New methods for geoinformation systems of tests and analysis of causes of failure elements of pumping stations

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Abstract. The large pumping stations (PS) planned for reconstruction in our republic in terms of consumption, power-to-weight ratio, and controls are the largest in the world: failure of them even for a small period of time can lead to enormous damage. Therefore, the formulation and solution of theoretical problems in the operation of these facilities, taking into account the reliability indicators, is an extremely important national economic task. Until now, the design of the National Assembly, including large ones, has been conducted without taking into account the quantitative index of reliability. The value of reliability has long been underestimated, and error correction required significant costs. Currently, increasing the efficiency of the operation of pumping stations is associated with the development of energy-saving and resource-saving technologies. Diagnostics is one of the modern and perfect ways to determine the main malfunctions that occur in pumping units. The main goal of diagnosing the technical condition of pumping units is to preliminarily identify the occurring malfunctions in it and ensure durability, reliability, reliability, and operational efficiency. The article presents the effect of vibration on pumping units and analysis of methods of vibration diagnostics, information is given on the possibility and advantages of devices for continuous vibration diagnostics.

1. Introduction
Accounting for reliability indicators can significantly reduce operating costs. Measures to improve reliability should be based on the accumulation of operational experience of the National Assembly. Therefore, in 2008 TIIAME set up a system for collecting and processing statistical materials on the reliability of the large NSs in operation and their elements. When selecting information, it is planned that it gradually passes from the passive (such as it is) to the active one (such as it is needed) [1].

The collection methodology should allow the relevant data to be concentrated in a form that would allow them to be used by the operational personnel. An analysis of these statistics makes it possible to develop appropriate measures, drastically reducing costly research.

Attention, which is given to reliability in the industry, equally applies to hydroelectric facilities. It can be noted the increased interest in recent times to the reliability of hydraulic structures. Conservatism in designing with the help of tried and tested methods should not be a hindrance to the introduction of new methods for analyzing reliability indicators, including measures for technical diagnostics and maintainability [2–6].
In this article, we describe various methods for calculating the reliability of individual elements, as well as recommendations for improving the reliability of these objects.

There is still no hope for such a level of reliability, in which one can hope for uninterrupted operation of the National Assembly for quite a long time.

Therefore, in further studies, it is necessary to pay special attention not only to the study of reliability but also to the issues of optimal preventive maintenance, repair, and technical ensuring the maximum duration of a satisfactory complex. At present, the inability to repair work, not the maintainability of many engine channels, leads to a large expenditure of money and time for repairs.

It is necessary to develop methods of diagnostics and operation that ensure the reliable operation of the facility. It is incorrect when, when creating an object, the issues of its maintenance and repair are considered as secondary. This disregard for the planning of repairs is worth a lot of money.

If measures are not taken to develop scientifically based methods of calculating reliability at the level of the requirements of the present and the future, this issue will lag more and more behind the general level of technological development, and this should not be allowed [7].

The techniques described in this paper are among the first in this field. However, they are already opening new prospects in the field of reliable design. Further theoretical fundamental research in this direction is needed to generalize practical experience in similar industries. Solving the problem of reliability requires the joint work of mechanics, hydraulic engineers, economists, mathematicians, experts in reliability theory, and system analysis [6, 8, 9].

The purpose of the pump diagnostics is to increase the reliability, durability, and efficiency of operation. New diagnostic methods suggest:

- study of the behavior and state of pumps in the past, including an analysis of the previous technology of operation (failures, accidents);
- study of the technical condition of pumps at present, including the study of characteristic parameters and their evaluation;
- prediction of the technical state in which the pumps will be in the future, including the definition of the resource according to the technical condition at present [10–14].

The focus was on the head pumping station (PS) of the Karshi Main Channel (KMCh). The main pumps installed on it with four impellers operated in unfavorable conditions due to low water levels in the avancamera, insufficient pump penetration depending on low water horizons in the Amudarya River. The pumps operated in cavitation mode, which repeatedly led to failure. This was especially noted on the extreme aggregates.

In recent years, the PS-1 has been reconstructed. Based on the actual mode of operation of the PS (3 new units of different supply to stabilize the water levels of the lower and upper pools (DWL and HL), two new units of type 300VO-37/26C (Pump № 1.3) and one operating unit were selected for testing type OPV11-260 (Pump № 6).

At the same time, the non-identical operation of the extreme and medium pumps is established. The unevenness of the approach of water to the extreme aggregates created the reverse currents of water in the suction pipes, the work of the aggregates with vibrations, and in modes close to cavitation (Table 1) [15, 16].

| Pump     | No filters | On the reverse frequency | At the pole frequency | V mm/s | notes               |
|----------|------------|--------------------------|-----------------------|--------|---------------------|
|          |            | Impeller chamber: vertical vibration |                       |        |                     |
| Extreme 6 | 35…40      | 25…35                    | 8                     | 2.2…3.5 | P=8.2 mW           |
| Average 4 | 17…20      | 13…20                    | 4                     | 1.5…2.2 | 8.5                 |
|          |            | Horizontal               |                       |        |                     |
| 6        | 60…70      | 26…35                    | 24                    | 2.7…3.2 | Siphon not charged  |
| 4        | 62…68      | 17…24                    | 21                    | 2.8…3.2 |                     |
Upper motor spider, vertical vibration

| Measurement location | Average air gap stator-rotor before offset | after offset |
|----------------------|--------------------------------------------|--------------|
| Upper reach (UR)     | 12,5                                       | 13,5         |
| Right Bank (RB)      | 16,5                                       | 10,5         |
| Lower pool (LP)      | 12                                         | 11           |
| Left Bank (LB)       | 4                                          | 11,5         |

The results of measurements of vibration accelerations in non-stationary modes on the pumps before and after elimination of the non-uniformity of the stator-rotor air gap are shown in table 3.

Table 3. General and 1/3 –octave vibration levels of the unit before and after repair

| Vibration direction | The name of the frequency range, Hz | Vibration parameter | acceleration, dB | speed, dB |
|---------------------|------------------------------------|---------------------|------------------|-----------|
| Radial              | joint                              | before repair       | faulty           | serviceable | before repair | after repair |
|                     | 100                                | 62                  | 56               | 111        | 96          |
|                     | 1000                               | 57                  | 51               |            |             |
| Tangential          | joint                              | before repair       | faulty           | serviceable | before repair | after repair |
|                     | 100                                | 68                  | 61               | 112        | 95          |
|                     | 1000                               | 63                  | 58               |            |             |
| Vertical            | joint                              | before repair       | faulty           | serviceable | before repair | after repair |
|                     | 100                                | 55                  | 52               | 108        | 96          |
|                     | 1000                               | 48                  | 46               |            |             |

It follows from the table that the overall vibration levels in the horizontal direction after moving the stator of the unit decreased by equal values: acceleration by 6 dB, speed by 25 dB. In the vertical direction, the reduction in the general level of vibration acceleration was 3 dB, and in terms of vibration velocity 12 dB. A reduction in vibration accelerations in the 1/3-octave band of 100 Hz in all directions corresponds to a reduction in overall vibration levels. The component at the average geometric frequency of 100 Hz significantly (20 dB) decreased in the radial direction, by 14 dB in the tangential and by 7 dB in the vertical directions. These measurements show that an excessive vibration change is recorded in the tangential direction, both at the general level and in the frequency band of 100 Hz (Table 3). Diagnosing the offset of the stator axis relative to the rotor axis should be done by measuring the vibration of the upper cross of the engine in the horizontal direction along the general
vibration level and levels in 1/3-octave bands of 100 and 1000 Hz, where the vibration change is 6...20 dB [18].

Based on the results of diagnostics, the list of the investigated priority issues of the reconstruction of pumping stations was clarified:
1. Improving the anti-cavitation properties of the flow-through part of the OPV-260 EG pumps and the development of methods and means for the vibration diagnosis of the onset of cavitation;
2. Development of devices for signaling friction blades on the impeller chamber, bearing assemblies, pump rectifiers [19].

The advantages of the device are to do remote monitoring system. With the installing remote sending apparatus one can achieve opportunity to got information in distance. Scheme of this sending system is such (figure 1) [14].

2. Methods
In the works of SANIIRI and TIIAME on the similarity of resistances during fluid flow in the flowing part of the pump, it was possible to analytically determine the hydraulic losses in the impeller and the tap. However, this model does not take into account the influence of the resource on the change in hydraulic parameters. Also, the model does not take into account the probabilistic nature of the change in the geometric parameters and the roughness of the surfaces of the flowing part of the pump from the test time, which makes it impossible to use statistical methods for predicting its technical state.

Changes in the pump head under the influence of water jet wear and cavitation erosion of its elements during operation can be represented as a product of energy parameters

\[
H(t) = H_m(t) \cdot \eta_{o6}(t) \eta_k(t) \eta_o(t)
\]

here: \(H_f(t)\) is the theoretical head of the wheel as a function of \(t\), \(m\);
\(\eta_{o6}(t)\) is the volumetric efficiency of the pump as a function of \(t\);
\(\eta_k(t)\eta_o(t)\) is the efficiency of the wheel and the retraction as a function of \(t\).

The theoretical head of the impeller depends on the angular velocity of the impeller, hydraulic, and geometric parameters, which vary from time to time.
The change in the geometric parameters during the operation takes place under the influence of the external conditions of the waterjet medium, its mineralization and temperature, the suction and discharge heights, vibrations, etc. A different combination of these factors leads to the dispersion of the hydraulic parameters.

The volumetric efficiency of the pump is determined by the formula

\[ \eta_{ob}(e) = 1 - \frac{Q_0}{q(t)} \]  

(2)

here: \( Q \) is the nominal pump feed, \( \text{m}^3/\text{s} \); \( q(t) \) is the dependence of the change in leakage in the gap seal on time, \( \text{m}^3/\text{s} \).

To calculate the wheel efficiency and retraction, expressions

\[ \eta_k(t) = 1 - A_1(t) \]  

(3)

and

\[ \eta_0(t) = 1 - \frac{A_2(t)}{H(t)} \]  

(4)

where: \( A_1(t) \) and \( A_2(t) \) are the coefficients characterizing the change in the geometric parameters of the wheel at the helix spiral from the test time.

After the necessary transformations, we obtain

\[ H^2(t) - A_1(t) - H(t) + A_2(t)A_2(t) = 0 \]  

(5)

Equation (5) characterizes the change in pump head from time as a result of the wear of geometric parameters under the influence of a water jet medium and cavitation.

Indicators of the dynamics of the geometric parameters of the pump and the probabilistic characteristics of their distributions are determined by the results of operational observations or bench tests. To do this, use the known methods of mathematical statistics. With the help of the dynamic model of pump operation, a set of realizations of pump head changes from the test time is obtained by statistical simulation.

By setting the maximum value of the pump head, established on the basis of technical and economic calculations, and using the random variable conversion theorem or the results of statistical modeling, determine the pump resource by the parameter (head) and the values of the resource distribution density (figure 1).
To test the reliability of the developed dynamic model in SANIIRI, we carried out bench tests of the centrifugal pump DA-86 ($Q_0=0.13$ m$^3$/s, $H_0=36$ m, $n=1687$ min$^{-1}$), close to its characteristics for general-purpose pumps of the type K 290/30 (Figure 2). The theoretical curve of the change in the pump head from the test time is calculated from the results of the micrometer of the parts.

A good coincidence of the theoretical and experimental curves was noted. The relative error is 2-9%, which allows drawing a conclusion about the effectiveness of the developed model. It can be used in controlling the reliability of pumps, determining the optimal sequence of increasing the longevity of their elements, developing methods for assessing the quality of repairs using methods and means of accelerated testing.

To study the technical condition of the pump unit, a unit of continuous measurement of vibration was set up and several experiments were performed (figure 4).

With the help of a propulsion device, the pump unit is operated differently and the amount of vibration in the inventory is determined. With this unit, pump units have been used in various cases to determine the exact amount of vibration in the pump unit.

Permanent vibration diagnostics are followed by the use of non-clamping results:

- the vibration traction pumps in the pump units can be extracted and stored in the letter;

3. Results and Discussion

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Permanent vibration diagnostics are followed by the use of non-clamping results:
— each pump has the opportunity to receive and analyze data in parallel, provided by aggregation;
— analyzing received reports and pumping aggregation techniques allow you to evangelize.

![Figure 3. Pump aggregates export vibrations](image)

Diagnostic pumping system ensures continuous operation of pump aggregates, securely securing and reducing maintenance costs and maintenance costs. This system provides an automatic database for automated drilling changes, which will provide a database of specific tasks that need to be addressed and addressed to professionals.

Pump valves, canal tubes, or pump failure may cause permanent damage to the pump immediately after the vibration occurs, chills, malfunctions, and defects occur. The main units, bearings, and shafts for emergency and continuous operation of pump units are calculated. As a result of the impact of vibration on the pump valve, the voltage must be continuously monitored. Permanent vibration diagnostics have been observed for many different reasons, and the vibration control and discharge of the bladder and during the time of the collision. Under the conditions of the pumping unit, the exact results of the vibration exerted by the pumping unit, the vibrations of the center of the vibrations, the pumping valence cycles, and the substrate proportional. Experimental studies have shown that the pump aggregates operated under the cavitation regime show that the vibration range is 98-107 Hz.

Along with the functional, the pumps have parametric failures, which involve a significant deterioration in its operating parameters. For horizontal pumping units, a parametric failure is a decrease in their efficiency by more than 15-20 or pressure of 10-12%. Taking into account survey data, it can be concluded that approximately 30-40% of pumps are operated in the state of parametric failure. This leads to a significant shortage of irrigation water (about 15-20%) and over-consumption of electricity.

4. Conclusions
Innovative technologies developed by scientist plays an important role in different branches. Thanks to the new technologies and techniques accuracy and protected working condition is increased.

The vibration of pumping devices during a long time causes to retiring of details of this equipment. Which constructions pump valves, canal tubes, or pump failure may cause permanent damage to the pump immediately after the vibration occurs, chills, malfunctions, and defects occur. The main units, bearings, and shafts for emergency and continuous operation of pump units are calculated. As a result of the impact of vibration on the pump valve, the voltage must be continuously monitored. Permanent vibration diagnostics have been observed for many different reasons, and the vibration control and discharge of the bladder and during the time of the collision. Under the conditions of the pumping unit, the exact results of the vibration exerted by the pumping unit, the vibrations of the center of the vibrations, the pumping valence cycles, and the substrate proportional. Experimental studies have shown that the pump aggregates operated under the cavitation regime show that the vibration range is 98-107 Hz.
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New technologies invented in this article bring remote control of the technical condition of the device.

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References
[1] Ikramov N and Mjidov T 2013 Factors affecting the operational and energy mode of operation of pumping stations Mater. Int. Sci. Conf. Problems complex Arrange. techno-natural Syst. part 1 "l. reclamation, Recultiv. Prot. lands. pp 215–220
[2] M . TTN and IN 2010 Evaluation of operational and energy regimes of large pumping stations Tashkent
[3] Mamajonov M, Uralov B 2005 Change of water supply of pumps Agric Uzb 1 28
[4] Ikramov N and Eduard K 2019 Effect of parallel connection of pumping units on operating costs of pumping station France; p 5008
[5] Glovatskiy O, Djavburiyev T, Urazmukhamedova Z 2019 Interconnection of influent channel and pumping station units France; p 5008
[6] P. O 2016 Genetic Optimization and experimental verification of complex parallel pumping station with centrifugal pumps Appl Energy, 527-539 p 178
[7] Bazarov D R, Vokhidov O F, Lutsenko L A and Sultanov Sh 2019 Restrictions Applied When Solving One-Dimensional Hydrodynamic Equations Proc. EECE 2019, Lect. Notes Civ. Eng. 70. pp 299–305
[8] Menon S. Menon S 2010 Working Guide to Pumps and Pumping Stations Calc. Simulations B.
[9] Shankar A, Kalaiselvan V, Subramaniam U and Shanmugam P 2016 A comprehensive review on energy efficiency enhancement initiatives in centrifugal pumping system Appl Energy, p 181
[10] Beglov I F and Glovatsky O Y 2001 Analysis of fault diagnosis systems for pumping units Moscow; pp 61–65
[11] Chebaevsky V F and Vishnevsky K P 2000 Design of pumping stations and testing of pumping units Moscow
[12] Bazarov D, Shodiev B and Norkulov B 2019 Aspects of the extension of forty exploitation of bulk reservoirs for irrigation and hydropower purposes France; p 9
[13] Eduard Kan Ikramov N and Mukhamadiev M 2019 The change in the efficiency factor of the pumping unit with a frequency converter France; p 5008
[14] Ergashev A A and Majidov T Sh 2016 The results of field studies of the pump unit with a frequency converter J Irrig L Reclam 01 31
[15] Bazarov D, Shodiev B, Norkulov B, Kurbanova U and Ashirov B 2019 Aspects of the extension of forty exploitation of bulk reservoirs for irrigation and hydropower purposes E3S Web Conf. EDP Sciences
[16] Mamajonov M, Bazarov D, Uralov B, Djumabaeva G and Rahmatov N 2019 The impact of hydro-wear parts of pumps for operational efficiency of the pumping station J Phys Conf Ser 1425 012123 doi: 10.1088/1742-6596/1425/1/012123
[17] Bekchanov F, Ergashev R and Majidov T 2019 Mathematical model of vibrating air pump unit France; p 4015
[18] Yu-qin W and Ze-wen D 2020 Influence of blade number on flow-induced noise of centrifugal pump based on CFD/CA Vacuum 172 doi: 10.1016/j.vacuum.2019.109058

[19] Khasanov B, Azimov A and Djurabekov A 2019 Full-scale testing of water intake pumps of pumping stations p 5008