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Recommendations for Determining the Sizes of the Water Receiving Chamber of the Pumping Station

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ABSTRACT: The article considers the issues of determining the dimensions of the water intake chamber of an irrigation pump station, taking into account the minimum hydraulic resistance in the input part of the suction pipe of the pump.

KEY WORDS: pump, advance chamber, water intake chamber, water supply, hydraulic resistance, flow, speed, pressure, coefficient of resistance, pressure loss.

I. INTRODUCTION

Irrigating pumping stations are the largest consumers of electricity.That are why improvement of water intake facilities in order to increase the efficiency of their work has a huge economic and energy effect nationwide.

Improving the hydraulic characteristics of water intake structures is possible by creating constructive solutions to reduce the pressure loss when entering the suction pipe of the pump unit.

II. PROPOSEDMETHOD

In laboratory studies with the width of the water intake chambers the inlet part of the cone shaped $K = \left(\frac{D_{ent}}{d}\right)^2 = 2{,}25$ suction pipe is considered equal to length $l_{con} = 2D_{ent} = 0{,}15\ m$ (where D_{ent} is the diameter of the inlet of the suction pipe, $d$is the diameter of the suction pipe, l_{con} is the length of the cone of the inlet).

To reduce the influence of local resistances on measurements, the measuring target should be located at a distance of more than 3d according to the recommendations of A.V.Alexandrov and A.M.Grabovskiy[1; from. 112-113; 2; from. 35-38].The first measuring target is located in the final part of the supply channel, i.e. in the initial part of the fore chamber. In this section, the flow spreading velocities are equal, the distribution of pressure obeys hydro statistical laws.

The second section is located at the end of the inlet part of the suction pipe confuser. The confuser is considered a good flow stabilizer, therefore, in the second measured section, the velocity field is uniform and the pressure is the same. The bottom of the channel is taken as the comparison plane. For sections 1 and 2, the Bernoulli equation is compiled taking the bottom of the channel as the reference plane:

$$\frac{P_{ch}}{\gamma} + \frac{a_{ch}V_{ch}^2}{2g} = \frac{P_p}{\gamma} + \frac{a_p V_p^2}{2g} + h_p \qquad (1)$$

From here

$$h_p = \frac{P_{ch} - P_p}{\gamma} + \frac{a_{ch}V_{ch}^2 - a_p V_p^2}{2g} \qquad (2)$$

where are $\frac{P_{ch}-P_p}{\gamma} = \Delta Z$ the pressure losses in the piezometers.

The pressure loss h_p consists of the pressure loss in the pressure chamber, water chambers and at the entrance to the confuser part of the suction pipe.

When filling the channel up to h_{ch}=0,198*m*, when the water supply is 0,0045 ... 0,0065 m^3/s, the flow rate is 0,055 ... 0,08 *m/s*. In this case, the pressure loss in the tank and water intake chambers and their difference for each of the 2 options is very small. Therefore, the pressure loss h_p consists of the loss at the inlet to the pipeline and the confuser. Since the flow velocity in the inlet channel is
V_{ch}=0,05…0,08 *m/s*, it can be ignored, therefore, the pressure loss is determined as follows:

$$h_p = \Delta Z - \frac{a_p V_p^2}{2g} \tag{3}$$

When the pump was supplied within the range of 0,045 ... 0,065 m^3/s, the Reynolds number *Re* in the outlet section of the intake manifold confuser varied from $1{,}1 \times 10^5$ to $1{,}6 \times 10^5$. In this limit, the resistance coefficient is independent of the Reynolds number.

In table 1, the numerator shows ξ_p values relative to the pressure head in the output section of the confuser, i.e. $\xi_p = h_p \times \frac{2g}{V_{ent}^2}$, the denominator shows values relative to the velocity flow at the entrance to the confuser, i.e. $\xi_p^1 = h_p \times \frac{2g}{V_{ent}^2}$, by decreasing the width of the chamber, ξ_p increases from 0,582 to 0,678 i.e. increases by 16,5%.

The coefficient of hydraulic resistance of the suction pipe of the pump is determined from the ratio of hydraulic resistance h_p to high-speed pressure in the inlet section of the suction pipe:

$$\xi_p^1 = h_p \cdot \frac{2g}{V_{ent}^2} \tag{4}$$

The determination of the resistance coefficient by the formula (4) is more reliable, because the simulation of the pump operation mode is performed for the inlet part of the suction pipe.

Table 1
The coefficient of hydraulic resistance of the suction pipe of the pump

Variant	D_{ent}, *m*	$\frac{b_{cham}}{D_{ent}}$	*d*, *m*	*K*	$\frac{\xi_p}{\xi_p^1}$
1	0,075	2	0,005	2,25	$\frac{0{,}582}{3{,}06}$
2	0,075	1,2	0,005	2,25	$\frac{0{,}671}{3{,}35}$

Based on the experiments, N.A. Gretsov recommends a formula for determining the coefficient of resistance of the confuser of the suction pipe when taking water from a large pool [3; from. 210-214]:

$$\xi_{con} = \left[\frac{2}{K} - \frac{\beta^2}{K\left[\beta - 0{,}294\left(\sqrt{K} - 1\right)\right]^2}\right]^2 \tag{5}$$

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$$\xi_b = \lambda \frac{\sqrt{K+1}}{2}\sqrt{0{,}25(\sqrt{K}-1)^2+\beta^2} \qquad (6)$$

where $K = (\frac{D_{ent}}{d})^2 = \frac{\omega_{ent}}{\omega_{ex}}; \beta = \frac{l_{con}}{d};$

ξ_{ent} and ξ_{len} - respectively, the coefficient of resistance at the input and along the length;
λ - coefficient of resistance to friction along the length.

Due to the reduction in the width of the water intake chamber, the flow is restricted at the entrance to the suction pipe by two side walls and a rear wall, as a result, the coefficient of resistance increases.

When calculating the values ξ_{ent} and ξ_{len} according to the above formulas (5) and (6), according to our data, β = 3, k = 2,25 and λ = 0,17 obtained ξ_{ent} =0,395and ξ_{len} =0,066 the total coefficient of resistance is equal ξ_p=0,461. Based on the results of I.E.Idelchik, given the increase in the coefficient of resistance ξ_{ent} by 53%, which is compressed by three walls with a width of the water intake chamber equal tob_{cham}=1,2D_{ent}equally ξ_p=0,395·1,53+0,066=0,671. According to the data of I.E.Idelchik, the smallest value of the resistance coefficient falls ξ_{ent} on the flow inlet to the conical part of the suction pipe l_{con} = (0,1 ... 1) d, where l_{con} is the length of the cone and a= 40 .. .60^0 flow compression angle. The values ofξ, under the condition $l_{con}>d$, are not given, therefore, it is not possible to compare with our experimental data [4; from. 153-164].

III. EXPERIMENTAL RESULTS

The experimental data of the coefficient of resistance amounted to $\xi_p = 0{,}678$, what is in line with the calculated values. N.A. Gretsov notes that with an increase in the narrowing angle of the inlet part of the cone of the suction pipe, that is, increasing the values $K = \left(\frac{D_{ent}}{d}\right)^2$ and reducing $\beta = \frac{l_{con}}{d}$ the decrease in the coefficient of resistance [3; from. 210-214]. Therefore, by increasing the narrowing angle of the confuser, it is necessary to reduce the length of the inlet confuser of the suction pipe.

To improve the hydraulic characteristics of the intake chambers, it is necessary to establish a connection between the shape of the intake chamber and the hydraulic structure of the flow formed by its walls in order to find the best conditions for supplying the flow to the suction pipelines of the pump.

According to the rules of geometry and trigonometry it is sufficient to determine the most advantageous dimensions of the water intake chamber by an economic calculation, the dimensions of which are determined from the condition that the shape of the suction pipe is constant, according to the rules of geometry and trigonometry.

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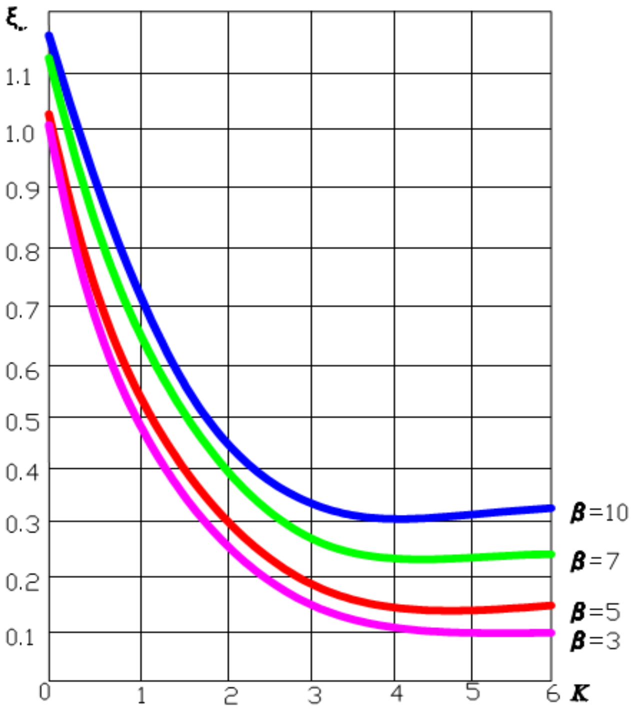

Fig. 1. The dependence of the coefficient of resistance ξ_p when β = 3; 5; 7; 10 from taper K

To calculate the hydraulic resistance of the design of a water intake chamber with a confuser transition section, we use the Idelchik formula in the following form [4; c. 153-164]:

$$\xi = \frac{\Delta P}{\frac{\rho\omega_0^2}{2}} = \xi_{loc} + \xi_p \qquad (7)$$

The calculation of the coefficient of local resistance of the confuser is made according to the formula:

for flat $$l_p = \frac{a(n-1)}{D-a} l = \frac{a(n-1)}{\frac{D}{a}-1} l$$

$$\xi_{loc} = \frac{\Delta P}{\frac{\rho\omega_0^2}{2}} = (-0{,}01125n_0^4 + 0{,}0224n_0^3 - 0{,}00723n_0^2 + 0{,}00444n_0 - 0{,}00745)(a_p^3 - 2\pi a_p^2 - 10a_p \qquad (8)$$

Where a_p= 0,01745α рад (α °)

When determining the coefficient of friction resistance $\xi_p$of the narrowing section, λ is assumed to be approximately constant along the entire confuser and depends on the Reynolds number Re at the entrance and the relative roughness of the walls Δ:

$$\xi_p \frac{\Delta P_p}{\frac{\rho\omega_0^2}{2}} = \frac{\lambda}{8\sin\frac{\alpha}{2}}\left(1 - \frac{1}{n_1}\right)^2 \qquad (9)$$

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Given that the hydraulic resistance of the confuserh_c consists of the sum of the hydraulic losses at the input h_{ent} and friction along the length, taking into account the taper of the confuserh_l, we obtain:

$$h_{con} = h_{ent} + h_{len} = (\xi_{ent} + \xi_{len})\frac{V_{suc}^2}{2g} = \xi_{con}\frac{V_{suc}^2}{2g}$$

where ξ_{con} is the coefficient of resistance of the confuser; ξ_{ent} - input resistance coefficient; ξ_{len} - coefficient of resistance along the length; $V_{suc}$is the exit speed from the confuser with the diameter $D_{suc}$of the internal combustion engine.

Using geometric relations, the following expression is obtained:

$$\varepsilon_p = \frac{\varepsilon}{\left(1 - Atg\frac{\varphi}{2}\right)^2} = \frac{0,5}{\left(1 - 0,588en\frac{\varphi}{2}\right)^2}$$

$$tg\frac{\varphi}{2} = 0,5\frac{\sqrt{\kappa} - 1}{\beta} \qquad (10)$$

where is the φ-angle of taper.

The formula for determining the resistance coefficient at the entrance to the confuser is obtained by substituting formula (10) in (9), and (9) in (8), taking into account formula (7):

$$\xi_{ent} = \left[\frac{2}{K} - \frac{\beta^2}{k[\beta - 0,29](\sqrt{k} - 1)^2}\right]^2 \qquad (11)$$

The above formula determines the loss in length h for:

$$h_{len} = \lambda\frac{\lambda_{ekv}}{D_{suc}} \cdot \frac{V_{suc}^2}{2g}$$

In the ℓ_{ekv} formula, the equivalent length is obtained if we equate the area of the inner surface of the cone with the ℓ_{con} length increasing with increasing k to the cylinder surface with the ℓ_{ekv} length and the diameter $D_{suc}$of the internal combustion engine (for $k = 1$, $\ell_p = \ell_{ekv}$), then:

$$\xi_{len} = \chi\frac{l_{ekv}}{D_{suc}} = \chi\frac{\sqrt{k} + 1}{2}\sqrt{0,25(\sqrt{k} - 1)^2 + \beta^2} \qquad (12)$$

where$\chi$is the coefficient of resistance to friction along the length.

Summing up expressions (11) and (12), we obtain the ξ_{con} value of the resistance coefficient ξ_{con} according to formula (13) depending on k and β at
χ = const:

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$$\xi_{con} = \left[\frac{2}{K} - \frac{\beta^2}{k[\beta - 0{,}29](\sqrt{k} - 1)^2}\right]^2 + \chi\frac{\sqrt{k}+1}{2}\sqrt{0{,}25(\sqrt{k}-1)^2 + \beta^2} \qquad (13)$$

Obviously, ξ_{con} = *f (Re)* starting from *Re*= 2×10^5, ξ_{con} does not depend on the number *Re* and is equal to some constant value.

For the convenience of using formula (13), Figure 1 shows a graph of ξ_{con} = *f* (*k*, β) at χ = 0.017. For less thorough calculations with an increase in ξ_{con} to 6 ... 8%, formula (13) is used in the following simplified form:

$$\xi_{con} = \frac{1}{k^2} + \lambda\frac{\sqrt{k}+1}{2}\beta$$

When the number *Re* assigned to D_{ent} is more than 2×10^5, k within the range of 1 ... 6 and β from 3 ... 10, one can use the above formulas. For metal confusers, the coefficient χ is recommended to be taken in the range of 0.017 ... 0.020.

The rational design and study of the water intake chambers of irrigation pumping stations is based on the definition of such a shape of the water intake chamber and the type of fluid flow at which there is a minimum of vortex and rotational movements at the bend, with optimal sizes of the water intake chamber [5; c. 304-307; 6; from. 241-244].

IV. CONCLUSION

It is recommended to take the value of the equivalent taper angle to 25 ... 30 °, to pair the adjacent to the inlet of the suction pipe with a ratio of inlet and outlet areas of at least 3 ... 4 for suction pipelines. The length of the cone ℓ_{con} is not associated with a certain relationship with D_{ent} and is assigned based on the design dimensions of the water intake chambers.

Reducing the width of the water intake chamber with $b_{cham} = 2D_{ent}$ to $b_{cham} = 1{,}2D_{ent}$ leads to a decrease in hydraulic resistance in the outer chambers by 1,5 times, this brings closer the working conditions of the middle and extreme chambers.

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