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EXPRESS-DIAGNOSIS OF THE TECHNICAL STATE SLURRY PUMPS IN SYSTEMS HYDROTRANSPORT PROCESSING TAILS OF ORE

Summary. Analysis of the work hydrotransport systems in processing plants shows that the efficiency of this type transport does not match its technical capabilities: the high laboriousness involved in the operation of the equipment, high hydroabrasive wear of slurry pumps and pipelines, low working life pumps, high metal consumption and energy. The main reason for the lack of effectiveness of hydraulic transport is hydroabrasive wear impellers of slurry pumps, causing rising levels of vibration pumps, reducing the pressure characteristics, general technical state of hydrotransport system and as a result - low pumps life, not exceeding 500 hours of continuous operation.

Keywords: hydrotransport systems, processing plants, energy consumption, slurry pump, hydroabrasive wear, express-diagnosis.

EKSPRESOWA DIAGNOSTYKA STANU TECHNICZNEGO POMP ŚCIEKÓW PRZEMYSŁOWYCH W SYSTEMIE TRANSPORTU WODNEGO PRZETWORZONEJ RUDY

Streszczenie. Na podstawie analizy działania systemu transportu wodnego w zakładzie przetwórczym wykazano, że wydajność tego typu transportu nie osiąga maksymalnych możliwości technicznych z następujących powodów: wysoka pracochłonność obsługiwanego sprzętu, duże hydroabrazywne zużycie pomp i rurociągu ścieków przemysłowych, krótki cykl życia pomp, wysokie zużycie metalu i energii. Głównym powodem braku efektywności transportu hydraulicznego jest hydroabrazywne zużywanie się wirników pomp, co powoduje wzrost poziomu wibracji pomp, obniżenie właściwości ciśnienia oraz pogorszenie ogólnego stanu technicznego systemu transportu wodnego i w rezultacie – krótką żywotność pomp, nieprzekraczającą 500 godzin ciągłej pracy.

Słowa kluczowe: systemy hydrotransportu, zakład przetwórczy, zużycie energii, pompa ścieków przemysłowych, zużycie hydroabrazywne, ekspresowa diagnostyka.

1. Introduction

The problem of the reliability of the hydrotransport systems on processing plants in Russia, is currently one of the most urgent. Analysis of the technical state of the systems of technological equipment, as well as improve reliability issues are considered in a large number of scientific and practical work, both in Russia and abroad. To date formed several lines of research in the field of improving reliability and assessment technical condition equipment systems hydrotransport of ore tailings on of processing factories. An example of this trend can serve as a book by G.H. Sandler on the theory of designing complex systems with specified reliability indices [1]. In this study, a significant place allocated models serviced systems which in turn are the technological units of mining and processing plants and factories. It is of interest I. Bazovsky book by giving a definition of "mixing effect" [2]. Research methods of quantitative indicators of reliability of hydrotransport systems are set out in works of N.N. Boloshin and V.I. Gashichev [3]. The paper T.V. Alekseev etc. [4] considers the parameters of reliability of slurry pumps and the methods of optimization quality of pump installations.

For purposes of this paper is of great interest the direction of research that devoted to studying the reliability of the parameters defined by hydroabrasive wear of hydrotransport equipment and slurry pumps. In many ways, this interest is determined by fact that methods express diagnostics of slurry pumps hydrotransport systems are closely linked with changes in their technical state while in service, which directly depends on the degree and intensity of hydroabrasive wear elements of the pump. Significant contribution to the study of the question hydroabrasive wear imposed S.P. Turchaninov [5], who conducted extensive research in the laboratory and industrial applications in the field of transportation of coal and filling mixes. The author notes that the wear of the walls pipelines is a result of impact with the walls of the pipe solids particles, and the abrasion of the surface of the pipe as a result of sliding and friction. Similar models of particle motion were viewed in works of A.E. Smoldyrev [6] and in the works of other authors Karimi A. [7], Suchanek J. [8], Dube N.B. [9], Sherington I. [10], Yao M. [11], Alexandrov V.I. [12].

2. Coefficient of technical state - the main criterion for the period normal exploitation of a slurry pump

A major shortcoming in the work of pumping equipment is its low reliability. For this reason going up to 80% of accidents and equipment failures, one third of which falls on the slurry pumps. The results of observations of the causes of failure of ground parts pumps at the Almalyk Mining Metallurgy Plant are summarized in Table 1.

Table 1

Reasons for failure of slurry pumps

Reasons for failure		Mean % failure slurry pump parts								
		10	20	30	40	50	60	70	80	90
1	Wear parts									
	front cover									•
	impellers								•	
	volute									•
	valves								•	
2	Imperfection of construction units									
	weak support units			•						
	imperfection of fastening of the impeller		•							
3	Disadvantages of exploitation and control									
	insufficient lubrication of bearings	•								

Source: Own work.

From Table 1 it follows that the most loaded elements of a slurry pump, for which the probability of failure the maximum are the working elements of flowing part - the impeller, pump housing, the front cover, because they are in constant contact with the abrasive mixture. Analysis results of exploitation slurry pumps on mining processing plants and data of reasons for refusal leads to the conclusion that from all factors that determining the resource of slurry pumps greatest influence has hydroabrasive wear of the impeller.

Experiments and statistics show that with increasing hydroabrasive wear of impeller appear considerable dynamic loads associated with an imbalance of the drive shaft due to low frequency vibrations perceived bearings. These factors contribute to the reducing the pressure created by the slurry pump. Practice shows that reducing pressure to 0.75 of the theoretical ($0,75H_{th}$) the pump needs to major repairs or complete replacement. At present on pumping stations of hydrotransport do not applied systems for rapid assessment of technical state of slurry pumps. Operating resource of elements pump determined by the time of work, after which the part is replaced by a similar new. For example, the resource of slurry pump impellers for different operating conditions does not exceed an average of 750 - 900 hours of continuous operation.

Such an approach, in a constantly changing modes of pump station, variations in volume, concentration, physical and mechanical characteristics of the transported mixture that significantly affect the rate of hydroabrasive wear elements ground the pump is not accurate and effective. In determining the mode of the pumps the technical condition of their elements are not taken into account, while the accuracy of determining the parameters of the pumping equipment is the key to effectively addressing the problem of optimizing the parameters of hydraulic transport of slurry and for increasing the life time of slurry pumps. In this regard, special significance efforts aimed at the development of robust and reliable methods for determining the operating mode, and, first of all, diagnosing and operative control of a technical state of pumping equipment. Evaluation of the technical state of pumping equipment advisable to carry out by means of parametrical methods diagnosis based on the measurement of hydrodynamic characteristics slurry pump. It should also be noted that most methods of parametrical diagnostics are based on the data of a passport characteristics of the respective pumps which are obtained by production tests on clear water. Therefore, when turn on the pump in the work for of pumping the slurry will be immediately obtained deviation basic hydraulic parameters of slurry pump from passport factory data. During operation, characteristics of the pump may also vary. This can be due to many factors, chief among which is the hydroabrasive wear, due to the peculiarities of the pumped liquid. Therefore, for assess the actual condition of the pump is convenient to introduce the concept of the coefficient of the technical state of the slurry pump. Relative head of slurry pump during its work on the slurry is equal as:

$$\frac{H_h}{H_w},$$

where:

H_h - head at work on slurry,

H_w - head at work on water.

$$\frac{H_h}{H_w}$$

According to A.E. Smoldyrev this relationship can be represented in the form of the empirical relation:

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

where:

ρ_w - density of water;

ρ_h - pulp density;

β - coefficient, taking into account the effect of the size of the pump on the value of hydraulic losses.

With increasing number Re hydraulic losses are reduced; should be taken at $Re > 1200000$ $\beta = 0{,}6$, at $Re < 1200000$ $\beta = 800/\sqrt{Re}$.

Coefficient α in formula (1) determined by the formula:

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

where:

r_1 - radius of the impeller;

r_m - mean radius;

D_R - hydraulic diameter of outlet;

r_2 - outer radius of outlet;

u - circumferential speed of the impeller.

In fact, the relative head can be considered as hydro-mechanical coefficient (k_{tsh}) of the slurry pump technical state which takes into account the losses in the impeller and the outlet

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

Relative head pump can also be expressed as:

$$\frac{H_h}{H_w} = \frac{Q_w}{Q_h}\cdot\frac{\eta_h}{\eta_w}, \quad (4)$$

where:

Q_h and Q_w - flow rate at work on slurry and water, accordingly;

η_h and η_w - pump efficiency rate at work on slurry and water, accordingly.

This expression (3) can be regarded as a mechanical coefficient technical state of the slurry pump:

$$k_{tsm} = \frac{Q_w}{Q_h}\cdot\frac{\eta_{h.m}}{\eta_{w.m}}, \quad (5)$$

The total value of the coefficient technical state of the slurry pump is equal to the product of the hydro-mechanical coefficient of technical state (3) and a mechanical coefficient of technical state (5):

$$K_{ts} = k_{tsm} \cdot k_{tsh} = \frac{Q_w}{Q_h} \cdot \frac{\eta_h}{\eta_w} \cdot \left(1 - \frac{\Delta\rho}{\rho_h} \beta\alpha\right) \tag{6}$$

The maximum value of K_{ts} to correspond the slurry pump on the nominal parameters corresponding to passport characteristics obtained during tests pump at the factory and indicated in the technical documentation on this pump. Coefficient of technical state is by generalized characteristic of slurry pump and can be taken as a criterion for period of normal exploitation hydrotransport system. A significant reduction in the value of K indicates mechanical wear of working elements slurry pump and increase the hydraulic losses in the flow channels of the pump.

Figure 1 shows the typical dependence of the coefficient of technical state of slurry pump GrT-8000/71 from time of work with taking account the repair operations. Limit coefficient of technical state of the slurry pump before output it in repair taken equal to 0.75.

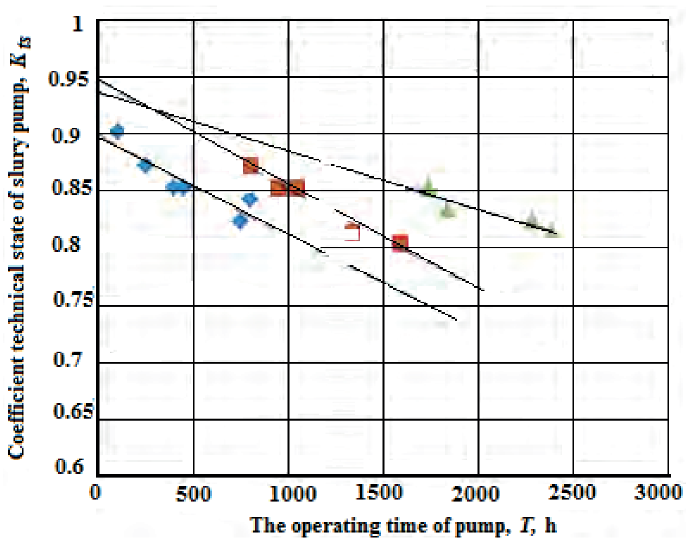

Fig. 1. Dependence of the coefficient technical state of slurry pump from operating time in the overhaul period

Rys. 1. Zależność współczynnika stanu technicznego pompy szlamowej od czasu pracy w okresie remontu

Source: Own elaboration.

As seen from the graphs, the dependence is clearly not monotonic. After the next repair coefficient technical state of slurry pump abruptly increased. However, full recovery does not occur.

3. Experimental results

Experimental hydrotransport installation is shown in Fig. 2. The vibration characteristics of a slurry pump were measured with a portable diagnostic system Pryuftehnik using a stand-alone device Vibscanners. Table 2 summarizes the main results of experimental studies of slurry pump 5GrT-8 and Fig. 3 shows the supplies and pressure characteristics of the pump.

In the formula (6) dependence of the coefficient technical condition from speed hydroabrasive wear as the main parameters affecting the efficiency of the slurry pump, defined implicitly. Coefficient technical state can be calculated using the value of the pump head at a given time. In this case the current head can be determined from the ex-experimentally obtained dependence:

$$H_T = H_0 - \left(k_{Q_0} + k_H\right)T_{work}\ , \tag{7}$$

where:

H_T - head at any given time, m;

H_0 - head of pump at zero flow at the beginning of operation;

k_{Q_0} - the slope at zero flow pump;

k_H - coefficient of head;

T_{work} - operating time.

Coefficient of head in (7) is given by:

$$k_H = f\left(Q_{pump}\right) = k_{Q_0} - aQ_{pump}^m = 0{,}01 + 0{,}0369Q - 3{,}3962Q^2\ , \tag{8}$$

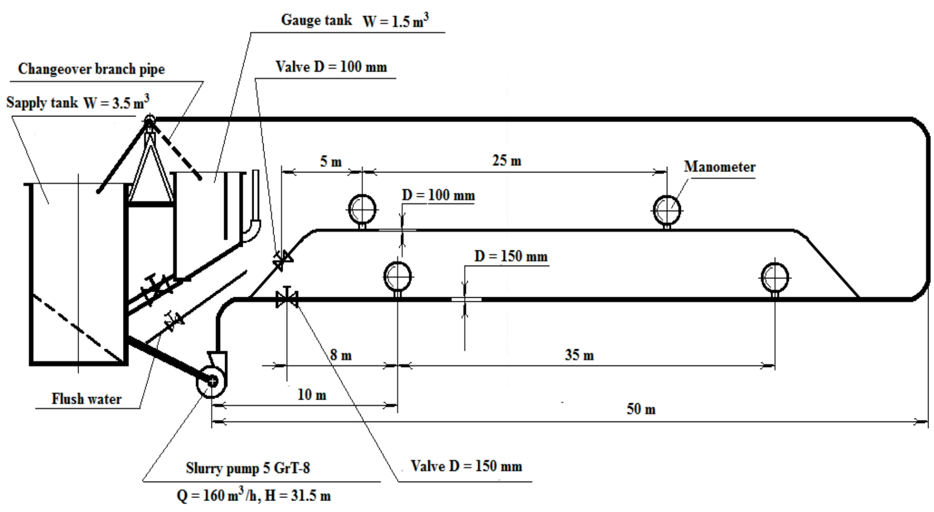

Fig. 2. Scheme an experimental installation
Rys. 2. Schemat instalacji eksperymentalnej
Source: Own elaboration.

Table 2

Experimental data on the pilot installation of hydrotransport

Pump flow, m^3/s	Head losses in pipeline, m H_2O/m	The pump head (m) of operating time, h					Vibration parameters	
		10	200	400	600	800	Working hours	Vibro-speed m / 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		

Source: Own work.

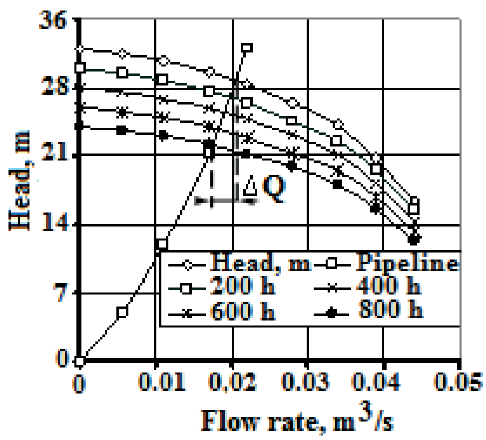

Fig. 3. Head-flow rate curve of pump 5GrT-8 at work on tailings slurry to the various periods of work
Rys. 3. Krzywa wielkości przepływu pompy 5GrT-8 przy pracy ze szlamem w różnych okresach pracy
Source: Own elaboration.

Note that for a given operating conditions absolute hydroabrasive wear will be determined only by the time of operation.

With increase of operating time of the pump increases the weight loss of the impeller, which in turn leads to an increase of vibration parameters. Thus, it can be assumed that the change in the vibration characteristics of the slurry pump is determined by time the operating pump.

Accept the changes RMS (Root Mean Square) vibration velocity slurry pump as the main diagnosed parameter characterizing the degree of hydroabrasive wear of pump impeller. The convenience of the decision is that today there are a number of devices, with high accuracy in real-time measurement of parameters of vibration of the pump equipment.

For RMS value vibration velocity can write the following function:

$$\overline{V}_{RMS} = f(T_{work}) \tag{9}$$

Figure 4 shows a graph of the RMS value vibration velocity slurry pump 5GrT-8 of operating time.

According to the analysis of the experimental data was obtained relationship:

$$T_{work} = 74.0 \cdot \overline{V}_{RMS}^{1,1}, \tag{10}$$

Consequently, the coefficient of the technical state of a slurry pump can be represented in follow

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

In the formula (11), the coefficient technical state of slurry pump is expressed through the current RMS value of vibration velocity. According to available data plotted graphics changing of a coefficient technical state from RMS vibration velocity, Fig. 5. It should be noted that the dependence of $K_{ts}(T_{work})$ can be obtained only on the basis of continuous control operation parameters (rms vibration velocity) of the particular slurry pump.

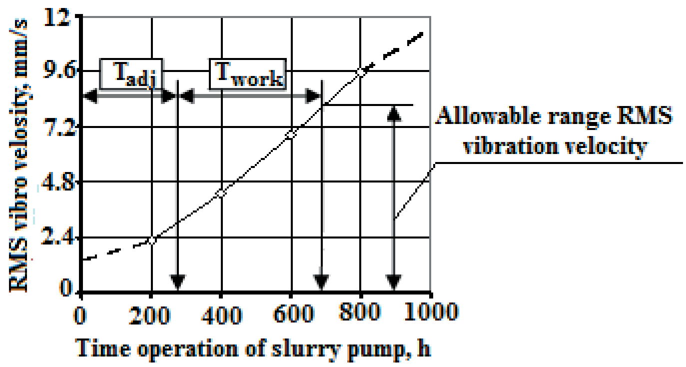

Fig. 4. Graph of RMS vibration from the operating time of the pump
Rys. 4. Zależność wibracji RMS od czasu pracy pompy
Source: Own elaboration.

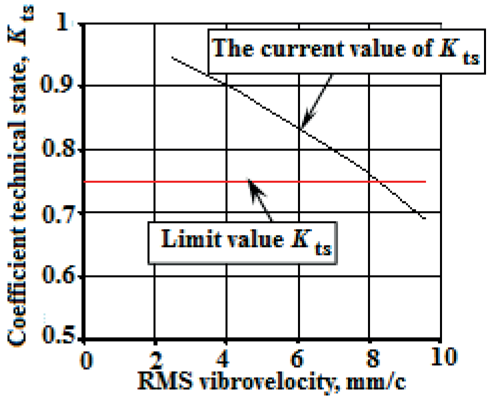

Fig. 5. Graph of coefficient of technical state of slurry pump from RMS vibration velocity
Rys. 5. Zależność współczynnika stanu technicznego pompy szlamowej od prędkości wibracji RMS
Source: Own elaboration.

According to the formula (11) obtained according to the results processing and analysis of experimental data on the operating time of a slurry pump 5GrT-8 and to determine the current values of the of technical state of slurry pump on a workstation dispatcher of parametric systems and vibration diagnostics should arrive value of the current flow rate and the RMS value of vibration velocity. Embedded software should perform processing of the data, comparison with the permissible values of controlled parameters, and inform the dispatcher about the current state of the pump equipment. Vibration diagnostics and monitoring of slurry pump can be carried out on the basis of stationary equipment monitoring system.

Stationary vibration monitoring system should include:

- a distributed system of sensors that control the main parameters of the equipment;
- a distributed system of remote modules that provide primary conversion of signals from sensors and their translation into diagnostic controller, as well as providing control over the integrity themselves sensors and communication lines;
- diagnostic station that provides collection, storage, processing, displaying the results of monitoring;
- diagnostic network, to provide users' computers (from shop personnel to the company's management) complete and timely information about the technical condition of the equipment.

The system interface (Fig. 6) allows the operator monitor output current values of the performance parameters obtained from the diagnostic tools, the current estimated values of the of technical state of slurry pump, obtained by the formula 11, embedded in the soft computing system.

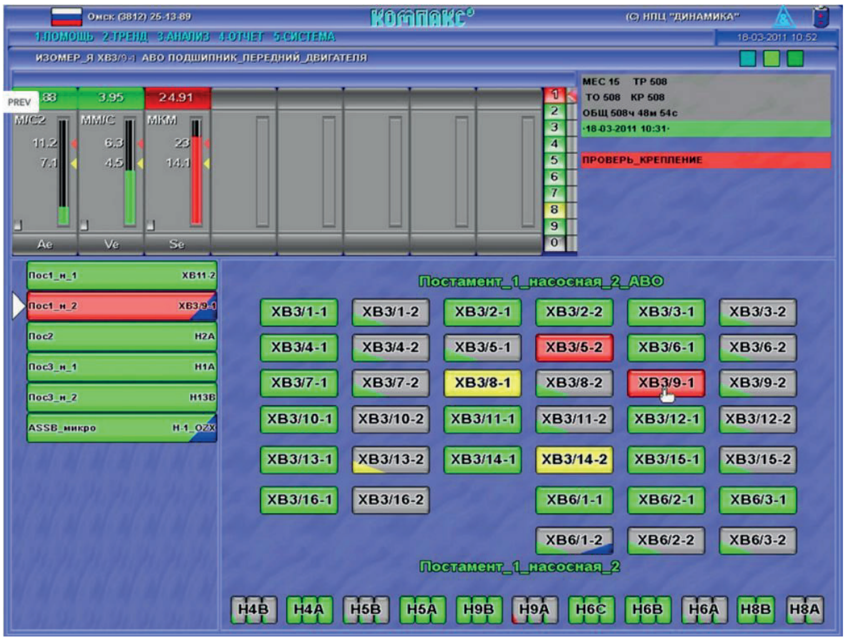

Fig. 6. The system interface is in the operating mode "Monitor"
Rys. 6. Interfejs systemu w trybie „Monitor”
Source: Own elaboration.

4. Conclusions

1. The main factor in determining the efficiency and reliability of slurry pumps in the hydraulic transport is hydroabrasive wear elements of the flow, which leads to weight loss of the impeller, an increase of vibration parameters and reduction of the pump head.
2. Theoretically and experimentally proved the dependence of the working life of the slurry pump vibration parameters and showed that working life is a power function of the specified range RMS value of vibration velocity.
3. Coefficient of technical state of a slurry pump, actually a relative head can be adopted as a criterion for evaluating the period of normal operation of the pump, whose value in this period varies within the range from 1 to 0.75.
4. Coefficient of technical state of slurry pump, as a criterion for a period of normal operation is a function of RMS value of vibration velocity and flow rate of the hydrotransport system.
5. In this paper, developed an algorithm diagnosis and the express method for determining the operating parameters of a slurry pump in the hydrotransport system by the value of the coefficient technical state slurry pump on the basis of monitoring of vibration characteristics of the pump, its head and flow rate.

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Omówienie

Na podstawie analizy działania systemu transportu wodnego w zakładzie przetwórczym wykazano, że wydajność tego typu transportu nie osiąga swoich możliwości technicznych z następujących powodów: wysoka pracochłonność obsługiwanego sprzętu, duże hydro-abrazywne zużycie pomp i rurociągu ścieków przemysłowych, krótki cykl życia pomp, wysokie zużycie metalu i energii. W artykule autorzy dowodzą, że jako kryterium okresu

normalnego działania pompy ścieków przemysłowych można użyć współczynnika stanu technicznego, którego wartość jest proporcjonalna do stopnia zużycia hydroabrazywnego wirnika i czasu ciągłego działania. Współczynnik stanu technicznego pompy ścieków przemysłowych może być zaprezentowany w postaci funkcji bieżącego strumienia i wartości średniej kwadratowej prędkości wibracji.