the dependency $K_{ts}(T)$ is, obviously, a non-monotonic one. Upon accomplishing the current maintenance repair the technical state quotient increases stepwise. However, no full recovery takes place.

3. Experimental Results

The experimental plant is shown in Figure 2. The vibration characteristics of the slurry pump were measured with the Pruftechnik portable diagnostic system using the autonomous encoders Vibscanners. Table 2 presents basic results of the experimental investigations with the slurry pump type 5GrT-8, and Figure 3 shows the graphs of the head pressure alteration depending on the pump flow rate.

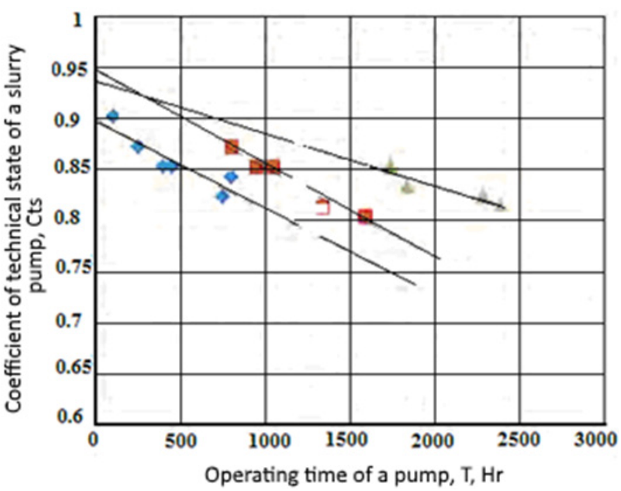

Figure 1. Diagram - Change of coefficient of technical state, Cts versus operating time T between repairs.

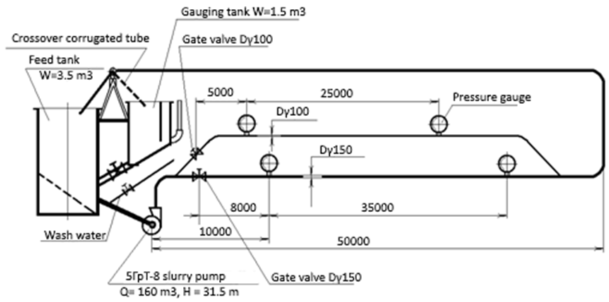

Figure 2. Scheme an experimental installation.

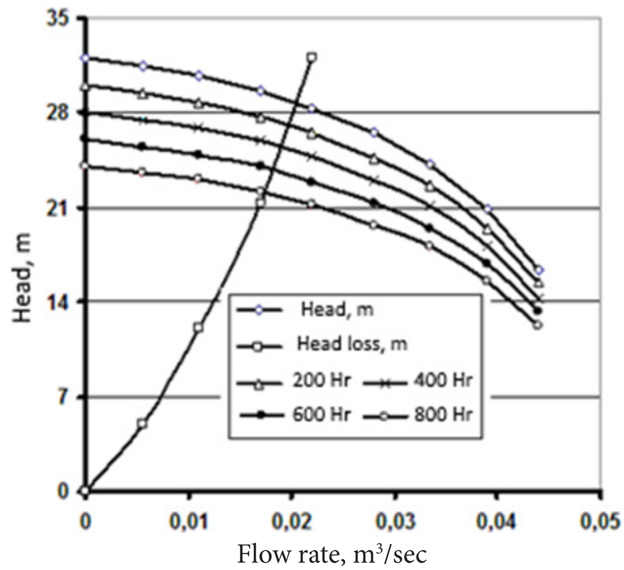

Figure 3. Head and Flow rate– operating time curves of 5GrT-8 slurry pump.

In Equation (6) the dependency of the technical state quotient on the rate of the hydroabrasive wear, as on the basic parameter affecting the slurry pump operation,

Table 2. Experimental data

Feed, m³/s	Head loss, m wc/m	Pump head (m) versus operating time, hr					Vibration parameters	
		10	200	400	600	800	Operating time, hours	Vibration velocity, mm/s
0	0	32	30	28	26	24	200	2.29
0.0055	5	31.5	29.5	27.5	25.5	23.6		
0.011	12	30.8	28.7	26.9	24.9	23.1	400	4.3
0.017	21.3	29.6	27.7	25.9	24	22.2		
0.022	32	28.3	26.5	24.8	22.9	21.2	600	6.8
0.028	-	26.5	24.6	23	21.3	19.7		
0.034	-	24.1	22.6	21.1	19.5	18.1	800	9.55
0.039	-	20.8	19.5	18.2	16.8	15.6		
0.044	-	16.4	15.4	14.3	13.3	12.3		

has been specified implicitly. The value of the technical state quotient can also be obtained when the pump head pressure is known at a definite preset moment of time. Due to the fact that the transported medium is represented by slurry, it is difficult to determine the head pressure with the standard instruments (pressure gages) and thus the obtained value can be inacceptable for its inaccuracy. In this case, the current pressure head can be determined based on the experimentally obtained dependency as follows:

$$H_T = H_0 - \left(k_{Q_0} + k_{head}\right) T_{op} \quad (7)$$

where H_T is the head pressure for any random moment in time; H_0 is the pump head pressure at zero feed value and at the start of operation; k_{Q0} is the angular quotient at zero feed value; k_{head} is the head pressure quotient; T_{op} is operation time;

$$k_{head} = f(Q_{pump}) = k_{Q_0} - aQ^m_{pump} = 0{,}01 + 0{,}0369Q - 3{,}3962Q^2 \quad (8)$$

Note, that for the given operational conditions the absolute hydroabrasive wear will be determined by the operation time only.

As the operation time of the pump increases the impeller is losing its weight increasingly, which, in its turn, leads to an increase in the vibration parameters. Thus, it can be assumed, that the alteration in the vibration characteristics is determined by the time of the slurry pump operation.

Assume the alteration of the root-mean-square value of the slurry pump vibration velocity as the basic diagnosed parameter, characterizing the degree of the hydroabrasive wear of the process unit. This solution is convenient because now there are plenty of instruments that ensure the on-line measuring of the vibration parameters at the pumping equipment with high precision.

For the root-mean-square value of the vibration velocity the following function can be formulated:

$$\bar{V}_{rms} = f\left(T_{op}\right) \quad (9)$$

Figure 4 shows the graph of altering the root-mean-square value of the vibration velocity of the slurry pump type 5GrT-8 depending on operation time.

Based on the results of the experiments the following dependency has been obtained:

$$T_{op} = 74{,}0 \cdot \bar{V}^{1{,}1}_{rms} \quad (10)$$

Consequently, the slurry pump technical state quotient can be represented as follows:

$$K_{ts} = \frac{32 - 74 \cdot \bar{V}^{1{,}1}_{RMS}\left(-3{,}3962Q^2_{pump} + 0{,}0369Q_{pump} + 0{,}02\right)}{H_w} \quad (11)$$

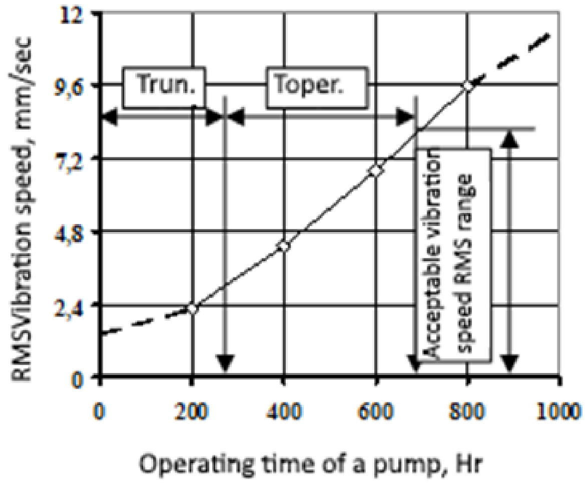

Figure 4. RMS Vibration speed versus operating time of a pump.

In the presented equation the slurry pump technical state quotient is expressed by means of using the current root-mean-square value of the vibration velocity.

Based on the available data, the graph was built illustrating the dependency of the technical state quotient on the vibration velocity and on the time of operation, Figure 5.

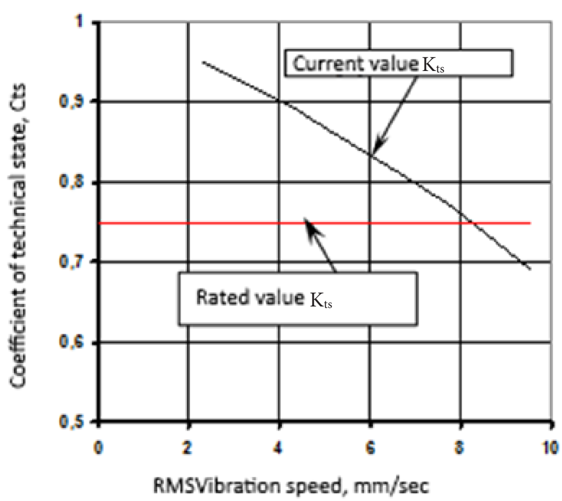

Figure 5. Coefficient of technical state versus RMS vibration speed of pump housing.

It should be noted that the dependency K_{ts} (T) can only be obtained based on continuous control over the operational parameters (in this study the root-mean-square value of the vibration velocity was selected as a prerequisite determining parameter) of a particular slurry pump.

According to Formula (11), obtained based on the results of analyzing and processing the experimental data on the operation time of the slurry pump type 5GrT-8, in order to determine the current value of the slurry pump technical state quotient, the values of the current delivery and the root-mean-square value of the vibration velocity should be transmitted from the parametric and the vibration-based diagnostic systems to the operator work station. The built-in software should process the received data, compare them with the admissible values of the controlled parameters, and inform the operator on the current status of the pumping equipment.

General sketch of the express-diagnostics system for the pumping process units is shown in Figure 6.

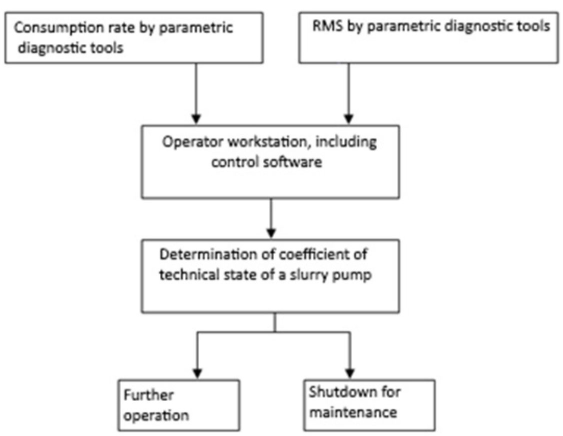

Figure 6. Common express diagnosis flowchart for pumping units.

The slurry pump vibration-based diagnostics and monitoring can be implemented on the basis of a stationary equipment monitoring system.

The stationary system for the vibration-based monitoring should include the following:

- The distributed system of sensors, controlling the basic parameters of the equipment.
- The distributed system of remote modules, ensuring the primary transformation of the sensor signals and their transmitting to the diagnostics controller, and also ensuring the control over the uninterrupted operation of the sensors and of the communication lines.
- The diagnostics station, ensuring data collection, storing and processing, displaying the monitoring results.
- Diagnostics network of the enterprise to submit comprehensive actual information about the current state of the equipment to the computers of different users (from the shop personnel up to the management of the enterprise).

System interface, Figure 7, should make it possible for an operator to display the current values of the operational parameters, obtained from the diagnostics instruments together with the current calculated value of the slurry pump technical state quotient, obtained according to formula 11, the latter being integrated within the software complex of the system, as well as the dynamic trends for specified parameters.

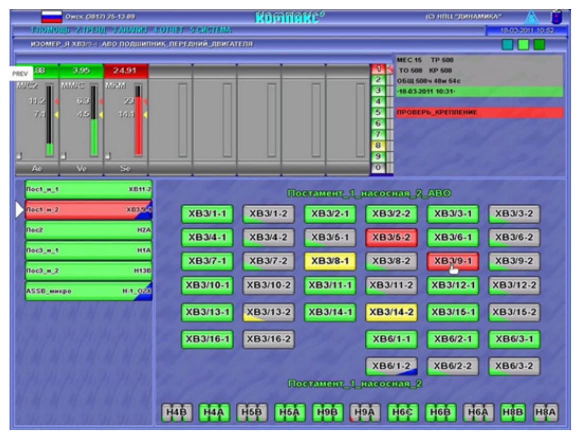

Figure 7. Slurry pump diagnosis system interface,"Trend" mode.

4. Conclusions

- The basic factor predetermining the efficiency and the reliability of the slurry pumps is represented by the hydroabrasive wear, which leads to the impeller weight loss, to the increase in vibration parameters and to the decrease in the pump head pressure.
- The dependency of the slurry pump operation life on the vibration parameters has been illustrated both theoretically and practically; it was shown that the operation life of the pump is an exponential function of the given RMS value of the vibration velocity.
- The slurry pump technical state quotient (relative delivery), which value can vary within the range of 1-0.75 can be assumed as a criterion for estimating the normal life of the pump.
- The slurry pump technical state quotient, as a criterion of the normal operation life, is a function of RMS value of the vibration velocity and of the pump feed value.

- The diagnostics algorithm has been developed together with the express-method to evaluate the operating state of the slurry pump in the hydraulic transportation system applying the value of the technical state quotient.

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