Design parameters of water intake chambers on water supply channels of pumping stations

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Abstract. The research is devoted to improving the working conditions of chamber water intakes of pumping stations (PS) on water supply channels, which is one of the main factors determining the efficiency of operation of pumping units and stations. An analysis of the current state of the operating conditions of chamber water intakes according to field surveys and literary sources shows that the dimensions of the water intake chambers were assigned based on the minimum energy loss in the suction pipeline of the pump, which, in conditions of high turbidity of water, leads to siltation and complicates the operation of pumping stations. When the water intake chambers are silted, its hydraulic resistance increases, air vortex funnels are formed, the water supply of the pump decreases and the likelihood of cavitation phenomena increases. A significant amount of work has been devoted to the issues of improving the hydraulic characteristics of the flow in the fore chamber and water intake chambers. Therefore, without duplicating them, we conducted research to establish the effect of silting of the chambers on the value of the hydraulic resistance of the suction pipeline and to develop measures to improve the hydraulic characteristics of the intake chamber under conditions of operation in a suspension-carrying flow. To solve the problem, a laboratory stand was made that simulates hydraulic processes in natural conditions based on modeling methods, taking into account the preservation of the constancy of the main similarity criteria.

1 Introduction

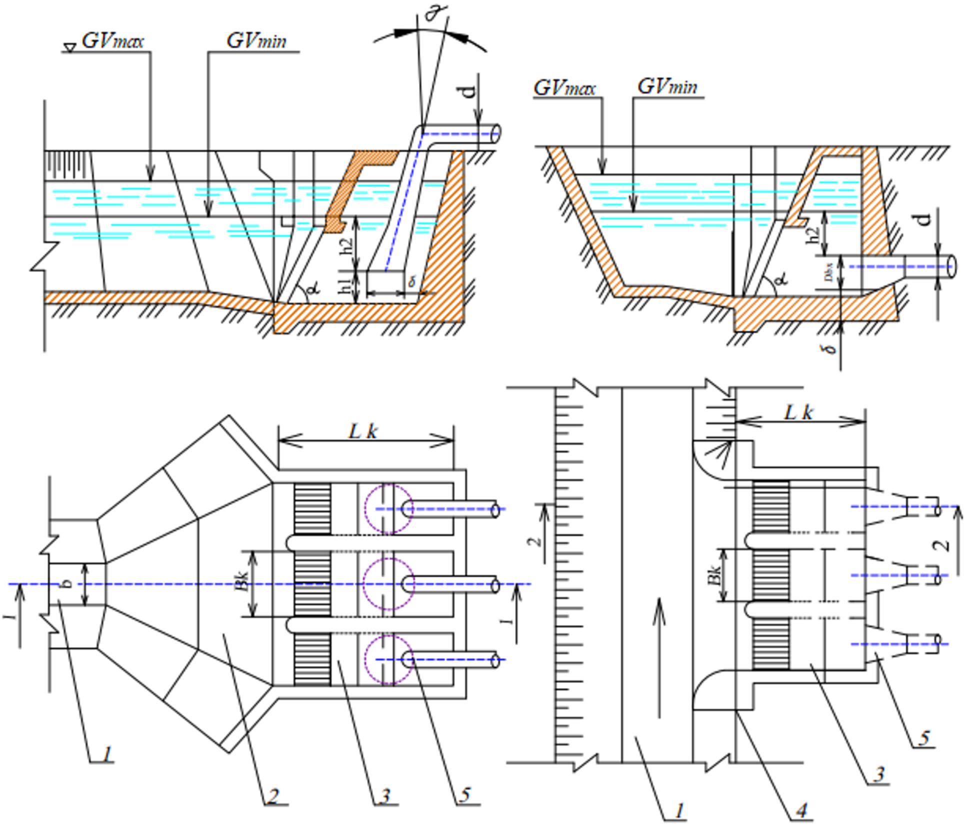
The water intake structure of pumping stations (PS) on water supply channels consists of an antechamber and water intake chambers (water inlet). In the practice of design and operation, direct, in some cases, lateral water intakes have found the greatest application (Fig. 1). Field surveys conducted by us, as well as studies carried out by other researchers [1-5], found that the efficiency of operation of pumping units largely depends on how rationally their water intake structures are designed, especially when pumping muddy water.

The analysis shows that the improvement of the hydraulic characteristics of the water intake devices of pumping stations (PS) can be solved by two areas of research:

1) Development of the most rational design of the antechamber in order to evenly distribute water over all water intake chambers;

2) Improving the structure of the flow in the intake chamber, i.e. in front of the suction pipe of the pump.

A number of papers [3-6] are devoted to the issues of rational design and improvement of hydraulic processes in the fore chambers of pumping stations (PS), in order to reduce whirlpool zones, and to a large extent, it was possible to solve the problem. Therefore, we did not consider the issues of studying the fore chambers. There are not enough works devoted to the second direction; although in [5] an attempt was made to create a uniform non-circulating velocity field by installing a cellular damper in the water intake chamber. But in this case silting of the chamber is not considered.



a) section 1-1 *b) section 2-2*

Fig.1. Direct (a) and lateral water intake (b) from the channel: 1-inlet channel, 2-fore-chamber, 3-water intake chamber, 4-bucket, 5-suction pipe of the pump

In conditions of increased turbidity of the pumped water, the use of cellular dampers leads to even more serious difficulties in the operation of water intakes of pumping stations (PS).

In this paper, questions are considered in the second direction - the study of the possibility of creating a favorable velocity field, which ensures a decrease in the hydraulic resistance of the suction line and siltation of water intake chambers with a vertical arrangement of suction pipes.

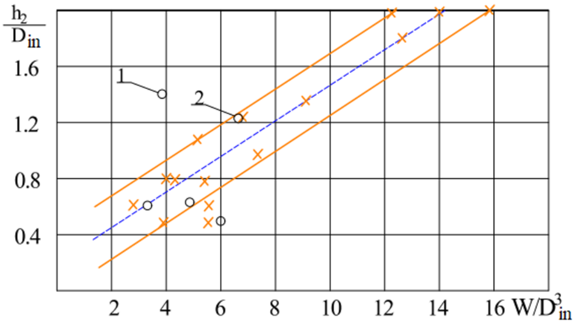
On the basis of the conducted field surveys, we have compiled graphs of changes in the relative sizes of water intake chambers from their relative volume for a number of existing pumping stations (PS) in the Fergana Valley (Fig. 2). The graphs show that the distance from the inlet edge to the bottom of the chamber is $h_1 = (0.6\text{-}0.8)\ D_{in}$ and is a constant value, i.e. does not depend on the relative chamber volume $W/\ D_{in}$.There is a tendency to increase the width of the chamber from $B_{kam} = 1.1\ D_{in}$ to $B_{kam} = 3D_{in}$, as well as the penetration of the leading edge under the minimum water horizon from $h_2 = 0.5D_{in}$. up to $h_2 = 2\ D_{\text{вх}}$. depending on the increase in chamber volume [8,9,18,19]. The increase in the depth of the inlet section of the suction pipes is associated with the need to combat the occurrence of vortex air funnels when the chambers are silted. It should be noted that the cause of funneling at the inlet to the suction pipeline has not been studied enough. Vortex air funnels arise at certain ratios of the dimensions of the water intake chamber and the suction pipe, the speeds at the approach and at the inlet to the pipe, as well as the water levels in the chamber [8,9,18,19]. Therefore, the values of h_2 recommended by various authors also have significant discrepancies. At the same time, the experience of operating full-scale pumping stations (PS) shows that when vortex air funnels are formed, the water supply of the pumps decreases and their vibration sharply increases, which is undesirable from the point of view of the reliability and durability of the units [3,10,11,12,20].

2 Research methodology

An analytical method for determining the design of water intake chambers prevents sedimentation around the suction pipeline and improves the hydraulic characteristics of the flow before entering. The generally accepted methods for calculating laboratory and field tests of various designs of water intake chambers with centrifugal pumps of the "D" type (grades D4000-95) were used.

3 Results and discussion

Leading foreign firms recommend the following values of the minimum penetration of the pipe inlet section: Alta (France) $h_2 = 1.5D_{in}$, Ganz-Movat (Hungary) $h_2 = (0.75\ldots1.2)\ D_{in}$ [15] and firm "Ebara" (Japan) $h_2 = (1 \div 1.8)\ D_{in}$ [7]. As you can see, these recommendations also have discrepancies. Based on the analysis of the works of previous researchers [13,14,16,17,18] and surveys of chamber water intakes of existing full-scale pumping stations (PS), it should be noted that there are a number of issues that require research, in particular



a)

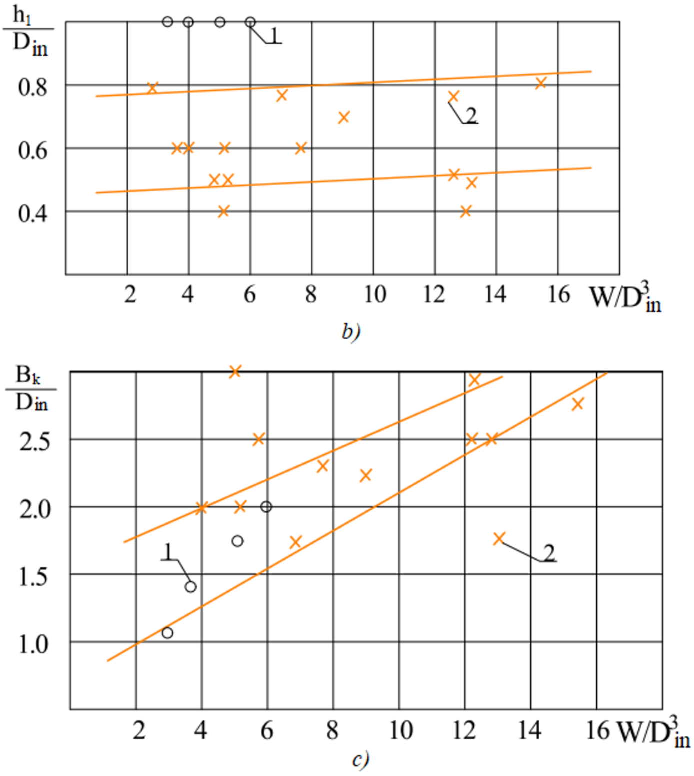


Fig 2. The value of the penetration of the inlet section of the pipe (a), the growth from the inlet section to the bottom of the chamber (b), and the width of the chamber (c) depending on its volume: 1- with a horizontal pipe, 2 - with a vertical pipe

1) the dimensions of the intake chambers were assigned on the basis of the minimum energy loss in the suction pipeline of the pump, which, in conditions of high turbidity of water, leads to their silting and complicates the operation of pumping stations (PS), especially with a vertical arrangement of pipes in the chamber;

2) the influence of sedimentation in the intake chamber on the hydraulic characteristics of the suction pipeline and pump has not been sufficiently studied;

3) there are no sufficiently substantiated and effective design solutions for leveling the flow in the water intake chambers, since the “oblique” approach of water to the water intake chambers worsens the operating conditions of the outermost pumps due to the uneven circulation velocity field in it [19];

4) it is required to develop specific measures to improve the operating conditions of the water intake chambers of pumps with high turbidity of the pumped water.

Simulation conditions, as well as experimental and laboratory studies were carried out in order to develop the design of water intake chambers, providing favorable hydraulic conditions for supplying water to the inlet sections of the suction pipe. The laboratory unit is made in accordance with the simulation of the hydraulic process in natural conditions.

If we take into account that the laboratory model of the water intake structure is made on a reduced scale, and the tests are carried out on water, then all the conditions of kinematic and dynamic similarity will not be met. Therefore, it is necessary to strive to meet the most important criteria for the similarity of the fluid flow. It is known that the flow regime in the water intake chamber is stationary, and therefore the Strouhal criterion

"Sh" can be ignored. In the water intake chamber, the flow is open and uneven. Here it is necessary to ensure the equality of the Froude criterion of the model and nature, since under such conditions the nature of the flow is determined by the forces of gravity and inertia. To eliminate the influence of the Reynolds criterion, laboratory experiments should be carried out with the flow regime corresponding to the zone of the self-similar region, i.e. when $Re_{,m} > Re_{,gr}$ – Reynolds number corresponding to the lower boundary of the self-similarity zone. The Euler criterion in the absence of a pressure drop on the free surface is equal to zero and does not affect the position of the shape of this surface [16].

The Froude number for the considered stations is Fr =0.0006….0.009. It was noted in [16, 26] that the Froude criterion is not decisive, since in case of non-uniform flow the averaged characteristics of the open flow do not depend on it. It is also noted that at Froude numbers Fr < 0.1, the change in the relative length of the whirlpool with a sharp one-sided expansion of the flow is insignificant [16]. The author of [5], using the results of the works of previous researchers, argues that when the Froude number changed by more than 30 times, the hydraulic resistance coefficient of the suction pipe was practically constant, i.e. the hydraulic characteristics of the flow in the intake structure do not depend on the change in the Froude number Fr.

Based on the foregoing, it was stated [5] that the main indicator of similarity in the case under consideration is the identity of the resistance coefficients of the model and nature ξ = idem. In this case, it is necessary to maintain the geometric similarity and similarity of the kinematic boundary conditions, as well as to comply with the conditions for ensuring the self-similarity of the flow movement in the water intake chamber, i.e. $Re_{,m} > Re_{,gr}$.

Using the technique described in [17], we determine the minimum scale of the model:

$$M_{\min} = \left(\frac{\mathrm{Re}_n}{\mathrm{Re}_m}\right)^{3/2} = \left(\frac{1.26\cdot 10^6}{8.3\cdot 10^4}\right)^{3/2} = 59 \qquad (1)$$

Where, Re_n is the Reynolds number for full-scale pumping stations. For example, for a pump brand D4000-95 (22NDs) with a suction pipe diameter $Dv,n\ =\ 0.9\,m,\ Re,n\ =\ 1.26\cdot 10^6$. Re_m is the boundary Reynolds number for a model that provides a self-similar resistance region:

$$\mathrm{Re}_m = \mathrm{Re}_{avt} = \frac{10^4}{\varepsilon_0} = \frac{10^4}{0.12} = 8.3\cdot 10^4 \qquad (2)$$

Where, ἐ$_o$ is the degree of turbulence according to [17, 30] in the outlet section of the confuser of the suction pipe έ$_o$ = 12-28.

The geometric scale of the model with the outlet diameter of the suction pipe $d_{v,m}$ = 0.075 m is taken:

$$M = \frac{Д_{v,n.}}{d_{v,m}} = \frac{0.9}{0.075} = 12 < M_{\min} = 59 \qquad (3)$$

The allowable scale of the model $M_{\min}$ was checked in the same way, according to the empirical formula [4, 31]:

$$M_{\min} = (30...50)\sqrt[3]{V_n^2\, R_n^2} = (30...50)\ \sqrt[3]{0.208^2\cdot 0.774^2} \approx 9...15 \approx 12 \qquad (4)$$

Where, V_n is the flow velocity in the water intake chamber of nature, for example, for the D4000-95 pump, Turakurgan-1 pumping station (PS), $V_n = 0.208$ m/s.

The resulting allowable scale of the model corresponds to the accepted scale of the model $M = 12$.

The equality of the resistance coefficients of the model and nature can be ensured only if the roughness is geometrically similar. We observed the approximate equality of the Chezy coefficients of nature and the model $C_n = C_m$, corresponding to the similarity of hydraulic resistances. In nature, the chamber walls are with concrete lining, and the roughness coefficient is - $n = 0.017$; on the model, the chamber walls are made of planed boards, painted with oil paint twice and $n = 0.012$. With a hydraulic radius $R_m = 0.073$ m and $R_n = 0.774$ m, the values of the Shezy coefficients $C_m = 54.5$ and $C_n = 57.6$, which have approximately the same values. On the basis of the adopted scale of the model $M=12$, the dimensions of the intake chamber model were determined according to the diameter of the design section of the suction pipeline $d_{v.m} = 0.075$ m. The values of the Froude numbers Fr and Reynolds Re for the model were determined, calculated for the flow in the intake chamber. At model flow rate $Q_m = 3.5 \ldots 22$ m/s, $Fr_{,m} = 2.7 \cdot 10^{-3} \ldots 10.5 \cdot 10^{-2}$ and $Re_{,m} = 0.26 \cdot 10^{3} \ldots . 3.4 \cdot 10^{4}$, if the minimum water depth in the chamber $h_{k,min} = 0.21$ m is provided. then $Fr = (2.7 \ldots 10.6) \cdot 10^{-3}$.

At the minimum depth $h_{k,min} = 0.21$ m, the self-similar resistance area occurs at $Q \geq 7$l/s, i.e. then $R_{e,m} \geq 1.08 \cdot 104 > Re_{,gr} = 104 \ldots 2 \cdot 104$ [14,32]. Therefore, it was decided to carry out the main part of the research on the model at $Q = 7 \ldots 12$ l/s, taking into account the change in the flow depth h_k up to 0.3 m.

Model studies were carried out on a specially assembled experimental setup. Fig. 3. shows an experimental setup consisting of the following elements:

1) tank 1, installed at a height of 4 m from the floor surface and having a length of 3.5 m, a width of 2 m and a depth of 0.8 m. The tank has several stilling walls 15, an adjustable overflow wall 5 made of wooden boards and a discharge pipe 6. It houses a water intake chamber 2 with a suction pipe head 3. A piezometer 13 is connected to the tank;

2) confuser head 3 of the suction pipe with an inlet section diameter $Д_{в.х} = 0.15$ m and an outlet diameter $d = 0.075$ m, 0.3 m long, made of iron sheet 0.7 mm thick. At the end of the confuser head there is a pressure sampling chamber 12, made of steel, having four opposite holes for connection to piezometers 14;

3) the siphon pipeline 7, connected to the head of the suction pipe 3, serves to suck water from the tank 1. Flow control is carried out using the valve 9;

4) lower tank 10 with a stilling wall and a weir to determine the flow rate Q;

5) tank-trolley 11 with a volume of 200 l moved along the rail for determining the flow rate by volumetric method;

6) pump 4 brand 4K-90/35 (4K-12), which supplies water from the lower pool to tank 1 through pressure pipe 16. The pump flow is measured using differential pressure gauge 17 connected to diaphragm 18 and is regulated by valve 19.

piezometers 14 connected to the pressure sampling chamber 12.

The operation of the installation and the measurement of the necessary parameters were carried out in the following order. Water from the lower pool is supplied to tank 1 using a pump 4 through a pressure pipeline 16. The water level in tank 1 and water intake chamber 2 is provided by replaceable wooden shields 5 and a discharge pipe 6. pouring" of all lines of piezometers 14 and the water levels on them are set at one mark. Further, by opening the valves 9 with the help of a weir installed in the lower tank 10, a given water flow is provided.

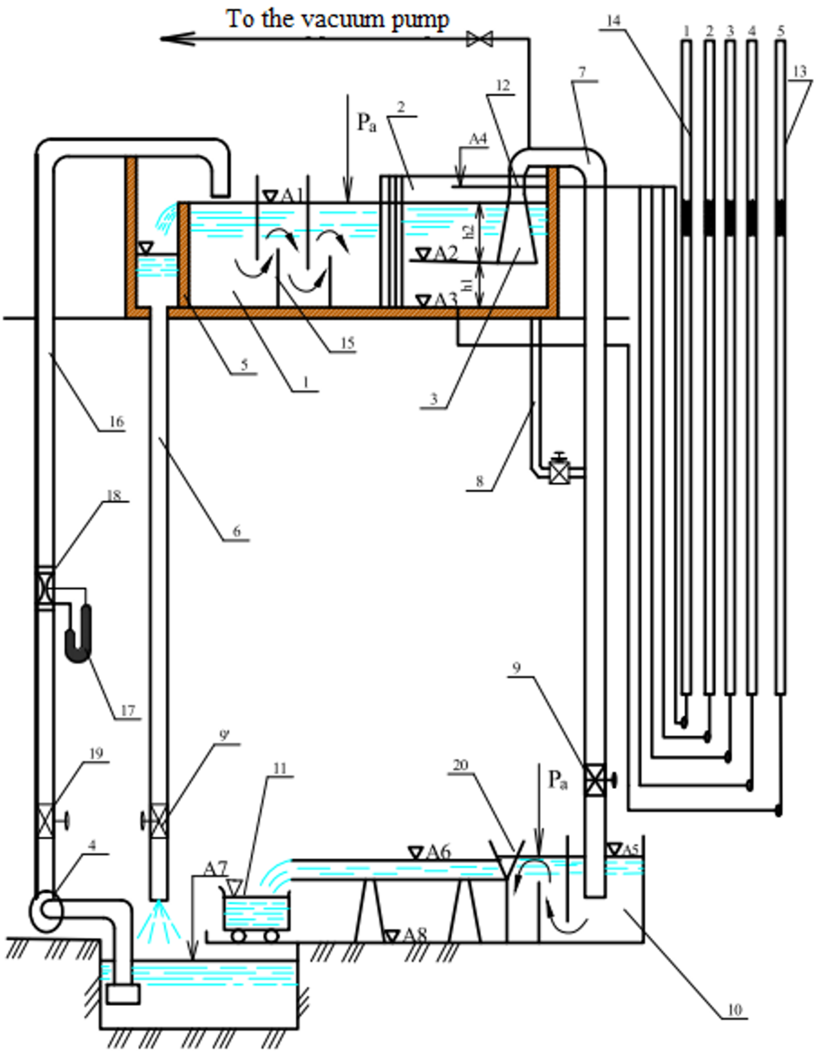


Fig 3. Scheme of the experimental stand for the study of the water intake chamber

For this, the heads h above the edge of a triangular weir with a sharp edge were measured and calculated by the formula:

$$Q = 1.343\ h^{2.47} \quad m^3/s \tag{5}$$

The siphon flow rate was checked by a volumetric method using a 200-liter trolley tank 11, which is mounted on rails. Also, comparisons were made of the flow rates determined by the diaphragm with a spillway with a sharp edge. The flow rates determined by the weir and diaphragm gave discrepancies of no more than ± 3%.

4 Conclusions

1. The proposed design of the water intake chamber of pumping units with a jet guide wall makes it possible to reduce operating costs by reducing the hydraulic resistance at the

inlet to the suction pipeline and contributes to the formation of a dead zone around the vertical suction pipeline, which leads to a decrease in the depth of penetration of the inlet edge of the suction pipeline to values that do not allow the formation of air funnels, due to which construction costs are also reduced.

2. The proposed design of water intake chambers prevents sediment deposits around the suction pipeline and improves the hydraulic characteristics of the flow before the inlet, and also allows to reduce the height of the structure to 20 ... 25% due to the formation of dead zones above the inlet section of the pipeline.

3. A full-scale test of the proposed design of the water intake chamber established an increase in the water supply of pumps D4000-95 by 8.31%, and efficiency by 5.2% compared to the basic design. The annual economic benefit from the additional equipment of water intake chambers with a jet guide wall for only one five-unit pumping station (PS), with D4000-95 pumps, is 2250 US dollars.

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