ABOUT ENERGY LOSS IN THE HEAD WATER PASSAGES

G. GIGIBERIA

Be received 07.12.05

Based on the calculation methodology recognized by International Engineering Industry, hydraulic energy decreases in increasing the diameter under the environment of the turbulent flow developed in the water passages.

Opposite to this provision, as a result of the research run at Enguri Hydropower Plant (HPP)diversion tunnel in 2010-2013, it was clear, that in increasing the diameter the real values of the energy (head) loss significantly exceed the values defined under the official methodology.

The identified discrepancy should be explained both by the inadequacy of the assumptions accepted in theory and the data obtained as a result of limited laboratory means during estimating experimental coefficients included in the calculations.

To determine the real regularity with respect to the above, it is necessary to thoroughly research this issue which will allow to clarify the physical nature of the flow and to resolve this issue realistically.

In order to achieve the goal, we believe it is reasonable to run large-scale research on a wide spectrum of water passage diameters by means of the field experiments which should be run with high accuracy measurement units.

So, the results obtained based oh realistic base will unable to resolve number of hydropower issues in an optimal way.

Key words: *diversion tunnel of Hydropower Plant, water pass, turbulent mode, filtration, energy loss.*

We believe that one of the most important activities for planning the hydropower plans and rationally managing their operations is identification of the energy loss value. The value obtained for calculating this parameter is extremely interesting in planning and designing the HPP tunnels and pipelines and helps to select the optimum working mode of the plant.

Widely recognized methodology in the environment of the developed turbulent flow of the liquid flow considers the flow dynamics when elementary particles invade in the neighboring mass with the pulsation speed thus causing the energy loss as a result of exchanging their motion number (impulse). Within the flat motion voltages tangent to the flow direction (x) are presented by multiplicand of the pulsation speeds.

$$\tau_{x,y} = -\rho v'_x v'_y . \quad (1)$$

According to L. Prandtl assumption correlative relation of such speed components is close to 1, i.e. the adequacy of the equation $v'_x \approx v'_y$ can be assumed. Based on one of the fundamental dependence of hydromechanics the authorrelated the pulsation speed of particles to the speed flow gradient at normal.

$$|v_x| \sim l\frac{\partial v_x}{\partial y}. \quad (2)$$

The term "length of mixing way" was given to *l* proportionalitycoefficient hydraulic content of which is understood as a length section, the distance along which the elemental mass entirely gives its motion number ρv_x.

Finally, the image - Prandtl equation for the tangent voltages is obtained.

$$\tau = \rho l^2\left(\frac{\partial v_x}{\partial y}\right)^2. \quad (3)$$

Prandtl gave the following form to the empirical coefficients participating in the equation:

$$l = æy\,, \quad (4)$$

where y is the distance of the flow from the wall and æ - is Karman constant for which (based on the experiments run by I. Nikuradze) æ=0,38...0,40forhead and æ=0,306 for open flows. By establishing this dependence the author believed that the impulse caused by mixing the liquid masses depends on the movement length which was indicated in the linear connection (4).

In order to resolve the hydraulic tasks, together with integrating the Prandtl equation, it was necessary to use some theoretical views that were strengthened by experimental data.

The calculation formula based on the above provisions that is recognized by specific international literature and proved by the experiments run at highly professional level was initially suggested by I. Nikuradze.

$$\frac{1}{\sqrt{\lambda}} = 1{,}74 + 2.0\lg\frac{r_0}{\Delta}\,, \quad (5)$$

where λ is hydraulic resistance coefficient according r_0=d:2to Dars-Weisbach, Δ- absolute roughness of the water pass and r_0=d:2 - radius of the water pass.

Later, large amount of experimental researches have been run in this direction and respective calculation images have been suggested based on their results. Thus, international practice recommends Kolbruk-White formula for calculating the circular section and cylinder form pipes as well as the water passes constructed with the construction material, which claims to be universal

$$\frac{1}{\sqrt{\lambda}} = -2\lg\left[\frac{\Delta}{3{,}7d} + \frac{2{,}51}{Re\sqrt{\lambda}}\right], \quad (6)$$

Reynolds number $Re = v \cdot d : \nu$ appears in the equation where v is an average speed, and ν – kinematic viscosity coefficient of liquid.

Except for the above mentioned, there are number of formulas and calculation methods including Freinkel (7), Altmule (8), Shevelyov (9) equations

$$\lambda = \frac{1}{\left\{2\lg\left[\frac{\Delta}{3,7d} + \left(\frac{6,81}{Re}\right)^{0,9}\right]\right\}^{2}}, \tag{7}$$

$$\lambda = 0,1\left(\frac{\Delta}{d} + \frac{100}{Re}\right)^{0,25}, \tag{8}$$

$$\lambda = \frac{0,021}{d^{0,3}}. \tag{9}$$

and the calculations provided in the references recognized by the industry are spread in the scientific and technical literature. The mentioned calculation methodology is the basis of the applicable normative papers: technical terms and conditions (ТУ) from the Soviet period, relevant instructions and recommended references.

Respectively the above mentioned approaches have been used when making the hydraulic calculations for functioning HPP water passes or the HPP water passes being under planning.

The results of such calculations for metal pipes and hydraulic tunnels are illustrated in the table by their diameters.

Table

Inside diameter of water pass, mm	Kolbrewhite formula	Frenkel formula	Altshule formula	Shevelyev formula	According to Mostkov's reference	
					Metal pipes	Tunnels with gunite lining
50	0,0280 0,0490	- -	0,0270 0,0380	0,051	0,0368	-
100	0,0250 0,0300	0,0234 0,0379	0,0227 0,0359	0,042	0,0305	-
300	0,0180 0,0260	0,0178 0,0270	0,0173 0,0244	0,030	0,0210	-
1000	0,0140 0,0200	0,0120 0,0196	0,0127 0,0202	0,017	0,0166	-
3000	0,0105 0,0155	0,0111 0,0153	0,0097 0,0137	-	0,0128	0,0149
5000	0,0102 0,0133	0,0101 0,0137	0,0085 0,0012	-	0,0119	0,0133
9500	0,0085 0,0120	0,0096 0,0109	0,0073 0,0108	-	-	-

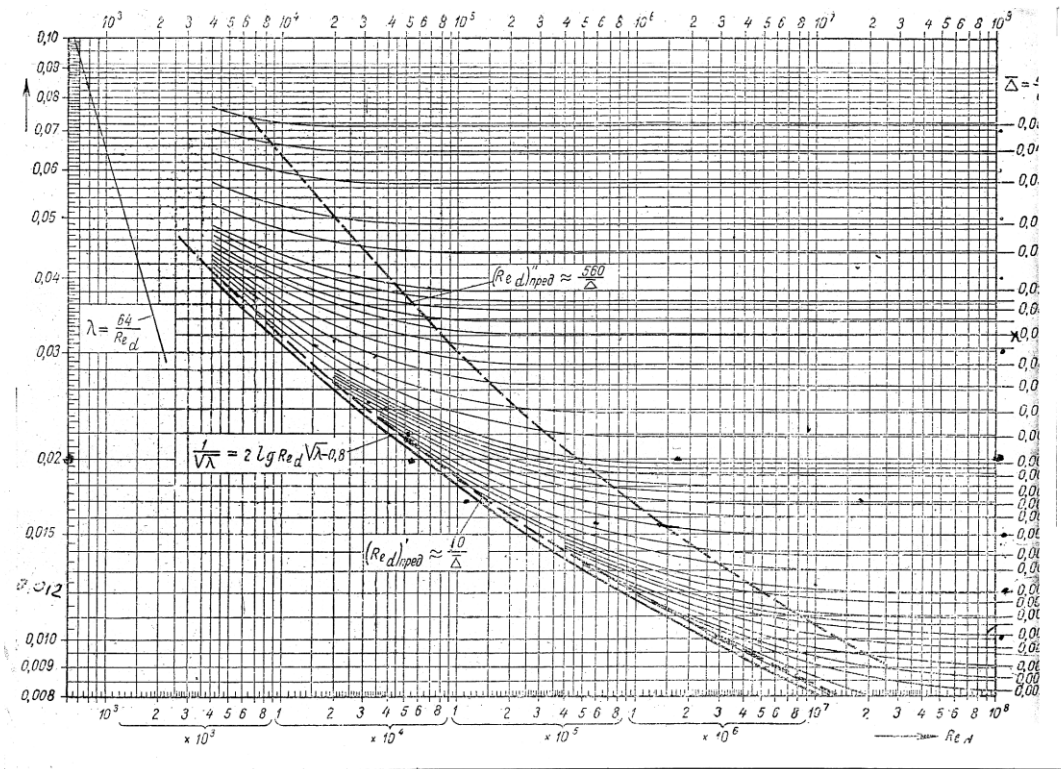

Fig. Graphic image of Kolbruk-White Formula

The data in columns 2, 3 and 4 of the table are presented for two absolute magnitudes of roughness - Δ=0,2and Δ=1,0. First corresponds to the pipes with minor roughness and the second (Δ=1,0 mm) – to poor tunnels' lining or metal pipes as a result of their long utilization. As λ depends on the Reynolds number Re, the calculations are conducted for the fixed water speed (2.00 m/sec) and kinetic viscosity coefficient ν-0,0131 m^3/sec which corresponds to the water temperature t=10^0C.

It is seen from the table that the hydraulic resistance reduces with the increase of latitudinal dimensions of the water pass. At the same time the resistance value for a high value of the absolute value of roughness Δ increases by more than 50%.

As a result of analyzing the above we may made a clear conclusion that the decrease of relative roughness conditioned by the increase of the water pass latitudinal dimensions (together with almost immutability of the roughness of the inside surface of the water pass) weakens the cohesive influence of the tangent forces on the flow – the effect of the forces causing hydraulic resistance reduces.

An alternative view opposite to the correctness of some assumptions and logical approach (even based on general regularity basis of the mechanics) by the above described recognized theory used for the developed turbulence conditions has been established with

the circumstances that together with the increase of the water pass latitudinal dimensions the degree of free motion of liquid masses grows by all means, the process of mixing intensity is longer, discharge of the energy caused by the exchange of the number of motion among the liquid mass (particles) strengthens which should be reflected in the increase of the resistance. Under general viewpoint the effect of the gravitational forces grows in the process.

Certain clarity was given to this issue with the researches run for the determination of the energetic modes of Enguri HPP unit in 2010-2014 [3,4,6]. It is obvious, that it is necessary to determine the hydraulic resistance at the diversion tunnel which requires proper measurement of the accuracy of the head drop and water discharge along the tunnel length.

Drop of the head is measured byhigh accuracy self-recording pressure gauges Level Troll-500 located at the initial (edge of the water intake) and the last (equalizing basins) sections. Due to constructional peculiarities of the HPP head system units, it was impossible to achieve the necessary accuracy with the single beam ultrasound discharge meter PT-878 (the tools are manufactured by famous USA company - General Electronics) used to measure the discharge.

With respect to the above, the calculations according to the power developed by the hydroelectric generators of the HPP were used to determine the working discharges of water with its analytical image

$$N=9{,}81\cdot Q_t\cdot H_t\cdot\gamma_t\cdot\gamma_g \qquad (10)$$

allowing to calculate the discharge with the equation

$$Q_t = N:9{,}81\cdot H_t\cdot\gamma_t\cdot\gamma_g \qquad (11)$$

where Q_t is working discharge of the turbine, H_t head on turbine, γ_t and γ_g coefficient of efficiency.

The accuracy of the components participating in the formula (11) is inhomogeneous.

Power generated by the hydroelectric generators is obtained by the machine's electric parameters whichare measured with contemporary high accuracy devices. The head value H_t is determined with high accuracy. It is calculated by the difference of the equalizing basin and tail water levelsto which the head loss within the HPP power block in the turbine pipeline is subtracted. This value is obtained by the calculation, it depends on the working discharge of the turbines and due to the absolute lack of its value it is not reflected in $H_t$definition accuracy. The value of the coefficient of efficiency of the hydroelectric generators (γ_g) is provided by manufacturer's warranty. As for the turbine's

coefficient of the efficiency (γ_t), in the calculations we used the data provided by the manufacturer which as it is known is not determined under real tests.

For the issue of the determination of the head loss in the tunnel, except for the mentioned inaccuracy, it is necessary to consider some factors caused by some negative circumstances and to evaluate the errors of the components participating in the calculation. With respect to the above, it is reasonable to associate the energy loss to the discharge of water used by HPP turbines in the tunnel and to exclude filtration influence from the tunnel. As a result of the change of the filtration intensity, the discharge of water supplied by stationary mode along the tunnel occurs in a declining mode, the drop of the head along the tunnel is unequal – it drops on the way of the flow. Respectively, the value of the coefficient of hydraulic resistance reduces (infiltration cases are not reviewed here). Change of filtration discharge along the tunnel is considered by the linear dependence the legitimacy of which has been evaluated based on the data of the mode observation run using the facility forces.

Rather weighty deviation from real situation than the mentioned in the calculations is conditioned by using the manufacturer's data of turbinesefficiency coefficient. This deviation increases when running the unit at low capacities.

It was also necessary to make corrections in the calculations due to the constructions of two (Olori and Eris Tskali) crossings on the tunnel route. The energy losses in them were considered in relevant hydraulic parameters of the tunnel.

The mentioned issues are described in detail in the publications [4,5] and possible errors for each calculation component are evaluated. 6% was obtained as an average value of the sumof the errors.

On the background of the above mentioned circumstances, the value of the hydraulic resistance coefficient indeedchanges according the working mode. As a result, it is reasonable to determine the calculation parameters for the conditions close to the average mode of HPP. Range of 600-700 MW of the HPP capacity is taken as such. The water discharge ranges between 200-250 m^3/sec at the reservoir water level of 490±5 m.

With the calculations run according to the determined parameters [4, 5], for the head drop images we have

$$L_w = 0{,}261 \cdot 10^{-3} \cdot Q_{\text{ტ}}^2 . \qquad (12)$$

The value of the coefficient considering the possible errors and corrected hydraulic parameters in 12 makes 0,245 and the respective hydraulic resistance coefficient equals λ_0=0,0152.

For the diversion tunnel of Enguri HPP comparison of the coefficient (λ_0) with the table data obtained with widely recognized approach provides:

- **to Kolbruke-White formula λ_0: λ_1=0,0152:(0,0085...0,0120)=1,77...1,41.**
- **to Altshtul formula 0,01502:(0,0073...0,0108)=2,06...1,39.**
- **to Frenkel formula 0,01502:(0,0096...0,0123)=1,57...1,22.**

As we see the λ values obtained based on the field experiments and the elaborated calculations significantly differ from normal values of these coefficients. Opposite to the view prevailing in the hydraulics, the hydraulic resistance in a large diameter tunnel significantly exceeds the normal hydraulic resistance.

Thus, we should almost be sure that the hydraulic resistance in the water passages increases together with the increase of the diameter (generally with the increase of the cross-section area).

This inconsistency with the normative value should be explained by reviewing the correctness and validity of the assumptions used in theoretical basics of the occurrence. In this regard the assumption of the mutual equation of pulsation components (v'_x and v'_y) in the water current is not convincingand the connection of the length of turbulent mixing length (l) to the distance from the wall of the liquid particles (y) with linear law (*l*=æy) in which the Karman constant (æ) combining the results of both assumptions,based on the experiments, is presented as a constant value (æ=0,38...0,40) for all other cases under the environment of the head movement.

Also, we cannot imagine it true that the experimental values required by theoretical research of the process are defined by I. Nikuradze with the experimental researches performed under the lab conditions on small diameter pipes when the range of the tests is so tight that the result fits in the accuracy dimension and cannot establish the connection of the occurrence to the geometrical factor.

Deep and thorough research of these issues will give clarity to the physical nature of the hydraulic resistance and will allow to establish an appropriate realistic methodology with all the supporting positive factors for planning and proper exploitation of the hydropower plants. In order to achieve this goal we believe that wide utilization of the filed experiments by means of high accuracy measurement tools manufactured by

contemporary tool manufacturers based on the latest novelties will lead to significant success. First of all one of the most effective equipment for the power plants of the country are high accuracy flow meters. Implementation of the mentioned activity will provide versatile positive factors of hydropower engineering nature.

R E F E R E N C E S

1. Мостков М.А. Прикладная гидромеханика. М.-Л.: Госэнергоиздат. 1963.

2. Чугаев Р.Р. Гидравлика. М.-Л.: Госэнергоиздат. 1984.

3. მაღალკაშხლიანი ჰესების უსაფრთხო და ეფექტური ექსპლუატაციის საკითხების გამოკვლევა და მონიტორინგის სისტემის შემუშავება. ა/ო "კოევოლუციური გადაწყვეტები ენერგეტიკაში" ფონდები. თბილისი. 2011.

4. მებონია ლ., მორგოშია დ., გერგედავა მ., საბულუა ლ., გიგიბერია გ. ჰიდრავლიკური კარგვების განსაზღვრა ენგურჰესის სადაწნეო სისტემაში ნატურული ექსპერიმენტის გამოყენებით // ენერგია. 2012. №4(64). თბილისი.

5. გიგიბერია გ. ჰიდრავლიკური წინაღობის შესახებ ჰიდროტექნიკურ წყალსატარებში ენგურჰესის სადერივაციო გვირაბში ჩატარებულ კვლევათა შუქზე//ენერგია. 2015. №3(75). თბილისი.