Constructive device for sediment flushing from water acceptance structure

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Abstract. The article discusses a constructive solution for sediment flushing from the water acceptance chamber of the pumping station, which is solved using a guide wall raised above the bottom of the chamber. The wall is installed at a distance $L_0 = (2.6 ... 3)D_i$ from the inlet of the suction pipe of the pump at an angle of $25 ... 30^\circ$ relative to the bottom of the chamber. Due to the installation of an inclined guide wall, the level difference is $\Delta h = (0.08 ... 0.1)D_i$, where $D_i$ is the diameter of the inlet of the suction pipe. To reduce the difference in water levels $\Delta h = 9 ... 11$ cm from the action of the guide wall, through holes of rectangular cross-section are made in it with a width of $D_i$ and a height of $0.2D_i$. If the drag coefficient $\xi$ for a chamber with sediment is $\xi = 0.61$, when washing off sediment it is equal to $\xi = 0.491$, so the pump flow from 424 l/s increased to 476 l/s, i.e. increased by 52 l/s. A comparative analysis of flushing sediment from the water acceptance chamber under laboratory conditions is compared with the results of the analysis under field conditions. According to the developed design, the pump efficiency increased by 5.9%, and the flow rate increased by 12.2%.

1. Introduction

Operating experience of pumping stations has shown that many of them operate with a supply significantly lower than the design ones. The main reasons for this are the unsatisfactory hydraulic regime of the water acceptance facilities, and the wear of the elements of the flow part of the pumps.

Studies by a number of scientists have shown that insufficient purification of irrigation water leads to a decrease in the supply of pumping stations located in transit sections of the main canals to 73%, and for dead ends to 63%. In addition, the clogging of the trash racks and the level difference of 0.1 m causes an increase in electricity consumption up to 1.22 kW/h for each cubic meter of water supplied, whereas during normal operation the consumption is 0.6 ... 0.7 kW/h. During operation of the systems, the difference on the trash racks can reach 0.3 ... 0.5 m, which causes cavitation processes in the pump units, rapid wear of the impellers and the failure of pumping equipment [1-5].
In most cases, problems with water acceptance facilities arise at water sources with heavy sediments that enter the water acceptance facilities, which increase the operating costs of the pumping station [6-8].

The increasing volumes of cleaning annually indicate an increasing struggle with the consequence, and not with the causes of siltation. Thus, in modern conditions, tasks related to improving the efficiency of the pump station. The aim of the research is to develop constructive measures to improve the hydraulic working conditions of the water reception constructions of pumping stations, taking into account their influence on the characteristics of the pump [9-14].

The objectives of the study are to improve the design of the water reception constructions of the pumping station to ensure sediment washout.

The object of research is the water reception constructions of the pumping station, and the subject of research is to study the hydraulic resistance of the water reception chamber and the inlet part of the suction pipe of the pump and measures to improve the hydraulic working conditions.

2. Research methodology

Parametric testing of the pump was carried out in order to verify the effectiveness of the use of the guide wall with sediment flushing device to directly improve the hydraulic working conditions of the pump unit by constructing the pump performance to compare it with the factory characteristics. In laboratory conditions, on a model setup, experiments were performed at angles of the guide wall $\alpha = 0^\circ; 30^\circ; 45^\circ; 60^\circ$. At various angles $\alpha$ of the location of the guide wall, the pressure, power and efficiency of the pump were determined. Taking into account the water intake structure, full-scale studies were carried out at the pumping station, the building of which is of the “not deep” type, where 2 (one spare) centrifugal pumps of the 18 NDs brand are located. Irrigation water enters the pumping station from the supply channel to the dead end advance chambers, the central angle of taper of which is 450. The bottom of the advance chambers is horizontal and sedimentation occurs in them, despite repeated cleaning of the advance chambers from sediment sedimentation occurs [9],[11].

The pressure of the 18 NDs centrifugal pump is determined using the readings of the instruments installed on the pump unit of the vacuum gauge and manometer according to the formula:

$$ H = h_{vak} + h_{man} + Z + \frac{V_x^2 - V_s^2}{2g} $$  

where $h_{vak}$ is the readings of the vacuum gauge installed in the suction pipe of the pump, m. of water. Art.; $h_{man}$ is the readings of the pressure gauge mounted in the pump suction pipe, m. of water. Art.; $V_x$ and $V_s$ is accordingly, the flow rate in the pressure and suction piping of the pump m / s; $Z$ is the height between the measuring points of the vacuum gauge and manometer relative to the axis of the pump, m [9],[11].

To disconnect the vacuum gauge and manometer and remove air from them, a three-way valve is installed on the connecting tube.

To measure pressure on the pressure pipe, the spring pressure gauge was used with an accuracy class of 0.4 and a maximum measuring range of 10 kg / cm$^2$.

The electric power consumed by the engine is determined by measuring the current strength $J$ using an ammeter and the voltage in the network $U$ using a voltmeter $U$.

The power consumed by the pump is determined by the formula:

$$ N = N_{dB}\eta_{dB}\eta_{uz} = \frac{\sqrt{3}ju \cos \varphi}{1000} \eta_{dB}\eta_{uz} $$  

where $J$ is the current strength, $A$; $U$ is the voltage, $V$; $\cos \varphi$ - power factor of the electric motor; $\eta_{dB}$ - motor efficiency; $\eta_{uz}$ - transmission efficiency.

The pump efficiency is determined from the formula:

$$ \eta_H = \frac{N_H}{N} < 1 $$  

where $N_H = 9.81QH$ – power consumption of the pump, kW.
When conducting parametric tests, cylindrical measuring tubes were used to measure the pump flow. Because the accuracy of their measurement is relatively high (3% error). They are simple and reliable in operation.

The principle of operation is to determine the pressure head due to the difference between the total and hydrodynamic heads at the measurement point.

Here, the hydrodynamic pressure over the cross section is assumed to be constant [9],[11]. When conducting studies to measure speed at the measurement point, a tube in the side wall in the form of a “probe” was used. The diameter of the measuring tube was determined from the condition of preventing vibration when the flow through it. The diameter of the measuring tube was taken equal to \( d = 0.025D_T = 0.025 \cdot 600 = 15 \text{ mm} \), and the diameter of the holes was equal to \( d_0 = 0.2D = 0.2 \cdot 15 = 3 \text{ mm} \). (figure 1).

![Figure 1. Cross section of the device. 1- cylindrical measuring tube; 2- measuring point of hydrodynamic pressure; 3- differential pressure gauge; 4-gland; 5-pressure line [9],[11].](image)

A gland is put on the measuring tube, and the gland casing is welded to the pressure pipe. The union is welded at an angle of 90° from the top of the measuring hole in the pressure pipe, 2 ... 3 times higher than the diameter of the measuring tube. A measuring device is connected to the union for measuring the average hydrodynamic pressure using a pressure rubber hose. As a measuring device, a spring manometer was used. From the readings of the two installed pressure gauges, the difference in readings is determined.

The flow rate in the pressure pipe is determined by the formula:

\[
v = k\sqrt{2g\Delta h}
\]

where \( k \) is the correction factor; \( \Delta h \)- pressure difference m. of water. Art.

The considered method allows to determine the average speed and flow rate of water in the pipeline:

\[
Q = v_{as} \cdot \omega
\]

where \( \omega = 0.785D_T^2 \) \( \omega \) is cross-sectional area, \( m^2 \).

In a circular pipeline in a developed turbulent flow, the average velocity is determined at a distance from the pipeline wall equal to \( 0.24R_m = 0.24 \cdot 300 = 72 \text{ mm} \), where \( R_m \) \( R_T \) is a pressure pipe radius.
The pump flow is increased by changing the position of the valve on the pressure pipe 6 ... 8 times, and at the same time, the readings of the above instruments are measured and the characteristics of the 18 NDs pump are built from the obtained values.

The developed design of the water acceptance chamber with a sediment flushing device was tested at the pump station. The wall is installed at a distance \( L_0 = (0.26 ... 3)D_i \) from the inlet of the suction pipe of the pump at an angle of 25 ... 30º relative to the bottom of the chamber.

Due to the installation of an inclined guide wall, the level difference is \( \Delta h = (0.08 ... 0.1)D_i \), where \( D_i \) is the diameter of the inlet of the suction pipe. To reduce the difference in water levels \( \Delta h = 9 ... 11 \) cm from the influence of the guide wall, through holes of rectangular cross-section are made in it with a width of \( D_i \), a height of 0.2\( D_i \), and a cross-section of \( \omega_0 = 0.2D_i^2 \).

At the pumping station, 2 pumping units (1 spare) of the D2000-34 brand (18NDs \( n = 750 \) rpm) with a minimum suction height \( h_s = 0.5 \) m were installed. The dimensions of the water acceptance chamber for testing are as follows: \( B_k = 1.65D_i \); \( L_k = 6.5D_i \); \( h_1 = 0.6D_i \); \( h_2 = 0.725D_i \); \( L_0 = 2.5D_i \); \( \phi = 27^\circ \); \( D_i = 0.6 \) m \( \phi = 27^\circ \), which corresponds to a chamber length of 4 m, a width of 1 m, a height of 2 m.

During operation of the pumping station, a rapid siltation of the water acceptance chamber occurs. The studies were carried out according to three options: option 1 - with siltation of the chamber, option 2 - after flushing sediment deposits from the chamber; Option 3 - for a camera with a mounted guiding wall and a sediment flushing device (figure 2).

![Figure 2. Water acceptance chamber with the guide wall and sediment flushing device.](image-url)

3. Results and discussion

The obtained characteristic of the pump \( H_f = f(Q) \) is the actual characteristic of the pump with the “oblique” approach of the flow to the water intake chamber. To determine the working point of the pump, the characteristic of the pipeline \( H_{tr} = f(Q) \) is built, the point of its intersection with the characteristic of the pump will give the working point of the pump.

When the flow approaches the water acceptance chamber in front of the impeller of the pump, a transverse circulation forms in the flow, as a result of which the pressure and flow of the pump change. With the coincidence of the direction of circulation in the flow and the direction of rotation of the impeller, the pressure decreases, and when their directions are opposite, an increase in pressure is observed. For pumps installed at the pumping station, the impellers rotate in one direction, and the transverse circulation in the flow in front of the impeller can have different directions. Depending on
the location of the pump unit along the front of the intake chambers, the direction and magnitude of the circulation depend [6], [7], [9], [15], [16], [17], [18], [19], [20].

The change in pump flow, which occurs due to a change in the transverse circulation in the flow, depends on the characteristics of the pump $H = f(Q)$ and the hydrodynamic characteristics of the pipeline $H_v = f(Q)$. When the magnitude of the geodetic lifting height is large and the length of the pipeline is small, the amount of hydraulic loss will be small, but the change in pump flow will be significant. If the geodetic height of the lift is small and the pipeline is long, then the change in pump flow will be negligible.

Research was conducted when the pump unit operates without stopping. At this time, the amount of sediment deposited (siltation volume) amounted to 20 ... 22% of the total chamber volume, siltation thickness reached 0.6 ... 1 m, and around the suction pipe was 0.24 ... 0.5 m.

Based on the results of the experiments conducted on 1 unit, the characteristics of the pump are constructed to determine the operating point and graphs of the dependence of the resistance coefficient on the pump supply (figure 3, figure 4).

![Figure 3. Comparison of the design operating mode of the pump D2000-34 (18NDs n = 750 rpm) with the data of field tests.](image)

$H$, $N$, $H^\text{per}_{\text{vak}}$, curves of pressure, power, permissible suction height and efficiency of the pump according to the factory characteristics; $H^1$ - actual pressure characteristic of the pump at the time of research; $H_p$, $H^\text{per}_p$ - hydrodynamic curve of the pipeline; $A$ is design operating point of the pump; $B$ is the operating point of the pump during siltation of the water intake chamber; $C$ is the working point of the pump when the guide wall is installed in the water acceptance chamber with sediment flushing device.

Due to the use of a water acceptance chamber with the guide wall and a sediment flushing device to washing off sediment deposition, the hydraulic resistance decreases when the flow enters the suction pipe, therefore the pump flow from 424 l/s increased to 476 l/s, i.e. increased by 52 l/s.

From the graph shown in Fig. 4, it can be seen that the resistance coefficient $\xi$ for the chamber with sediment deposition is $\xi = 0.61$, and when the sediment is washed off, it is $\xi = 0.491$. When installing the guide wall with the sediment flushing device, the resistance coefficient of the suction pipe decreased by 42.6% compared to a typical chamber, and by 55.3% relative to the sediment chamber.
The graph of the dependence of the resistance coefficient of the suction pipe on the supply of the pump brand D2000-34 (18NDs n = 750 rpm). 1 - for the chamber with sediment deposition; 2 - for a typical chamber with sediment flush; 3 - for the chamber with the guide wall and the sediment flushing device.

For the developed design of the water intake chamber, based on the results of field studies, an increase in the pump efficiency is determined:

$$\Delta \eta = \eta_2 - \eta_1 = 9.81 \left( \frac{Q_2 H_2}{N_2} - \frac{Q_1 H_1}{N_1} \right) \cdot 100 = 9.81 \left( \frac{0.476 \cdot 34.5}{200} - \frac{0.424 \cdot 33}{184} \right) \cdot 100 = 5.9\%$$

where $Q_1$ and $Q_2$, $H_1$ and $H_2$ - accordingly, the supply and pressure of the pump before and after the installation of the guide wall with the sediment washing device in the chamber; $N_1$ and $N_2$ - power consumption of the pump unit for a typical and developed design of the chamber (determined by the readings of the ammeter and voltmeter).

The results of laboratory and field studies showed good convergence, according to the developed design, the pump efficiency increased by 5.9%, and the flow rate increased by 12.2% in relation to a typical chamber.

As mentioned above, the formation of a uniform flow structure in the water acceptance chamber and in front of the suction pipe will make it possible to create a uniform circulation-free velocity field at the impeller of the pump. One of the options for achieving this goal is possible by installing the guide wall in a water acceptance chamber with a sediment flushing device. The presence of the guide wall prevents transverse circulation in the flow, and also creates the possibility of erosion of individual circulation flows, speed equalization after the guide wall.

4. Conclusions
1. The guide wall in the water acceptance chamber evens out the flow in front of the pump suction pipe and reduces the likelihood of various circulating flows forming behind the wall.
2. Resistance coefficient $\xi$ for the chamber with sediment deposition is $\xi = 0.61$, when washing off sediment is $\xi = 0.491$. When installing the guide wall with the sediment flushing device, the resistance coefficient of the suction pipe decreased by 42.6% compared to the typical chamber, and by 55.3% relative to the sediment chamber.
3. The operation of the pump with the guide wall in the water acceptance chamber and the sediment flushing device increases the pump flow by 12.2%, and the efficiency by 5.9%, and reduces operating costs.
4. Due to the use of a water acceptor with a guiding wall and a sediment flushing device, the hydraulic resistance at the flow inlet to the suction pipe decreases, so the pump flow from 424 l/s increased to 476 l/s, that is, increased by 52 l/s.
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