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Reducing Hydrodynamic Loads in Non-Stationary Modes of Operation of Pumping Station Units

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Abstract: The article discusses the issues of occurrence of hydrodynamic loads in non-stationary processes of pumping stations, negatively affecting the operational condition of the pumping station equipment. The results of experimental studies conducted at the 6-pumping station of the Karshi main canal during the start-up of the pumping unit are presented. A method for reducing hydrodynamic loads acting on the elements of the flow path of the pumping unit during its start-up by inlet of air into the discharge part and under the impeller of the pump is proposed and investigated.

Keywords: pump unit, hydrodynamic loads, pressure pipeline, guide vane, pump start-up, rotation frequency, pressure pulsation, vibration, pump pressure, air inlet.

I. INTRODUCTION

During the operation of pumping stations, in addition to stationary modes of operation, non-stationary processes are also observed, i.e. a change in the operating mode of pumping units (transition from one mode to another). In the process of changing the operating mode, the parameters of the pumping unit differ from the parameters under the specified standard operating conditions and can have a negative impact on the operating condition of the equipment.

This circumstance requires a comprehensive study of non-stationary processes in pumping stations with the identification of those operating modes of units in which high hydrodynamic loads are observed acting on the elements of the flow path and taking measures to reduce them.

II. SIGNIFICANCE OF THE SYSTEM

During normal use, a change in operating modes does not pose a significant risk to the pumping station equipment, since it is controlled. However, non-stationary modes of operation of the pumping unit can be dangerous and cause significant damage to the equipment due to their sudden, abrupt occurrence [1, 2, 3, 4, 5]. The process of changing the operating mode of pumping stations can occur in the state of normal operation and in emergency mode or due to a sudden change in the operating mode. The following processes are related to the processes of changing the operating mode that occur during normal use [1, 2, 3, 4, 5].

1. Starting the pumping unit.
2. Stopping the pump unit.
3. Changing the water supply by the pump.
4. Changing the number of revolutions (shaft rotation frequency) of the pump

Among the above-mentioned operating modes, in which the greatest loads occur, are the start and stop of the pumping unit and in connection with this, it is in these modes that it is necessary to use methods and mechanisms to reduce loads.

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III. LITERATURE SURVEY

Non-stationary operating modes do not last long, but the hydromechanical processes occurring at this time are rapid, causing strong vibrations and pulsations of water pressure. In this regard, most emergency situations and breakdowns are a consequence of hydromechanical and hydrodynamic processes in non-stationary operating modes [1,2,3,4,5].

For example, when starting, the pump can go into surge mode due to an increase in pressure caused by pumping water into the discharge pipeline, or when overcoming the resistance of the check valve, which is accompanied by a sharp change in pressure in the discharge part of the pump [1,3,5].

One of the features of starting the OPV10-260G pumps in the pumping stations of the Karshi main canal is an increase in the hydrodynamic torque of the shaft with an increase in pressure and, in connection with this, in most cases, in order to facilitate starting, water is pumped into an empty pressure pipeline [1,3,4,5].

In this case, the pump goes through the following stages of the starting process [3].

- transition from a stationary state to a rotating one with achievement of a synchronous rotation frequency and synchronization (stage I);
- filling the pipe with water and increasing the pressure (stage II);
- operation of the pump with increased pressure until the vacuum break valve closes (stage III);
- Closing the vacuum break valve and switching to a specified mode (stage IV).

IV. METHODOLOGY

Fig. 1 shows the analysis of oscillograms obtained in our studies of the start-up process of the 1st unit of pumping station No. 6 of the Karshi main canal [1].

Stage I of the pump start-up process takes 8...10 seconds, when the operating point of the operating mode moves from the origin of the characteristic coordinates to the point $H=H_{opt}$ on the pressure characteristic H – Q. At this stage, the pressure in the pressure pipeline is 15...33% of the geometric pressure, the moment of the hydrodynamic force acting on the blades increases by 2.5...3.0 times, the vibration value of the pump unit slightly exceeds the permissible norm. Therefore, when starting the pump, the blade installation angle should be as small as possible. At the 8th second of this stage, the number of revolutions of the pump shaft reaches the nominal value - 250 rpm. At stage II, the operating point begins to move up H-Q, and at 13...17 seconds of start-up, the highest values of pressure pulsation (50...83% of the H value) are observed in the section behind the pump guide vane, and by the end of the stage (22...26 seconds), its values are normalized.

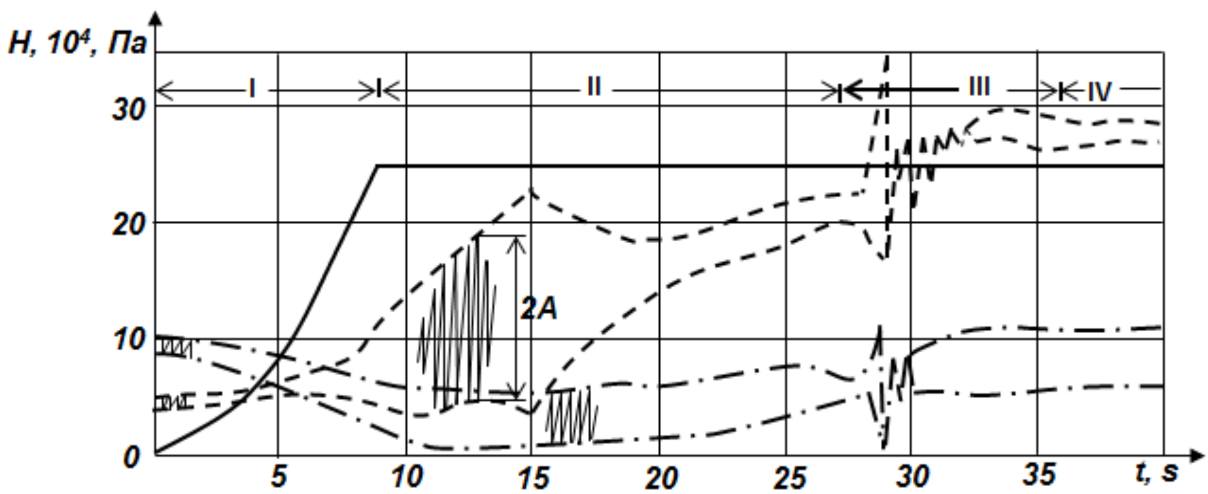

Fig. 1. Change in the pulsation of hydrodynamic pressure in the flow path of the pump ОПВ10-260 6 - pumping station of the Karshi main canal

——— *n =f(t)* – change in pump shaft speed over time

— · — $H_1 = f(t)$ – change in pump pressure in the section under the impeller

– – – – $H_2 = f(t)$ – change in pressure in the outlet part of the guide vane

At the beginning of stage III, high-pressure air begins to exit through the aeration pipe located at the end of the pressure pipeline, as well as through the vacuum breakaway valves, and at this time, the working pressure of the pump exceeds its nominal value, that is, the pump begins to operate with increased pressure, and at the same time, increased pulsation of hydrodynamic pressure (up to 75% of H) is observed in the flow path in a short period of time (at 27...29 seconds of start-up). At this stage, the geometric pressure of the pump can exceed the norm by 3...4 meters. At stage IV, with the vacuum break valve tightly closed and the siphon loaded normally, the working pressure reaches the optimum value, i.e. $H = H_{opt}$. If this is achieved, the pressure pulsation and vibration value in the pump will be normal.

When the pump is started, the current supplied to the electric motor exceeds the norm by 5-7 times, the pressure pulsation and vibration amplitude in the guide vane zone in the pressure pipeline increase [1]. Based on experiments conducted at the pumping stations of the Karshi main canal, it can be said that when the pump is started, the maximum pulsation of the hydrodynamic pressure occurs in the outlet zone of the guide vane, and its value can be 5-6.5 times greater than the value in normal operating mode and 60-83% of H_{opt} [1].

When the pump is started, the double amplitude of radial vibration in the upper section of the electric motor increases to 420 µm at a frequency of about 40 Hz, which is 15...17 times greater than its value during normal operation. In this mode, the double amplitude of vertical vibration has a value of 50 µm, which is 2 times greater than in the normal operating mode (Fig. 2) [3].

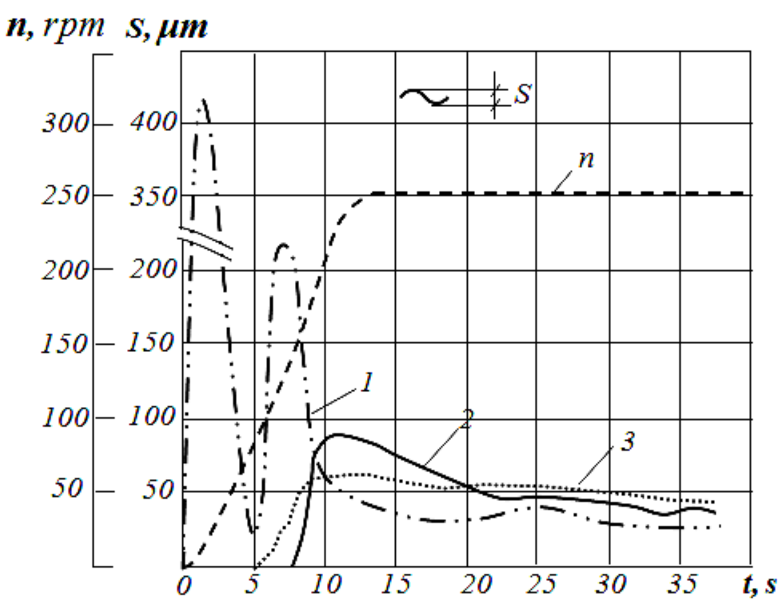

Fig. 2. Change in equipment vibration values when starting the OPV10 – 260 pump (φ = - 6⁰)

Double amplitude of radial vibration: 1 – in the upper section of the electric motor, µm; 2 – in the upper bearing of the pump, µm; 3 – in the chamber of the working impeller, *n* – pump shaft speed, rpm.

In this case, the magnitude of radial oscillations in the upper bearing of the pump and the impeller chamber has maximum values of 82 µm and 60 µm, respectively (in 9...10 seconds of starting), when the number of revolutions of the pump shaft reaches the nominal value, and then in the normal mode of operation of the pump, the vibration of the bearing and the impeller chamber has values of 30...35 μm at a rotation frequency of 4.17 Hz.

Thus, the mode point in the operating characteristic of the pump during its start-up goes through several stages, at which the amplitude of the hydrodynamic oscillation is large. To reduce these oscillations, a method of supplying air to the discharge part of the pump in parallel with the pump start-up was proposed [6].

V. EXPERIMENTAL RESULTS

The results of studies on supplying compressed air under a pressure of $60 \cdot 10^4$ Pa for 24 seconds to the holes located along the perimeter of the outlet part of the guide vane during the 1st and 2nd stages of pump start-up led to a decrease in the amplitude of the hydrodynamic pressure by 40...50%. The amount of air supplied is 0.7% of the nominal water flow rate. In this case, the pulsation frequency was about 35...40 Hz, which is about 10 Hz less than in the operating mode without air supply. This situation confirmed the idea that air introduced into the flow can change the frequency spectrum of the flow pressure.

When starting pumps with a discharge pipeline equipped with a check valve, the unit is subjected to high hydrodynamic loads. This occurs because the pump supplies water to the discharge pipe filled with water behind the check valve. In this case, when starting the pump, the operating point of the operating mode may enter the surge zone, which leads to the occurrence of high hydrodynamic loads (Fig. 3).

Based on the results of our studies, to prevent this negative situation, it is recommended to supply compressed air under the impeller in parallel with the start of the pump [7].

It is known that supplying air under the impeller of the pump up to 1.0% of the optimal performance (Q_{opt}) can reduce the pressure and flow rate of water supplied by the pump. In this regard, by varying the amount of air supplied under the impeller, it is possible to bypass the surge zone with the operating point of the pump, achieving the operating mode of the pump indicated on its pressure characteristic.

In Fig. 3 shows that during normal pump start-up, the operating point moves to point B on the pump's pressure characteristic and then reaches the operating point A through the surge zone, during which the flow rate and hydrodynamic flow pressure values change sharply, and the equipment vibration value increases significantly compared to its norm. For these reasons, undesirable events may occur in this process, such as blade breakage.

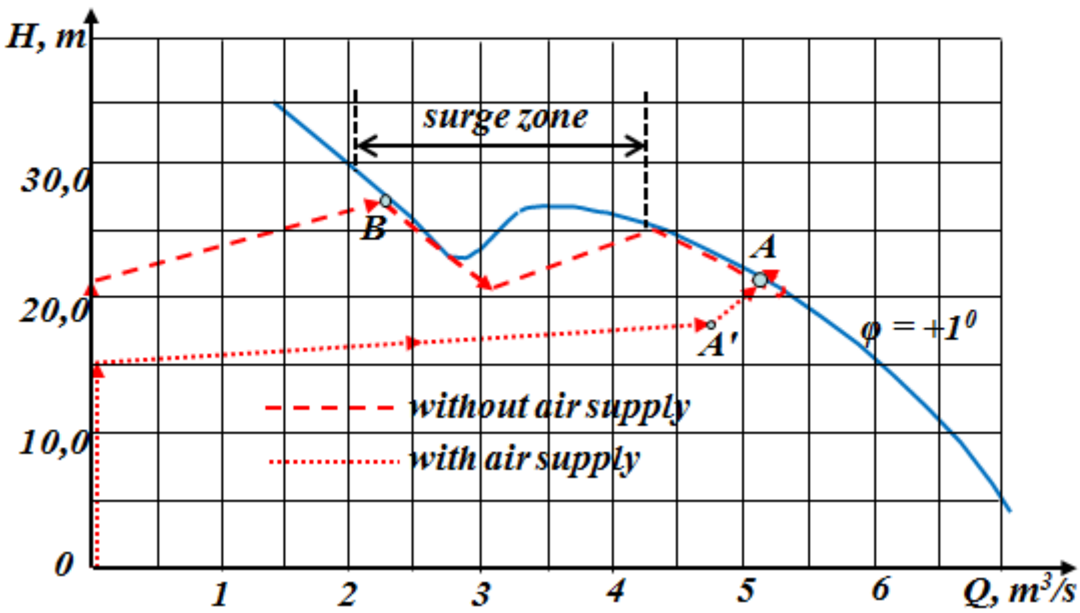

Fig. 3. Moving the operating point when starting the OPV3-110 pump equipped with a check valve in the pressure pipeline

Starting the pump with a certain amount of air supplied under the impeller ensures that the operating point A' is reached without entering the surge zone, and after the air supply is stopped, the operating point occupies a position at point A.

When starting pumps with a pressure pipeline equipped with a check valve, the unit is subjected to high hydrodynamic loads. This occurs because the pump supplies water to a pressure pipe filled with water, behind the check valve. In this case, when starting the pump, the operating point of the operating mode may enter the surge zone, which leads to the occurrence of high hydrodynamic loads (Fig. 3).

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Fig. 3 shows that during a normal pump start, the operating point moves to point B on the pump pressure characteristic, and then reaches the operating point A through the surge zone, during which the flow rate and hydrodynamic flow pressure values change sharply, and the vibration value of the equipment increases significantly compared to its norm. For these reasons, undesirable cases may occur in this process, such as blade breakage. Starting the pump with a certain amount of air supplied under the impeller ensures that the operating point A' is reached without entering the surge zone, and after the air supply is stopped, the operating point occupies a position at point A.

VI. CONCLUSION AND FUTURE WORK

1. Analysis of the results of scientific research conducted at the 6-pump station of the Karshi main canal shows that when starting the OPV10 - 260 pumps, the pulsation of hydrodynamic pressure at the outlet of the guide vane is 4.0...6.5 times, the current of the electric motor is 5.0...7.0 times, and the vibration of its elements is 15...17 times higher than their values observed in the optimal operating modes of the pumps.
2. In order to reduce the pulsation of hydrodynamic pressure and vibration of the equipment when starting the 1-unit of the 6-pump station of the Karshi main canal, a method of supplying compressed air to the outlet of the guide vane was used, and the results of the studies showed that when air is supplied at 0.7% of the nominal water flow rate, the amplitude of the hydrodynamic pressure in the flow path decreased by 40...50%.
3. For pumps with pressure pipelines equipped with check valves, the use of compressed air under the impeller prevents surge mode during the start-up process.

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