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On the dependence of hydraulic resistances of machine and derivation channels of hydroelectric power plants on pressure losses of hydropower facilities.

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Annotation. The question of the study of hydraulic resistance to fluid movement in a turbulent regime has more than a century of history, but it continues to be relevant to this day. The extensive construction of numerous free-flow watercourses, as well as machine and diversion channels of hydropower facilities, requires scientifically based calculation methods. For the correct establishment of hydraulic calculation methods, a sufficiently deep study of the physical essence of the phenomena occurring in free-flow flows is necessary.

Keywords: Pumping stations, hydroelectric power stations, hydraulic resistance, machine channel, derivation channel, free-flow channels, channel shape, channel roughness, channel morphometric elements, pressure losses, coefficient of hydraulic friction, hydropower facilities.

Introduction. The question of head losses with uniform steady motion in cylindrical channels - head losses along the length - has more than a century of history. The currently widely used design relationships for determining the Chezy coefficient are based on the assumption that the longitudinal shear stresses acting from the flow side on the channel walls are uniformly distributed along the wetted perimeter. Assessing the acceptability of this assumption for flows with different cross-sections, three different groups of channels can be distinguished.

1st group. In such channels, the assumption corresponds to reality exactly (in the case of circular cylindrical pressure channels) or almost exactly, so that when performing practical calculations, the error is negligible (for example, in the case of very wide rectangular channels - pressure and non-pressure ones - excluding sections of the cross-section directly adjacent to short sides of the rectangle, the flow can be considered as flat and the shear stresses along the long side of the rectangle are assumed to be evenly distributed).

2nd group. The assumption does not accurately correspond to reality, and the error in performing practical calculations is not permissible, however, for a wide range of Reynolds numbers, an adjustment can be made that takes into account the geometric features of the shape of the open section, and thereby ensure the required accuracy of calculations. We will say that the channels belonging to the second group have a "correct" shape. As shown by the preliminary analysis, this group for the case of free-flow movement includes, in particular, rectangular, trapezoidal, parabolic, semicircular, which are often found in the practice of hydraulic engineering and hydropower construction, including the machine and derivation channels of hydropower structures (NS and HPPs).

3rd group. In the channels of this group, the Weisbach-Darcy formula requires the introduction of adjustments that depend not only on the geometric shape of the channel, but also on the Reynolds number, which makes the use of this formula practically inappropriate. This group includes channels, for example, with a star-shaped cross-section.

In the present work, it is planned to study the head losses along the length during the free-flow movement of water in the channels of the "correct" shape, i.e. in the channels of the 2nd group.

Until recently, it was believed that in free-flow channels with a "correct" cross-sectional shape, its influence on the value of pressure losses can always be estimated with an acceptable approximation using the hydraulic radius. However, this position is not always ensured in the case of channels having a "regular" cross-sectional shape [1,2]. The authors indicated in the literature have shown that for free-flow channels with a "correct" cross-sectional shape, the hydraulic radius as a parameter that must take into account its effect on the value of pressure losses in these channels is insufficient. The works of a number of authors (both already named and some others [3,5,7], it was also shown that the dependences obtained for calculating the hydraulic resistance in round pressure pipes cannot be extended without appropriate adjustments to gravity channels (subject to replacement in corresponding calculations of the pipe diameter - by the value, where is the hydraulic radius) .This position is justified by the presence of a number of factors that distinguish the pressure movement of the liquid in the pipes from its unpressurized movement in the channels, where there is a free flow surface, a wider range of roughness of the bottom and walls of the channel, a different (than in pipes) distribution of shear stresses along the wetted perimeter, the possibility of the existence of two different states of the flow (depending on the slope of the channel bottom). Hence, in particular, it follows (and this is confirmed by the data of the corresponding experimental studies published in the literature) that in the case gravity channels head loss coefficient and, consequently, the head losses depend not only on the relative roughness and Reynolds number, but also on the shape of the channel cross-section. Moreover, if for hydraulically smooth free-flow channels this dependence in the first approximation can be considered clarified, then for channels, the wetted surface of which is characterized by the presence of one or another roughness, the question of its influence, as well as the shape of the channel cross-section on the pressure loss value, is far from even roughly approximate solution.

Since until now there are no analytical dependences that fully describe the mechanism of turbulence and are suitable for practical calculations associated with the free-flow motion of a liquid, it is necessary to resort to experimental studies [5, 6]. Due to the lack of sufficient knowledge about the factors that determine the regularities of fluid movement in free-flow channels, as well as machine and derivation channels, it is assumed that the regularities of flow in circular pressure pipes are also applicable to free-flow channels, if, when calculating them, we have in mind the hydraulic radius, and not the diameter (as is done in relation to round pipes, with a pressure movement).

Research methodology. Analysis of the operation of the machine and diversion channels of hydropower structures in different modes, operating in different hydraulic conditions and different values of h - flow depth, Ṛ - hydraulic radius and χ - wetted perimeter of the flow area, taking into account the influence of the morphometric elements of the channel on the hydraulic resistance of the machine and derivation channels of hydropower structures is the research method of this work.

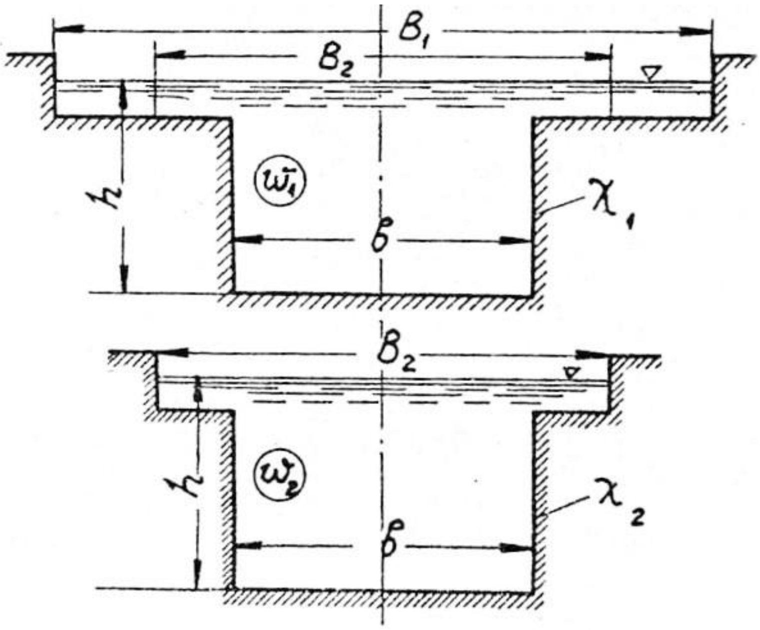
Research results and discussion. The experimental data obtained showed that the intensity of the influence of the morphometric elements of the channel on the hydraulic resistance of the machine and derivation channels is in direct proportion to the mode of operation of hydropower facilities (NS and HPPs). Experimental studies published in the literature, carried out in order to clarify the above assumption and elucidate the above-mentioned regularities in free-flow channels, as well as machine and derivation channels, were carried out at different times and in different conditions, some of their results do not always agree with each other, but the calculated dependencies are highly controversial. In particular, the question of the morphometric elements of the channel and its dimensions on the regularities of the hydraulic resistance of the machine and diversion channels of hydropower structures is not completely clear [7,8,10].

When fluid flows in free-flow channels, machine and derivation channels of hydropower facilities, a number of factors are added that usually do not occur during pressure flow of fluid in pipelines (where their entire living section is filled with liquid); the presence of a free surface, the existence of suspended materials in the flow, the difference in the shape of the cross-section of channels from a circular cross-section, the existence of two different states of the flow depending on the slope of the channel, the presence of a wider range of roughness in free-flow channels, machine and derivation channels of HPPs, etc. If the average velocity in a channel with a different correct cross-section is calculated by the usual equation of the average velocity, and in this case will have almost the same form, then it can be found that the expressions for the average velocity in this case will have almost the same form as the expressions obtained for average speed in the channel for a trapezoidal section (equations (1) and (2));

$$\nu/\nu_* = a_{гл} - b + b\ln(R\nu_*/\nu) + b\Phi - \overline{\kappa\nu}/\nu_* \qquad (1)$$

$$\nu/\nu_* = a_{ш} - b + b\ln(R/\Delta) + b\Phi - \overline{\kappa\nu}/\nu_* \qquad (2)$$

only Φ and, depending on the geometry of the channel cross-section, will change (from section to section). In view of the above, equations (1) and (2) can be considered rational equations for determining the average flow velocity in channels with a constant cross section and slope.



Picture 1. Cross-sections of two channels with different hydraulic radii and with approximately the same bandwidth.

If these general equations are compared with the corresponding equation for a channel of infinite width (Fig. 1 and Fig. 2), then one can see that they differ in the presence of terms in "bph" and $\overline{\kappa u}/\overline{u}_*$. These terms can be interpreted as reflecting the combined effect of the presence of a free surface and a non-uniform distribution of shear stresses on the bottom and walls of the channel on the head loss.

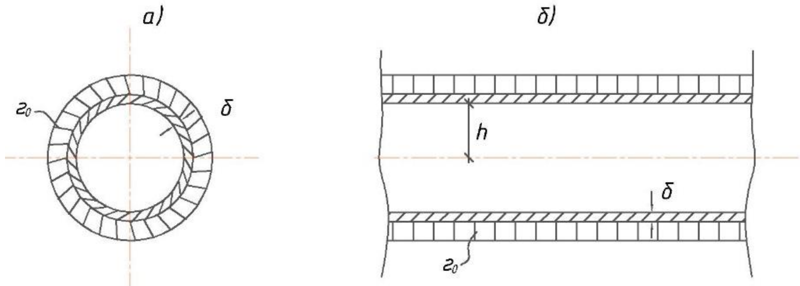


Figure 2. Distribution of shear stresses: a) in round;

b) in wide rectangular pipes and channels.

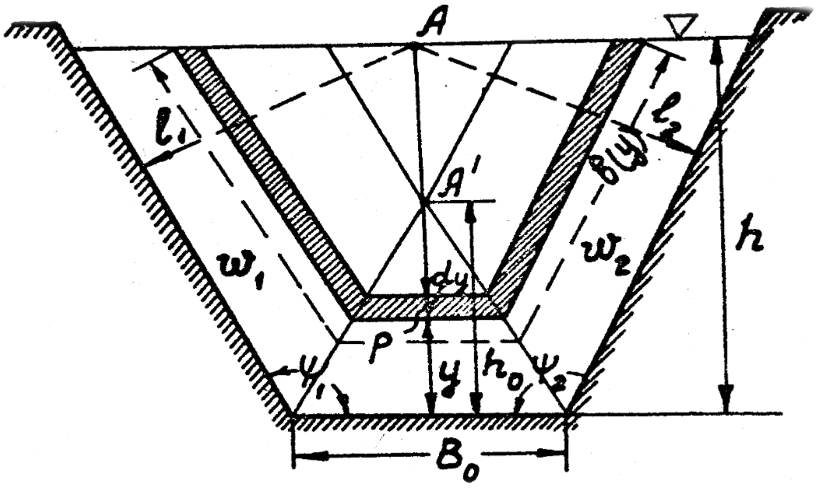
On the other hand, the indicated general equations (1) and (2), allow us to find the magnitude of the error in determining the pressure loss, which would occur if the terms "bf" and * are odd. The term "bph" can be calculated for any given shape of the channel cross-section, since it is determined only by its geometry. Calculation according to Kelegan [1,4,5,9] and according to our method shows that in the channels of triangular cross-section the value "Φ" does not depend on the depth of the water, and in this case Φ = 0.19. For channels of rectangular cross-section, the expression for "Φ" takes the form:

$$\phi = \ell n(1 + 2h / B_0) - h / B_0 \qquad (3)$$

For ducts with a semicircular cross-section:

$$\varphi = \int_0^h \left[\ln\left(\frac{y}{R}\right) \right] \frac{B_0}{R} \frac{dy}{\chi} + 1.0 \qquad (4)$$

To find the value, it will probably be necessary to introduce some parameter expressing the ratio of the transverse dimension of the free flow surface in the channel to the wetted perimeter. It is quite possible that the best can be found from experiments. However, as follows from equations (1) and (2), before carrying out these experiments, the characteristics of the bottom and walls of the channel must be determined in advance (also from experiments - preferably with very wide channels of rectangular cross-section, as well as a trapezoidal shape of the free cross-section (Fig. .3)).



Rice. 3. Cases when the bisectors intersect in a live section of the trapezoidal channel.

According to our method and according to the method of G. Kelegan, the formulas of hydraulic resistance for machine and derivation channels of trapezoidal shape and other forms of correct cross-section can be represented as:

$$\frac{1}{\sqrt{\lambda}} = \frac{1}{\bar{\chi}\sqrt{2}} \left(\ln\frac{\eta_\Lambda R}{\delta_\Lambda} - 1 + \ln\frac{h}{\eta_\Lambda R} - \frac{\xi h^2}{4\omega} \right) \qquad (5)$$

The same ratio is obtained according to V.T. Chow [2, 10] for channels with a curved transverse profile. In relation (5) it is accepted: $\bar{\chi}$ - Karman's constant [3]; $\bar{\chi}$ = 0.4, η_Λ - Reynolds number.

For a viscous sublayer, $\eta_\Lambda = \delta_\Lambda v_* / \nu$; δ_Λ - thickness of the viscous sublayer; h – filling the channel; ξ – channel shape function in relation $b(y)=\chi- \xi y$; χ – wetted perimeter; ω – Is the free area of the channel.

Formula (5) is valid for both fluid motion in smooth (η_Λ =1/9), and in rough channels (η_Λ =1/30, moreover $\eta_\Lambda = \delta_\Lambda / \Delta э$). The third and last terms in this formula take into account the influence of the shape of the free cross-section of the channel on its hydraulic resistance. However, formula (5) does not fully take into account the influence of the free surface on the distribution of velocities and head losses. Bearing this in mind and some other assumptions made when deriving formula (5), it should be assumed that formula (5) only allows us to outline the general form of the terms that determine the dependence of the hydraulic resistance of the channel on the shape of its open section. The specific form of the corresponding dependence can be established only from consideration of the corresponding experimental data for free-flow machine and derivation channels of hydropower structures, with turbulent fluid movement.

Conclusions and recommendation: With pressure flow in a round pipe *(R = D /4)* and infinitely wide rectangular channels (at $b \gg h$; $R = h$) , as well as in the machine and derivation channels of hydroelectric power plants, where a uniform distribution of shear stresses is ensured (τ_0) around the wetted perimeter ($\tau_0 \approx \tau_{ocp}$), the geometric interpretation of the hydraulic radius is justified, in other cases (at $\tau_0 \neq \tau_{ocp}$) - doesn't make sense.

The unpressurized machine and derivation channel of the correct cross-section corresponds to the law of hydraulic resistance determined by the shape of the open section Ф and K, which takes into account the effect of the free flow surface during the unpressurized movement of water in the machine and diversion channels of hydropower facilities.

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