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Forebays of the polygonal cross-section of the irrigating pumping station

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Abstract. The article discusses the use of the design of the forebays of a polygonal cross-section to improve the hydraulic characteristics of the water intake structures of pumping stations, in which the longitudinal slope in the direction of the middle chamber is $i = 0.1$, the adjacent longitudinal slope is 0.15 and with the extreme chambers the longitudinal slope is 0.2 . The faces of each chamber with a forebay have a transverse slope equal to $i_c = 0.1$ and the angle of taper of the forebays in the plan is $\alpha = 35^\circ$. In the joint operation of 5 pumps, for the forebays of a polygonal cross-section, the total resistance coefficient is $\sum \zeta_{total\ ext.} = 0.568$ and for a typical $\sum \zeta_{total\ ext.} = 0.72$. With the simultaneous operation of 5 pumps, the average supply of 3 pumps is $0.0051\ m^3/s$, 2, and 4 pumps, respectively $0.00498 \dots 0.00504\ m^3/s$, for 1 and 5 pumps, 0.00478 , and $0.00481\ m^3/s$, respectively at the extreme pumps, the flow rate increases by $4.9 \dots 6.3\%$ relative to the standard forebays.

1. Introduction

In some cases, the construction of new water intake facilities is not possible, which entails the need to choose other alternative technical solutions to mitigate the problems encountered during their operation, such as bottom sediment entering the water intake structures and the unsatisfactory hydraulic mode of operation of the extreme water intake chambers and, as a consequence, the supply of extreme pumps below design. The design of several water intake structures of the National Assembly, built decades ago, was carried out using calculation methods that far from meet modern requirements. Therefore, for the rational operation of old pumping stations, it is necessary to refine the data on the operating modes that have developed on them and take them into account in the practice of water supply and environmental protection, as well as the use of sediments as reclamants [1–6].

In this regard, in solving problems of improving the operation of the water intake structures of the National Assembly it is necessary to carry out studies that make it possible to compare the designed operation mode of the pumping station facilities with the actual operating conditions during operation, and also to obtain data on the mode that ensures its most efficient operation [7,8,9,10,11].

A uniform approach to the water intake eliminates the occurrence of a velocity moment at the inlet to the impeller blades and thereby stabilizes the operation of pumps, especially axial ones [8,12].

2. Methods



To establish a favorable hydraulic mode of operation of the forebays and water intake chambers, experimental studies were carried out in a laboratory setup according to three options [10, 11]. In these variants of the model, the forebays are structurally identical: the central angle of taper $\alpha = 35^\circ$, the slope of the bottom $i = 0.2$, the depth of the inlet of the suction pipe under the water horizon h_2 is the same and set horizontally concerning the rear wall of the chamber.

Forebays differ only in the width of the intake chamber, for the 1 variant, the chamber width $b_{cam} = 2D_{in}$ for the 2 variant is $b_{cam} = 1.2D_{in}$, where D_{in} is the diameter of the inlet of the suction pipe. Therefore, the length of the forebays is respectively m and m. According to option 3, the forebays are of a polygonal cross-section in which the longitudinal slope in the direction of the middle chamber along the bottom of the chambers is $i = 0.1$ and the longitudinal slope adjacent to it on both sides 2 and 4 of the chamber is 0.15, at the extreme forebays 1 and 5, the longitudinal slope with the forebays is 0.2. Besides, the faces of each chamber with an advance chamber have a transverse slope, so 1 and 2 chambers located from 3 forebays on the right have a transverse slope equal to $i_c = 0.1$ and the 4 and 5 forebays located on the left have a transverse slope equal to $i_c = 0.1$. The slope of the bottom of the forebays in this design, together with the activation of the bottom flow, reduces sediment deposition in it. The cone angle of the forebays in the plan is $\alpha = 35^\circ$ (Figures 1 and 2). The width of the water intake chamber is taken equal to $b_{cam} = 1.2D_{in}$ or is assumed to be the same as in option 2, where the length of the forebays is equal to $L_{fore} = 0.81$ m [13, 14, 15, 16].

The experiments showed that the spreading of the flow does not occur along the axis of the chamber, as a result of flowing around the gobies at an angle that leads to the formation of whirlpool zones. Whirlpool zones are formed in the outer chambers with a joint operating mode of 5 and 4 (1 + 2 + 3 + 4), 3 (1 + 2 + 5), 2 (1 + 2), 2 (1 + 3), 2 (1 + 5) pumps and 1 (1) pump. To prevent funnel formation, it is recommended to install flow guiding devices at the entrance to the chamber, but they worsen the operating conditions of the chamber. Besides, the oblique flow inlet into the chamber leads to an increase in hydraulic resistance [17].

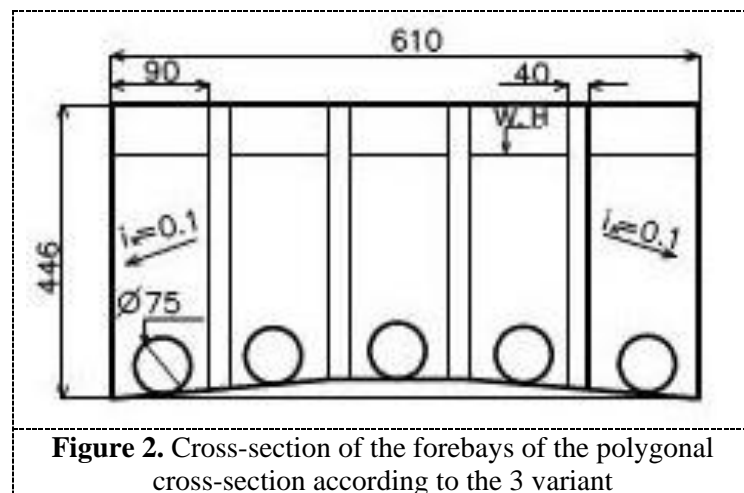
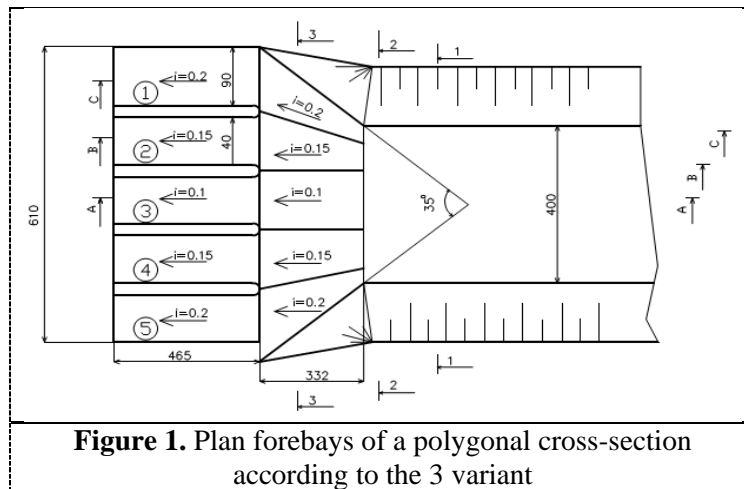
This dictates the need for research and development of the design of water intake structures providing a direct supply of flow to the water reception chambers and uniform spreading in the tank.

According to some researchers, the sudden expansion of the flow leads to the formation of two corresponding characteristic sections: 1 section is the distance from the beginning of the expansion of the stream to the center of the vortex zones, this distance is approximately equal to $2/3$ of the length of the vortex zones, in this section the flow gradually expands. The boundary of the transit flow is usually straight in the plan, the bending line relative to the axis of the channel is very small.

A.G. Solovyova in a laboratory setup researched various roughnesses, changing the ratio of channel width b to channel depth h in a ratio of 4 to 10 [6]. According to her data, the angle φ between the channel axis and the transit flow in the first section varies from 2° to 8° , with increasing roughness φ increases, and with a decrease in the b/h ratio, the angle φ decreases. According to A.G. Averkiev, the length of the first section is $\frac{2}{3}l_2$ [18]. In our experiments, the 2 site is from the center of the whirlpool to the end of the expansion zone; its length is $1/3$ of the length of the whirlpool. According to the research of A.G. Solovieva, in this section there is a sharp expansion of the flow, the boundary of the transit flow is a curved line in the form of a slash [17].

In studies, extended flow spreading is forced, due to the operation of pumping units, the boundary between the transit flow and the whirlpool does not have a vertical cross-section, so it is impossible to show any kind of line in the plan. The surface and bottom flow do not participate in the water supply of the intake chambers, but in depth, the layer of the stream in the center is closest in position to the expanding stream in the simple case.

To activate the flow in the bottom part of the fore chamber and to evenly spread the flow into the water intake chambers, as well as to reduce the angle of entry, a new design of the water intake construction of the polygonal cross-section was developed (Figure 1 and 2) [19, 20, 21].



The sidewalls of the extreme 1 and 5 chambers with a feed channel are connected using a vertical wall. Therefore, the sidewalls of the chamber in the initial part under a slope, further along, the length gradually passes into a vertical position. The cross-section of the chamber is polygonal or represents the shape of a polygon (Figures 1 and 2).

3. Results and discussion

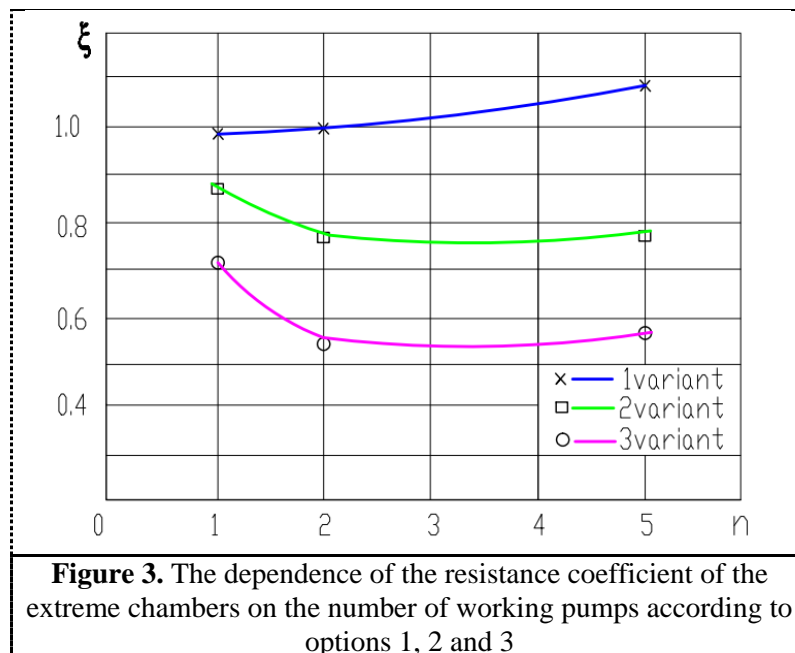
The experiments showed that the volume of the transit flow and the whirlpool zones significantly change in the 3rd version of the fore chamber. The direction of the bottom flow located in the gap in the center of the fore chamber coincides with the axis of the middle and extreme chambers. This phenomenon is observed in all pump operation modes. The angle of entry of the flow into the extreme chambers is approximately 6...80, which is established experimentally.

Slight flow rounding affects the camera mode. In all operating modes of the pumping station in the central and extreme chambers, the formation of whirlpool zones decreased. This indicates a shockless flow inlet into the water intake chambers. The determination of hydraulic resistances according to option 3 in the tank and water intake chambers was carried out in the same way as in options 1 and 2.

At the beginning of the fore-chamber, there is 1 measuring cross-section, and the 2nd target is taken 10 sm inland from the entrance of the water intake chamber. In the 3rd version, flow spreading in the fore chamber and the formation of whirlpool zones were studied with a different combination of the number of working pumps.

The results of the studies show that in the joint operation of 5 pumps, in version 3, the total coefficient of resistance is $\sum \xi_{tot.ext} = 0.568$, and in version 2 $\sum \xi_{tot.ext} = 0.72$, or a decrease in the coefficient resistance amounted to $\Delta \sum \xi_{tot} = 0.152$. In the middle chamber, in the 3rd variant, $\sum \xi_{tot.aver} = 0.163$, and in the second variant, $\sum \xi_{tot.aver} = 0.159$ or the decrease in the resistance coefficient is insignificant. The sum of the resistance coefficients $\sum \xi_{tot} = 0.364$ (in option 3) and $\sum \xi_{tot} = 0.428$ (in option 2) a decrease of $\Delta \sum \xi_{tot} = 0.066$ (Figure 3).

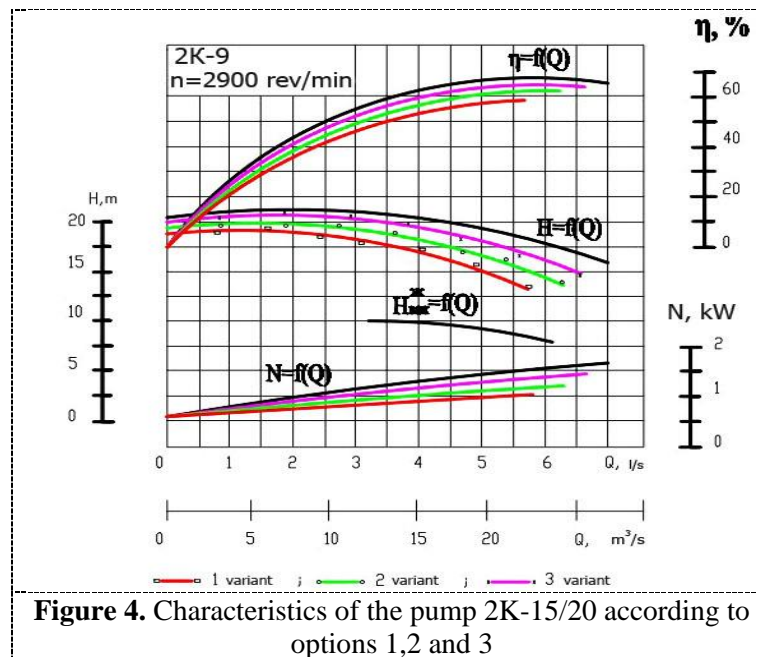
In working pumps according to scheme 2 (1 + 2) and 1 (1), a decrease in the resistance coefficient in the extreme chambers was also observed. During the operation of the average pump 1 (3), the resistance coefficient changed insignificantly.



On the section of the advance chamber and water intake chambers, a decrease in the pressure loss occurs due to the improvement of the conditions of the flow inlet to the outer chambers. Since the length of the chambers is constant, the pressure loss in it relative to the 2 options is almost unchanged [22].

When conducting experiments according to option 3, the amount of sediment in the whirlpool relative to option 2 is 1.5 times, and relative to option 1, it is 2.2...2.4 times less.

The expansion of the flow in plan and vertical activates the bottom flow of the fore chamber, reduces the degree of expansion of the transit flow, and the degree of decrease in speed, and sediment deposition in it decreases. During the experiments, the flow and pressure of the pump were measured. With the simultaneous operation of 5 pumps, the average supply of 3 pumps is $0.0051 \text{ m}^3/\text{s}$, 2, and 4 pumps, respectively $0.00498...0.00504 \text{ m}^3/\text{s}$, for 1 and 5 pumps, respectively 0.00478 and $0.00481 \text{ m}^3/\text{s}$ (Figure 4).



4. Conclusions

1. The spreading of the flow in the forebays of the polygonal cross-section creates a uniform distribution of the bottom flow into the water intake chambers and due to a decrease in the angle of rotation at the inlet, the transverse circulation in the flow near the suction pipe disappears and the hydraulic resistance decreases.
2. In the forebays of a polygonal cross-section with simultaneous operation of 5 pumps, the average supply of 3 pumps is $0.0051 \text{ m}^3/\text{s}$, 2, and 4 pumps, respectively $0.00498 \dots 0.00504 \text{ m}^3/\text{s}$, 1 and 5 pumps, respectively 0.00478 and $0.00481 \text{ m}^3/\text{s}$.
3. During the joint operation of 5 pumps, in version 3 the total coefficient of resistance is $\sum \xi_{total\ ext} = 0.568$, and in version 2 $\sum \xi_{total\ ext} = 0.72$, or the decrease in the coefficient of resistance is $2 \sum \xi_{total\ ext} = 0.152$.
4. In the forebays of a polygonal cross-section, the supply of 3 pumps does not change, but for 1 and 5 pumps, 5.7...6.3% relative to 3 pumps and 1.2...2.4% less for 2 and 4 pumps water supply. The supply of extreme pumps 1 and 5 relative to the 2nd option is 4.9...6.3% and relative to the 1st option it increases by 9.4...10.3%.

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