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Diagnostic model of great irrigation pump units

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Abstract. Based on the laws of classical mechanics, in particular, the law of conservation of momentum, the paper describes the developed mathematical model of signal propagation during vibration diagnostics. At the beginning, the problem of signal propagation was investigated, which was reduced to solving the problem of wave propagation. According to the analysis of experimental results investigated, that the attenuated nature of the signals must be taken into account. For this purpose, a mathematical model has been developed, which allows to solve the problem of the propagation of damped signals. Comparative analysis allows to conclude that the constructed model is adequate.

1. Introduction

Water management for irrigation of agricultural crops is one of the most important issues in the world, "4 billion 886.3 million people worldwide per hectare of agricultural land, 43.2% of which is irrigated by pumping stations".

One of the important issues is to use the latest scientific achievements and increase the economic efficiency in order to carry out the tasks set to improve the control method based on vibration indicators to ensure reliable and safe operation of pumping units.

In this regard, it is important to ensure the reliable use of pumping stations to supply the required amount of water to the growing area.

An analysis of the use of hydro mechanical equipment in a lifting machine system has shown that one of the main causes of their failure is vibration, which is important to identify and analyze. Detection and measurement of vibrations generated in the pumping units of hydro mechanical equipment can be used to study their current state and ensure their reliable operation in the future.

As a result of the introduction of the diagnostic system of pumping units, the causes of malfunctions will be identified, their technical condition will be determined without disassembly, and a database will be created on how long they can be used without interruption.

The pump set is a complex system that must be selected in such a way that their condition changes over time should be able to assess the actual state of the system as a result of determining these indicators. The condition of the system is important for the pump unit to deliver the required amount of water to the system.

This task is performed during the commissioning of the pump unit and in the first stage of operation, it is ensured that its performance remains the same or changes insignificantly. This is due to



the fact that the parts of the pump set during this period provide consistent performance. The correct formulation of the diagnostic problem is required to study the changes between the interconnected elements in the system and to determine how important they are in ensuring that they perform a common function [1].

2. Materials and methods

The analysis of the operation of pumping units revealed that the interconnection between its parts can be divided into three stages. The first stage is a pump unit with energy and mechanical parts, the elements of which consist of a pump unit and an electric motor. The pump unit and the electric motor, in turn, form the second stage, the elements of which consist of details and parts and the interconnections between them. By their nature, the bonds between these parts are of the mechanical type and belong to the kinematic pairs. Because they have one or more degrees of freedom of motion, they are considered to be a system of individual parts that can be incorporated into the motion of general mechanical systems.

This means that each element that makes them up has a different size relative to the fixed coordinates of the system. These parameters are qualitative characteristics of mechanical bonding and are called structural parameters (distance and distance between axes, bending, etc.). The bottom of the system consists of individual parts that are part of the elements of the second stage in the third stage, which are characterized by their molecular composition. Changes in their composition change the structure of the materials. These conditions can cause parts to crack, crack, corrode and erode.

In view of the above, in the qualitative characteristics of the pumping unit in terms of the structure of the system, three different systems are used to determine the systems:

- the first is a characteristic of energy systems Θ_k ;
- the second is a characteristic of mechanical systems S_i ;
- and third, the S_j 's that characterize hydraulic systems.

The meanings of the physical parameters Θ_k , S_i and S_j are considered to be the same, taking into account the defects in the pump set, their malfunction, the origin of vibration as a result of various effects. It should only be noted that Θ_k contains a set of structural parameters that characterize the structural properties of pumping units.

Factors leading to damage to pump units:

- long-term static effects, stresses;
- repetitive static effects and stresses;
- effects of vibrations and vibrations;
- wear of device design;
- corrosion effects and fatigue.

As a result of such effects, the pump unit parts may be adversely affected and cracked, there are cases that accelerate the process of erosion and change the shape of the waterways. Such uncontrollable processes, which lead to sudden breakdown of the pump set, lead to changes in functional characteristics. If the parameters of each structure are clear, it is possible to assess the technical condition of the unit. If the specified parameters correspond to the same details of the pump units, it can be called a model of technical condition.

The technical model can be presented in tabular or structural form. The technical model showing the condition of the pump units is given in Table 1. Two main issues need to be addressed in the analysis of this model:

- which parts of the pumping units can be identified by diagnostics;
- which parameters clearly characterize the changes in the pumping units.

Table 1. Model of the technical condition of the pump unit

Name of the pump unit part	Defective character	Structure parameters
Bearings	Slip	The diameter of the gap is S_{i+1}
Working blade surfaces	Hydro abrasive and cavitation erosion, cracking, fracture due to mechanical effects.	Uneven surface- S_{i+2} , variety of hydraulic resistances- S_{j+2} , m balance vibrations- S_{i+3} and noise generation- S_{j+3} .
Pump shaft	Erosion, breakage, cracking, bending	The change in diameter is due to the loss of density- S_{i+4} , imbalance- S_{i+5} , vibration- S_{i+6} , and the occurrence of interactions- S_{i+7}
Rotor system	Erosion, contamination, clogging, burning	Changes in size, the formation of cracks in the diameter- Θ_{k+2} , imbalance- Θ_{k+4}

3. Results and Discussion

An analysis of the literature shows that no analytical solution to this problem has been considered. Accurate diagnosis and assessment of the condition of pumping unit parts can be achieved using statistics obtained during their repair and maintenance. Using this data is the best way to compare the coefficient of variation of resource indicators.

$$C_v = \frac{\delta}{R_r}; \quad (1)$$

here: $R_r = \sum_{j=1}^n R_{rj} \cdot n^{-1}$; determined using the formula.

Expected resource of the part ($R_{rj} - j$); - the resource of the part before the overhaul, n-the total number of parts the resource is being studied;

$$\delta = \sqrt{\frac{\sum_{j=1}^n (R_{rj} - \bar{R}_{rj})^2}{n-1}}; \text{ the average deviation of the resource of the studied part.}$$

The highest coefficient of variation is the primary factor in determining the importance of parts [6].

The structure of the selected parameters must meet the following requirements:

Not functionally related to each other (the structural parameter of S_i can change independently of the parameters of S_j), that is, the parameters of S_j do not depend on the parameters of S_i depending on the exact values;

Defining the external boundaries of the selected structural parameters: defining the boundaries of its composition of functional, technological, durability and vibroacoustic characteristics

In the general case, the model of the technical condition can be expressed in the form of a set of structural parameters in a given n-dimensional space as follows:

$$S(t) = S_1 i_1 + S_2 i_2 + S_3 i_3 + \dots + S_n i_n; \quad (2)$$

here: $i_1, i_2, i_3, \dots, i_n$ - states of structural parameters in dimensional space.

This model shows that each detail or part in question must be in two different positions. These cases are both verbal and non-verbal. In order to determine the boundary between these states, the structural parameters must satisfy the following condition for the word to be in the state, i.e.:

$$S_i < S_f; \quad (3)$$

here: S_i - is a structural parameter of the part being diagnosed;

S_f - the value of the final state of the structural parameter.

The above and accepted limits can be used to determine the value of the latter condition.

When determining the suitability (operating condition) of a pumping unit in use, it is necessary to consider how far the measured parameters are from their values in the final state. The greater the difference between the measured and the final state values, the greater the resource of the part under study before repair. The large number of parts in a pumping unit and the fact that they perform different functions mean that they cannot be required to be the same. Each of them performs a specific function, so it is important to note that their condition is assessed not individually, but by the pumping

capacity of the pump. In this case, the changes in the values at the inlet and outlet points are studied separately in determining the parameters of the pump set. The following diagnostic model can be used to describe the changes that occur in the components of the pump unit (impellers, their shafts, bearings).

$$\begin{aligned} Y(t) &= f_1[S(t), V(t)]; \\ F(t) &= f_2[S_n(t), V(t)]; \end{aligned} \quad (4)$$

here: $Y(t)$, $V(t)$ - incoming and outgoing parameters;

$S(t)$, $S_n(t)$ - parameters of unrelated parts;

$F(t)$ - physical characteristics of internal parts.

If the values of $Y(t)$, $V(t)$ and $F(t)$ are known, it is possible to determine the values of $S(t)$.

This expression is a diagnostic model for determining the condition of the pump set, which allows you to detect changes in each part of the pump unit without breaking it down.

Acoustic processes in pumping units are complex and can only be studied using similar methods [2].

The hydrodynamic vibrations and noises that occur in the pump units themselves are the result of the processes that take place inside them, that is, the effect of the water supplied to the working blades. This process can be caused by vibrations and noises that occur as a result of the uneven impact of the water around the impeller and the sheaths during the movement of the water inside the pump [4].

Cavitation processes in pumping units and imbalances in rotating parts are the main causes of vibration and noise. Vibration in the pressure pipes also causes noise in the pump unit. Such vibrations can also be caused by changes in water pressure due to the distances between the pump blades and by acoustic vibrations of the water. In addition to the acoustic vibrations caused by the compression of water, there is also a hydrodynamic process [5].

Acoustic vibrations generated inside the pump can also be transmitted to the pump housing via shafts and bearings. The amplitude and shape of the resulting vibration depends on the shape, size, material, wall thickness and stiffness of the pump design. The vibration sources listed above cause resonance in the design of the pump unit parts. During the design, it is necessary to prevent the oscillations of the pump units themselves and the vibration frequencies of their parts from falling on top of each other. However, due to the complexity of the internal structure of centrifugal pumping units, there is no way to measure and detect vibrations.

The lack of these parameters makes it difficult for designers to design low-noise pumps. Many experiments and design changes are required to reduce the noise generated by the pump units through experiments. That, in turn, can be costly and time consuming. Based on the above, it is important to develop a method for calculating and determining the frequency of vibrations in the pumping units to reduce vibration and noise.

Irrigation and Water Problems Research Institute (IWPRI) scientists have identified the main causes of noise and vibration in centrifugal pumps and their frequency.

Noise and vibration spectra allow us to determine the following regularity. Part I shows the frequency of noise and vibration at $n/60$ revolutions per second of an unbalanced impeller on rotating parts. Part II shows the frequency of noise and vibration caused by the uneven outflow of water on the impeller blades at a speed of $n/60$ revolutions per second. In High Frequency Part III, the frequency of noise and vibration caused by the uneven motion and direction of water can be seen.

Case 2, in which noise and vibration increase rapidly, is caused by a disturbance in the direction of the water. Other pumps have similar noise and vibration spectra depending on their operating conditions. It can be seen that noise and vibration are caused by the loss of balance, variability of water flow and cavitation when the rotor of a rigid structure is mounted and moved on the rotor sliding bearings. Other causes of pumping can be secondary.

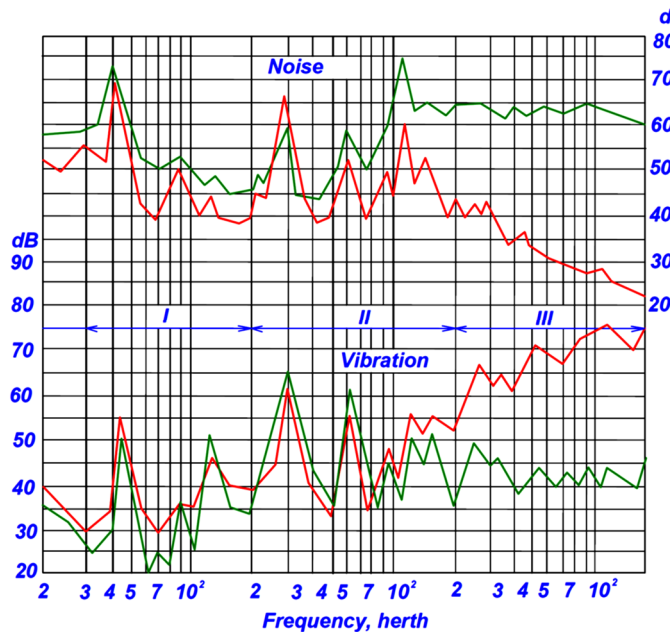


Figure 1. Spectrogram of noise and vibration in centrifugal pumps. 1-in the order of operation without cavitation; 2-when working in cavitation order.

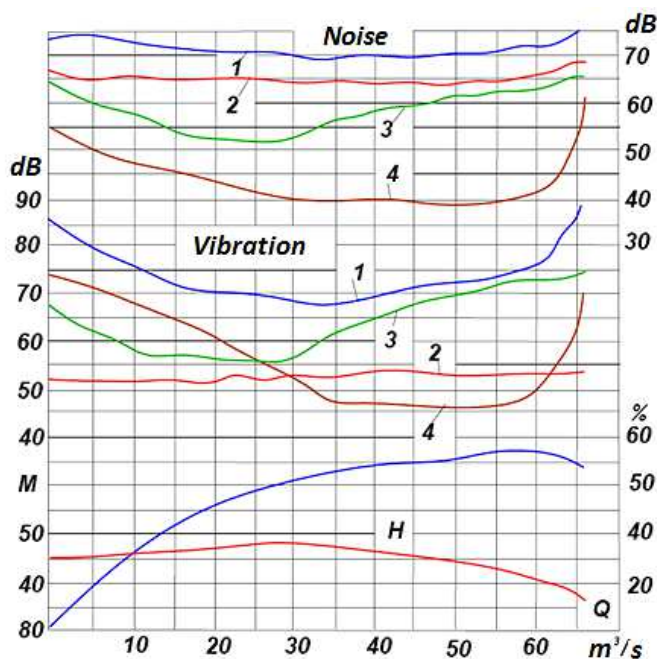


Figure 2. General state of noise and vibration in the pump in terms of water consumption. 1-general condition; 2-imbalance; 3-water change; 4-cavitation position.

Centrifugal pumps cause noise and vibration due to various design and technological factors. Experiments at IWPRI and data from “Suv mash” show that a number of data have been collected on the detection of noise and vibration and their classification. It is necessary to further develop scientific research in this area, to study in depth the occurrence of noise and vibration in high-speed pumping equipment, and to systematize the data obtained. If this information is taken into account during the design of pumping equipment, the reliability of pumping equipment will increase significantly.

It should be noted that the causes of vibration and noise in pumping units need to be studied separately. Particular attention should be paid to the study of noise and vibration due to hydrodynamic and mechanical causes.

Noise and vibrations are generated as a result of the analysis of data identified in scientific research conducted by IWPRI scientists; it is confirmed that the water in the canal is not uniform and their uneven flow is proportional to the rotational motion of 4-6 degrees and the diameter of the impeller by 2 degrees. Changes in the weight, elasticity and acoustics of the impeller do not have a significant effect on this law. A level 4 condition is observed in the hydrodynamic flow. Noise and vibration are subject to law 6 if they are acoustic in the case of rapid changes due to the compression of water.

Another major reason for the origin of the noise is the increase in the cavitation process. In this case, the different levels of cavitation are important in the formation of noise and vibration, and the cavitation coefficient is 4-6 degrees.

Experiments have shown that the intensity of noise and vibration depends on the number of revolutions of the pump impeller and bearings by 2-3 degrees. Installing a sliding bearing instead of a rolling bearing can reduce mechanical noise and vibration (15-30 dB) in centrifugal pumping equipment. Noise and vibration due to imbalance are of level 4, and can be level 2 if the speed of rotation of the pump impellers does not change.

4. Conclusion

1. While the large rotational motions of the pump units are affected by hydrodynamic noise and vibration, the small rotational motion is characterized by mechanical noise and vibration.

2. Noise and vibrations generated by hydrodynamic and mechanical vibrations are governed by the laws of similarity. They can be calculated using the method of calculating the speed and size of the pump impeller. Theoretical studies have shown that hydrodynamic and mechanical vibrations cause noise and vibration in pumping units. It is important to determine which indicators are important and to conduct research to reduce their causes.

Acknowledgments

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