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ENSURING RELIABLE OPERATION OF PUMP UNITS

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Abstract

In order to timely solve any problems that arise when using pumping units is impossible without conducting supervisory and analytical work. A modern and perfect way of detecting pumps that are not working properly in the units is diagnosing. The article gives the results of the work done on the development of a diagnostic system for pumping units at pumping stations. The use of the proposed diagnostic system leads to a reduction in costs when using pumping units and the costs of their maintenance.

Keywords: *pump; aggregate; device; water; pressure; vibration; cavitation; laboratory; analysis; frequency.*

Introduction. In the system of the Ministry of Water Resources of the Republic of Uzbekistan, over 50% of lands are irrigated by state pumping stations (PS). Currently, the fleet of state-owned motor vehicles alone is 1,441 units. Accordingly, in the republic out of 11 billion kW.h of electricity spent on agricultural needs is about 8 billion kW.h consumed by machine water lifting systems (WMS). According to preliminary estimates, electricity losses at the PS amount to up to 10% of total electricity consumption, and the average operational efficiency is 5-7% lower than the calculated values. Liberalization of energy prices has led to a significant increase in the cost of mechanical water lifting for land irrigation. Under these conditions, the problem of energy saving at water-lifting facilities is defined as a major national economic problem requiring urgent solutions.

In recent years, about 50% of the budget funds of the Ministry of Internal Affairs of the Republic of Uzbekistan has been spent on paying for electricity during the operation of pumping stations (PS). In connection with the sharp rise in prices and the growing shortage of energy resources, the problem of reducing their consumption by the NS comes to the fore. The lack of priority work on this problem makes it impossible to optimize NS modes at the current level of operation.

Uzbekistan is the most pump-rich Republic; more than half of the pumping capacity of the entire Central Asian region is concentrated here: 43 large PS, about 1,400 medium and 30 thousand small PS and installations are in operation. The largest pumping equipment is installed at the PS of the Amu-Bukhara (ABMK), Karshi Canal (KMK). Wear of elements of flow paths of pumping units (PU) during operation due to cavitation and abrasion by suspended sediment leads to deterioration of operating conditions. Specialists characterize the current stage of development of mechanical water lifting as a period of aging of equipment structures [1, 2].

The widespread development of water management in our country is expressed in an increase in the number of hydraulic structures and water management facilities and in the transition to an increasingly clear integrated use of water resources. At the same time, the interests of various sectors of the national economy are increasingly intertwined with each other [3].

Calculations of unsteady water movement are associated with meeting the demands of various sectors of the national economy. Thus, when designing hydraulic structures, the course of levels and flows over a significant length of the tail water is calculated under various operating modes of the pumping station (PS), determined by the water content of the year, season, day of the week, time of day, etc. It is especially important to determine for various sections the values of both maximum water levels (due to the danger of flooding of populated areas, bridges, roads, enterprises) and minimum values (to ensure the normal functioning of water intakes), as well as determination of water flow rates (for land reclamation purposes) and water velocities in intermediate channels of PS cascades [4, 5].

In the list of causes of failures that reduce the reliability of plant operation, deformation of water supply structures (receiving chambers, suction pipes and water outlets, siltation of the supply channel, front chamber, valve seats), and air leakage into the flow part of the unit are of particular importance. When drawing water from open sources, the use of new designs provides significant savings in capital investments and time and makes operation much easier and cheaper [6].

The emergence of an independent supervisory system for monitoring the technical condition of the NS stimulates the development of diagnostics. The technical policy in the hydropower industry of Russia, the USA, Holland and other developed countries testifies in favor of this way of developing a system of supervision over high-risk objects.

The objectivity and effectiveness of supervision will be maximized if the assessments are comprehensive and comparable for different NS. This can be achieved on the basis of a generalized quantitative indicator that reflects both similarities and differences in the design of pumps and their operating conditions. It is advisable to adopt a unified methodology and regulations for expert examinations, instrumental tests and presentation of results [7, 8].

Materials and experiments

To carry out the functions of transporting water and distributing it between water consumers, there must be a clear structure and organization of water distribution on the machine water lifting system (WMS). An automated water distribution control system in irrigation systems can be presented in the form of an information and control system that provides measurement of parameters that characterize the condition of canals and structures. The system should be organizationally built as a distributed block-modular design, which takes into account the possibility of increasing the volumetric structural structure during the modernization and reconstruction of process equipment [9].

The structure of the control system ensures the joining of its technical means into a single complex in order to ensure complete and reliable operation within the specified functions of the system and the technical characteristics of the means included in the complex of automated control

and dispatch. The functional structure of the SMV water distribution system consists of the following objects:

- central control center in the department;
- controllers for gate position sensors, water level sensors;
- a set of technical means.

The lack of complete data in some acts forced us to narrow the number of analyzed tests to ten (Table 1). Data on these tests are given in table 2. Parameters characterizing the operating mode of the pumps are also indicated here.

In table 3. shows the characteristics of the oil pumped by pumps at the time of testing. The characteristics of the oil were taken from dispatch logs in accordance with the test date, the parameters of the pumps were taken from a certificate from the department of the chief mechanic of the ONS.

Since the performance of the pumps during testing was not recorded due to the lack of metering units for pumped water at the stations, the performance was determined by the differential pressure of the pumps based on data on the pressure at the inlet and outlet of the pumps and the density of the oil. For this purpose, the passport Q-H characteristics of the pumps were used (Fig.1).

When conducting vibration tests, maintenance personnel noted a characteristic feature. It consisted in the fact that increased vibration was observed when operating at stations with a small number of pumps, mainly one. With the launch of an additional pump, either at the same station or at another one, but belonging to the same operational area, the vibration noticeably decreased or reached a normal value.

Figure 1 shows the rotor pressure characteristic of the NM 10000-210 pump for a flow rate of 1.25 from the nominal value. We can see that D=530 mm in the working range from 900 to 1300. When the speed of the pump unit is lower, the vibration in the total cavitation value is smaller. As the speed increases, the vibration in pumping units operating in cavitation mode increases. In pumping units with cavitation, the number of oscillations is maximum if the speed is 2200 rpm [10].

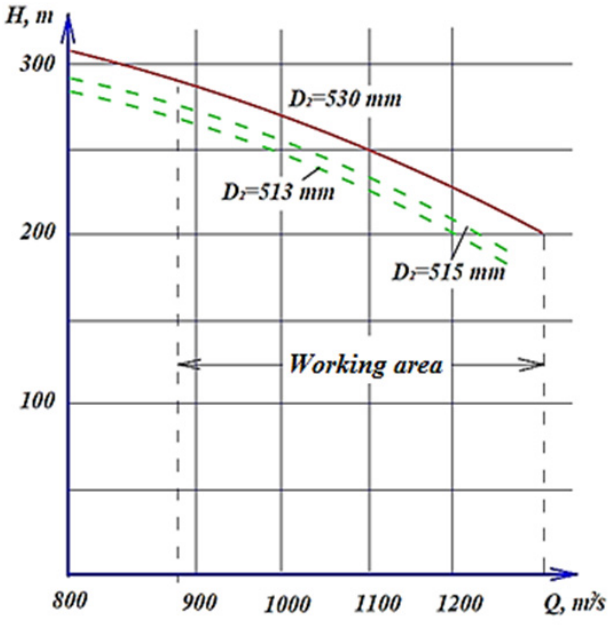


Figure 1. Pressure characteristic of the NM 10000-210 pump with a rotor for a flow rate of 1.25 of its nominal value [10].

Table 1.

Characteristics of the test object [11].

Test number	Test object		Pump rotor	
	station	pump number	flow, m³/h	diameter, m
1	3	4	12500	0,530
2	3	4	12500	0,530
3	2	2	12500	0,515
4	2	3	12500	0,515
5	2	2	12500	0,515
6	4	3	12500	0,515
7	4	1	12500	0,515
8	2	4	12500	0,515
9	2	4	12500	0,515
10	2	4	12500	0,515

Table 2.

Test results

Test number	Pump operating mode				Vibration velocity by direction 10^3 m/s			Vibration frequency, Hz
	P_s, MPa	P_d, MPa	pressure m	innings m³/h	V	T	A	
1	2,55	4,71	258	10500	>7,2	>7,2	>7,2	=400
2	1,08	3,53	293	8600	4,1	12,6	9,3	-
3	0,88	2,94	246	10200	7,2	7,2	7,2	=400
4	0,98	2,94	234	10900	7,2	7,2	7,2	=400
5	0,98	3,14	258	9600	4,0	13,1	11,6	350
6	0,79	2,94	261	9400	4,3	7,8	6,8	350
7	1,18	3,63	294	8600	-	10,2	-	350
8	0,98	3,14	257	9400	>7,2	>7,2	>7,2	=400
9	0,98	3,24	269	8600	4,6	8,3	6,4	350
10	0,98	3,34	281	8000	-	14,9	-	350

**) the vibration of the rear bearing of the pump is indicated in the following directions:*

V - vertical, T- transverse, A - axial [11].

Table 3.

Characteristics of oil pumped by the pump during testing [12].

Test number	Temperature, °C	Viscosity, 10^6 m²/s	Density, kg/m³
1	25	11,70	853
2	27	8,80	853
3	20	10,60	855
4	20	10,60	855
5	24	10,40	854
6	19	9,00	852
7	20	8,83	850
8	20	10,60	855
9	24	10,40	854
10	22	9,35	854

The noted feature gives reason to assume that the main reason causing vibration of pump-power units is the operation of the pump with a reduced flow, noticeably less than the rated performance of the pump.

This assumption is confirmed by data on the performance of the pumps at the time of testing, which are given in table 1. According to the data in Table 1, the performance of the pumps when measuring vibration on them was 16-36% lower than nominal and averaged 74% of the calculated pump load. That is, one of the causes of vibration can reasonably be considered to be of a hydrodynamic nature.

Another possible cause of vibration in the tested pumps could be surface cavitation. This type of cavitation, as is known, occurs when pump pressures are less than the minimum permissible value. To check the presence of this cause in the cases under consideration, the minimum permissible backpressure of the units was calculated for each test. The calculation was performed according to the method described in. Oil characteristics, which are given in table, were used as initial data for calculations. 1.4 and cavitation characteristics of pumps NM 10000-210 with a rotor of 1.25 of the rated flow. The calculation results are given in table 3.

As follows from the table 4, during all vibration tests, the actual pump head significantly exceeded the minimum permissible value. This gives grounds not to consider surface cavitation as a possible cause of vibration in the experiments performed [13].

The next cause of vibration can be considered separation cavitation. However, since this type of cavitation is not independent and, as a rule, only accompanies, and not always, vortices caused by reverse currents, this reason can also be omitted from consideration as not being an independent basis for the initiation of vibration.

Table 4.

Comparison of actual pump pressures with their minimum permissible values [14].

Test number	Unit change	1	2	3	4	5	6	7	8	9	10
Actual backwater	MPa	2,55	1,08	0,88	0,98	0,98	0,79	1,18	0,98	0,98	0,98
Allowable backwater	MPa	0,45	0,38	0,44	0,48	0,33	0,32	0,38	0,32	0,37	0,34

Of all the possible causes of vibration of pumping units, a whole group of them has not yet been considered, combining all the causes resulting from malfunctions in the mechanical part of the units, as well as a group of causes that cause pressure pulsations in the pipelines adjacent to the pumps.

The first of the two groups of reasons was absent during the tests, since the latter were carried out after the repair of the units and the corresponding balancing of the rotors, as well as other operations regulating the mechanical part. The serviceability of the units was confirmed by the absence of increased vibration at frequencies other than the blade one.

The second group of reasons also did not occur during pump testing, since dispatch documents for these periods of time do not contain information about accidents on the linear part of oil pipelines, as well as about starts and stops of other units and emergency closings of valves [15].

Thus, we can assume that the increased vibration recorded in the test reports of pumping units is technological in nature and is caused, with a high degree of probability, by a hydrodynamic mismatch between the flow part of the pumps and the transported flow. These conclusions can be confirmed by the data from table 2 about the frequency of recorded vibrations - in all cases, the vibration frequency is very close to or equal to the blade frequency and is 350-400 Hz. The same data allows us to state with sufficient certainty that mainly the processes occurring in the impellers of the pumps generate the technological vibration observed when the flow rate in pumping units is reduced. This conclusion can be justified by the following points.

Firstly, according to sections 1.1 and 1.2 of this work, with a decrease in pump flow, the flow structure in its flow path is disrupted mainly in the inlet part of the centrifugal wheel and at the outlet of the impeller.

Secondly, based on experimental data from a number of researchers, it is argued that as the pump flow decreases, an increase in pressure pulsations is observed in the area of the impeller, in particular, most intensely at the inlet to the wheel. The characteristic pulsation frequency is the blade frequency.

Thirdly, in the analyzed test reports, excess vibration of the unit is noted only in a narrow frequency spectrum corresponding to the blade frequency of the examined units.

The analysis of the work carried out in the area under consideration showed that objectively there is a certain physical connection between the main design parameters of pumps, their operating modes and the level of vibration of pumping units when their operating mode deviates from the optimal one.

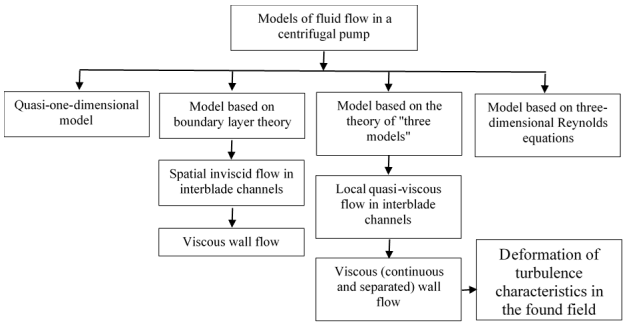


Figure 2. Models of spatial turbulent fluid flow in a centrifugal pump [16].

The same analysis indicates that existing work on the problem under study, as well as work in related areas, does not reveal the specific causes of technological vibration of centrifugal pumps; The existing research in this direction is relatively fragmented, with a predominantly empirical bias, and does not have a sufficient generalizing theoretical basis.

Such a state in the study of the problem under consideration requires, in order to achieve more effective results, to approach the solution of the issue under study primarily from a theoretical position on a sufficiently substantiated physical basis [17].

The formulated requirement for a theoretical approach implies its implementation at the modern scientific level. Currently, similar problems in hydrodynamics are solved on the basis of a model of spatial turbulent fluid flow. In relation to a specific problem being solved, this model can be represented in several ways, differing in varying degrees of adequacy to actually observed phenomena. Possible options for representing the model are shown in the following figure 2.

The given versions of the model differ not only in the degree of correspondence to the hydrodynamic processes that actually exist in pumps, but also in the complexity of the mathematical apparatus underlying them and, accordingly, in the complexity of using this apparatus.

In other words, model variants are tools of varying degrees of perfection and, accordingly, different levels of complexity. This circumstance leads to the need to select a specific version of the model, taking into account the characteristics of the problem being solved.

The problem being solved in the work inherently relates to production problems. This circumstance does not require the instrument through which the problem is solved to be particularly subtle. In addition, the selected tool must meet everyday engineering practice, that is, be accessible to manufacturing engineers.

Based on the above, to solve the problems posed in the work, the simplest option was adopted - a quasi-one-dimensional model. This option is distinguished by its simplicity and accessibility for engineers, but it also has a significant drawback - a rough reflection of actually occurring processes based on representing the flow as one-dimensional and with average values of the parameters characterizing it [18].

Results and discussion

The last feature of the chosen model dictates the need to verify the results obtained on its basis on another more scientifically advanced model. The third version of the model is sufficiently suitable as such. It is characterized by the necessary scientific level, since it is based on modern achievements both in the field of physics of hydrodynamic

processes and in the field of mathematical description of these processes. At the same time, this option is characterized by relatively low labor intensity.

The mentioned variants of the liquid flow model in the flow part of centrifugal pumps are discussed in the previous parts of this work.

The technical condition of the scientific equipment was usually determined by periodic or discrete control of the dimensions of its movable interfaces and the working body (diameters of rubbing pairs, sizes of blades and their geometry).

The maximum vibration amplitude among the pumps of both types (17.9 m/s2) at a frequency of 989,2 Hz in the vertical direction, which can be associated with increased mechanical vibration of the IB at low frequencies (figure 3).

A similar picture was observed during the inspection of the PS-1 in 2021, when on the PU No. 4, with a range of displacement at the revolving and blade frequencies of 32–42 microns, the value of the peak vibration acceleration was 22.1 m/s2.

On the pump chamber, the main source of increased vibration is the hydrodynamic imbalance and flow heterogeneity in the pump. The nature of these two defects is the same - an uneven gap between the blades and the chamber, differences in pitch and angle between the blades, in length and thickness, or their operational uneven wear, and the vibration manifestation is different [19, 20].

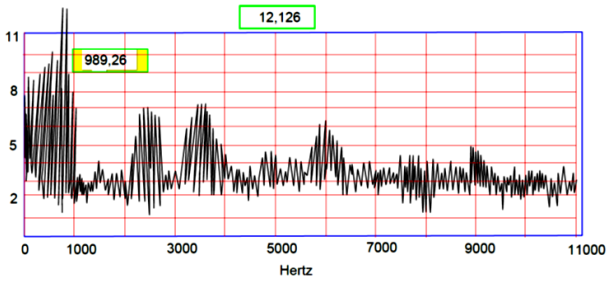
The growth of vibration at the blade frequency and its higher harmonics indicates the unevenness of the velocity and pressure field in the flow between the blades of the IB.

Hydrodynamic imbalance, as the asymmetry of the forces acting on the blades of the wheels, leads to an increase in vibration at the revolving frequency and the first three harmonics, depending on the form of symmetry breaking.

Since all the blades are already welded, it is not possible to correct the effect of some unevenness of the blade inclination angles on the hydrodynamic imbalance of the wheels and the flow in them.

Hydraulic imbalance is also present on two of the three new pumps 300VO-37/26C, where both the blades are new and the chambers are cylindrical.

At PU No. 1, the maximum swing exceeds 32-41 microns, and in the same place, at PU No. 6, the swing rises to 42-53 microns, which indicates unfavorable modes of water supply to the extreme PU.



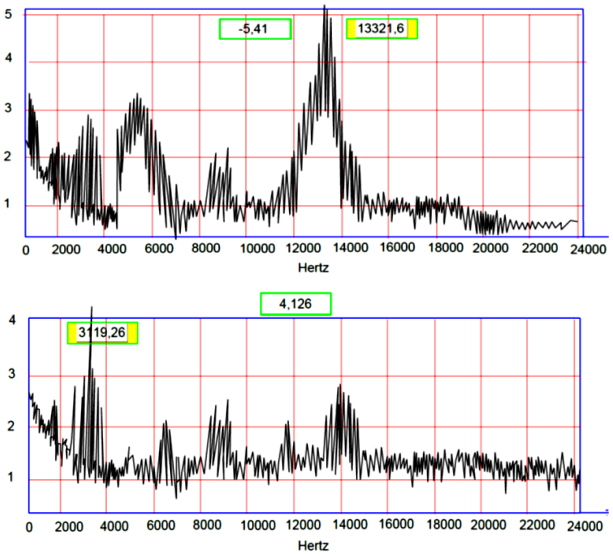


Figure-3. Amplitude spectrum of vibration acceleration on the impeller chamber of the PS pumps [19, 20].

Conclusions

1. The source of vibration of hydrodynamic origin (technological vibration) in centrifugal pumps operating with an underload of supply can be non-stationary phenomena arising as a result of hydrodynamic mismatch of the fluid flow with the flow part of the pumps.

2. The amplitudes and frequencies of flow pressure pulsations in the flow part of the pumps suggest. That with a decrease in pump flow, vibration is caused primarily by a hydrodynamic mismatch of flows with the inlet parts of the pump impellers, and with an increase in flow (above optimal) - by a hydrodynamic mismatch of flows with the output of the wheels. In this case, the hydrodynamic mismatch with the input of the wheels is accompanied by pressure pulsations with a blade frequency and with the output of the wheels - with a blade frequency.

3. Centrifugal pumps of main pumping stations, when operating with an underload of supply, experience vibration of hydrodynamic origin, the source of which, by all indications, is located in the inlet part of their impellers.

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