THE MODERNIZATION OF THE SECONDARY INTAKES DRAXIN AND CASCOE

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The main objective of the paper is to solve two problems of the Clabucet Hydropower, caused by the inlet piping system. The authors are trying to eliminate the air emulsions and the sediments which enter in the main inlet pipe Pecineagu-Clabucet.

The paper is based on the experimental studies performed in the Hydro-energy laboratory of Power Engineering Faculty from Politehnica University of Bucharest. Two installations are used at a proper scale and the results are extended for real scale installations using the similitude theory. Both installations represent original models and are used to predict results at real scale.

Keywords: air emulsion, sediments, ecological intake, laboratory models

1. Introduction

The authors are interested to solve the following issues:

1. The elimination of the air from the emulsion, sucked through the absorbing well in the main hydraulic circuit and
2. The improvement of the captured water drain parameters in the river Draxin until the levels of the water quality from the Pecineagu Lake reach the quality standards.

In this moment, at certain levels and flows, the air is not eliminated and sediments are absorbed [1], [2], [3]. Two new installations are proposed to change the whole operating process.

The air in emulsion is reaching in turbines, where, by expanding, produces dangerous phenomena, cavitations and vibrations with strong noises which put in danger the turbine operation. In a hazardous way, sediments are attracted in the hydraulic circuit and they amplify the dangerous phenomenon in the turbines.

The authors solved the above problems by performing the following activities:

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- Designing and building a new device used to stop the air from entering into the main pipe which leads to the turbines intake.
- Designing and building a new ecological inlet which uses, in an optimal manner, the water of the river and stops the entrance of the sediments into turbines.

The authors present the results obtained in laboratory on the installations and the mathematical calculus for both installations designated to improve the exploitation of the Hydropower Pecineagu-Clabucet.

The conclusions refer at the practical utilization of the new devices, both for air and sediment elimination.

Each device will be adapted in the future for other hydroelectric power plants where they will be useful, providing a better operation. Morphological changes will be considered and the constructive solutions will be modified.

2. Experimental model for air elimination

The fluid flow improvement follows the air elimination from emulsion in the vertical wells, which leads to the main hydraulic circuit to the secondary intake Draxin. The solution proposed in this paper starts from the idea that the separation of the two agents should be done in the same vertical well, inside the permeable nylon well. The latter has the cross section a half of the main cross section. The nylon device has the resistance assured and the axial and perimeter solicitation is minor. Using the laboratory setup, the separation of the two phases can be well seen, regardless the flow regime.

The experimental setup (fig. 1) is composed from:

- A horizontal metallic pipe with ϕ = 150 mm and the length 1750 mm, (1);
- Two valves disposed at the pipe end for fluid flow adjustment, (2);
- A vertical well made from transparent plastic material with ϕ= 60 mm and height 1850 mm, connected at the middle of the pipe, (3);
- A bell disposed at the upper part of the well, (4);
- A nylon bag suspended in the entrance bell on the whole well depth, (5).

Experimental results

The flow through the horizontal pipe was fixed using the valves and a constant water height in the well was obtained throughout the experiments. The measurements are effectuated on a scale length of 1.36 m; this value corresponds to the lower end of the vertical plastic tube.

During the first measurement a volume of 10 litters was poured from the upper part of the vertical tube during 42 s. It was found that the free surface is at the vertical distance of 57 cm, measured from the graded origin of the plastic tube, and the emulsion is comprised between 57 cm and the quota of 86 cm. The emulsion length is in this first case $L_1 = 29$ cm. The water velocity throughout the horizontal pipe is maintained constant during all the experiment performed.

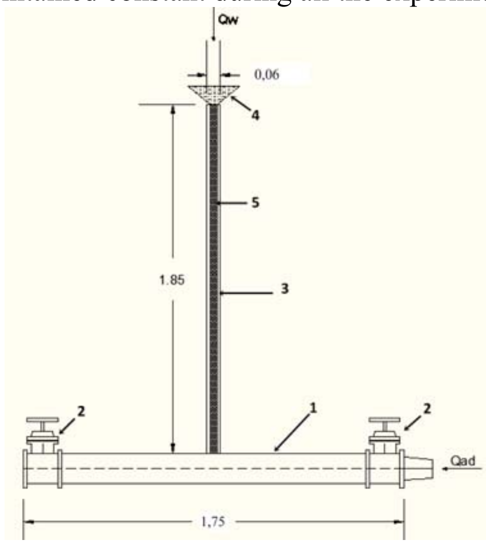


Fig. 1. Experimental setup

For a constant water volume of 10 litters poured in the time t in the vertical tube the authors obtained the emulsion lengths and the volumetric flows (Q), respectively the average water speeds (v) in the vertical tube (table 1).

Table 1

Hydraulic parameters variation in the laboratory setup

Measurement number	t [s]	L [cm]	Q [l/s]	v [cm/s]
1	42	29	0.238	8.4
2	46	26	0.217	7.7
3	54	19	0.185	6.5
4	69	22	0.145	5.13

The initial water quantity in the vertical tube was different for the fourth measurement, so a different emulsion length was obtained.

For Draxin and Cascoe wells, the emulsion length shall be expressed as a depth, denoted with h_D for Draxin and with h_C for Cascoe.

3. Experimental model for ecological intake

The experimental model (fig. 2) is used to simulate the water and the sediments flow. For the water flow rate determination, a rectangle spillway was used. As the depth measured was 5 cm, the flow is determined as follows

$$Q = \mu\sqrt{2g}\int_0^H b(z)dz = \mu\sqrt{2g}B\int_0^H z^{1/2}dz = \frac{2\sqrt{2g}}{3}\mu BH^{3/2} = 6.61\, l/s,$$

where B = 20 cm is the width of the spillway.

For this value of the flow rate and depths of the water between 3.5 and 5.4 cm in the model installation, the movement of the sand was observed.

The sand will be transported by the water downstream, so the water current will produce less erosion. Thus, the morphology of the river downstream the ecological intake will be less affected [4].

4. Experimental setup similitude computations for air elimination

Because during the de-aeration process which takes place inside vertical wells the mass forces are preponderant, the Froude similitude criterion is chosen to determine the emulsion depth.

The Froude number from the prototype installation, at natural scale, becomes equal with the Froude number on the model setup, for which the amounts are notated with the prime signed

$$Fr = Fr' \text{ or } \frac{V^2}{gh} = \frac{V'^2}{gh'}, \Rightarrow h = \left(\frac{V}{V'}\right)^2 h', \tag{1}$$

with h the emulsion depth in the well at real scale.

In order to calculate the mean velocities in the wells, the flow rates from the two installations at Draxin Q_{iD} = 0.42 m^3/s and Cascoe Q_{iC} = 0.77 m^3/s have to be considered and also the inner diameter, similar in both cases, D = 1 m.

The mean descending velocity of the fluid in the Draxin well is

$$V_D = \frac{4Q_D}{\pi D^2} = 0.535 \text{ m/s},$$

and in the Cascoe well, V_C = 0.981 m/s.

For the previous four cases, the emulsion depth in the wells at real scale, in which h' corresponds to the emulsion length, are obtained from equation 1. The values are shown in table 2.

Table 2

Depth of emulsion at Draxin and Cascoe

Attempt	L [m]	Qw (laboratory) [l/s]	h_D (Draxin) [m]	h_C (Cascoe) [m]
1	0.29	0.238	11.8	39.55
2	0.26	0.217	12.55	42.2
3	0.19	0.185	12.87	43.27
4	0.22	0.145	26.41	88.77

It can be seen that for Draxin well a depth of 13 m, respectively a depth of 44 m for Cascoe, is usually sufficient to produce de-aeration.

Even in the last case, the de-aeration depth of 27 m obtained for Draxin using the new proposed devices is smaller than the well depth, H_D = 87 m. It happens the same for Cascoe, where the depth of 89 m is smaller than the well depth, H_C = 94 m. After the de-aeration depth, which is smaller than the constructive depth of the wells, one can consider that water contains no air.

In conclusion, the new proposed devices solve the de-aeration issues from Draxin and Cascoe wells.

5. Transit flow rate computation for the ecological intake

5.1. Integral computation of the captured flow rate

A special interest presents the calculus of the transit flow which remains after water passes through the ecological intake for the downstream consumers. The affluent flow is the sum between the distributed flow captured by the intake and the transit one ($Q = Q_d + Q_t$).

In order to ensure the transit flow the authors propose a new ecological water intake. Because this one has multiple orifices on both sides, disposed at different depths, on the lateral direction due to the bank slope and on the longitudinal direction due to the backwater curve, the total distributed flow rate captured by the intake will be calculated with a surface integral.

The infinitesimal flow rate on the unit surface is calculated with the variable velocity as a function of the depth z, as in Fig. 2.

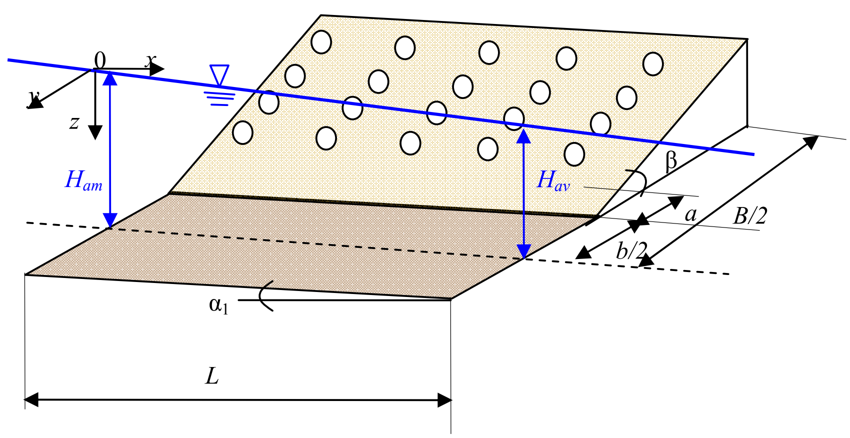
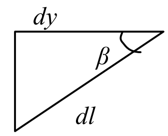


Fig. 2. Longitudinal sight through the ecological intake

$$dQ_d = \mu V \cdot dS = \mu \sqrt{2gz(x,y)} \cdot dx \cdot dl \,.$$

The infinitesimal area is determined with the length dl because it is considered the jet joining at the orifice wall and taking in consideration that the mean velocity inside the orifice is perpendicular on the bank slope.

$dl = \dfrac{dy}{\cos\beta}$ can be expressed as a function of *dy* from the triangle in the next small figure. The infinitesimal flow rate in its new form is:



$$dQ_d = \mu\sqrt{2g}z^{1/2}(x,y)\cdot dx\cdot\frac{dy}{\cos\beta}$$

Because the flow rate takes place on both bank slopes, as in the previous figure, the total flow rate through the orifices is obtained by integration both with *y* and with *x*

$$Q_d = 2\iint_S dQ_d = 2\int_L^0\left(\int_{y_i}^{\frac{B-b}{2}+a}\frac{\mu\sqrt{2g}}{\cos\beta}z^{1/2}dy\right)dx, \tag{2}$$

where *S* is the area of the orifices of a bank slope, *L* the length of the intake, $(B-b)/2+a$ the horizontal width corresponding to the zone with orifices from one bank slope and y_i is given by

$y_i = \dfrac{Ltg\alpha_2}{tg\beta}$, a positive value necessary to calculate the integral.

The relation of dependence between the variables *x, y* and *z* in the case of a fast flow through the intake is obtained from figure 3,

$ytg\beta = xtg\alpha_2 + z$,

from where the variable *z* is obtained.

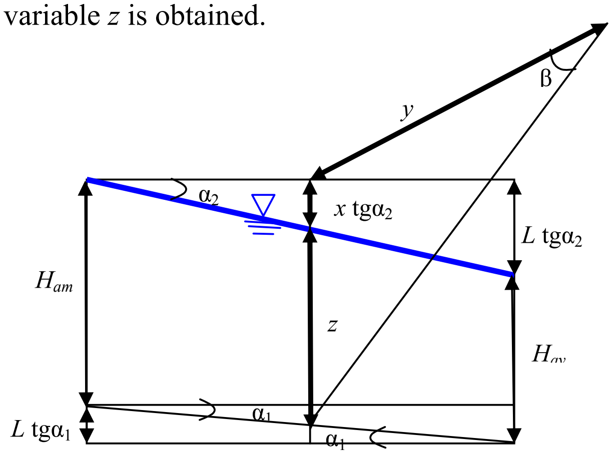


Fig. 3. The dependence between the variables *x, y* and *z*

One obtains also,

$Ltg\alpha_1 + H_{am} = Ltg\alpha_2 + H_{av}$.

Moving the constants in front of the double integral and replacing *z*, the volume flow *Q* becomes

$$Q_d = 2\sqrt{2g}\mu\frac{1}{\cos\beta}\int_L^0\left(\int_{y_i}^{\frac{B-b}{2}+a}\sqrt{ytg\beta - xtg\alpha_2}\,dy\right)dx = \quad (3)$$

$$= \frac{8}{15}\sqrt{2g}\,\mu\frac{\sqrt{tg^3\alpha_2}}{\sin\beta}\left\{\left[\left(\frac{B-b}{2}+a\right)\frac{tg\beta}{tg\alpha_2} - L\right]^{5/2} - \left[\left(\frac{B-b}{2}+a\right)\frac{tg\beta}{tg\alpha_2}\right]^{5/2} + L^{5/2}\right\},$$

a result valid as long as the expression under the first radical remains positive.

5.2. The flow rate captured through discrete orifices

If a limited number of orifices are taken into account, on both bank slopes of the intake, m along Ox and n along Oy, as in Fig. 4, then the total flow captured by the intake is given by:

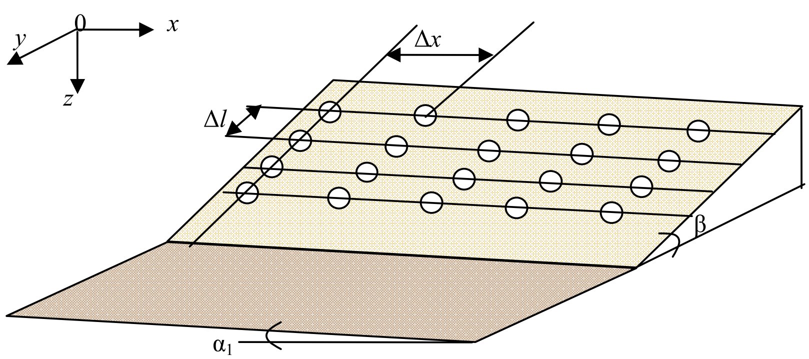


Fig. 4. Steps of the discrete orifices from one of the bank slopes of the intake

$$Q_d = \sum_{i=1}^{n}\sum_{j=1}^{m}\mu\sqrt{2gz(x,y)}S = \frac{\pi\sqrt{2g}}{4}\mu d^2\sum_{i=1}^{n}\sum_{j=1}^{m}(y_j tg\beta - x_i tg\alpha_2)^{1/2}. \quad (4)$$

As in figure 4, the current variables x_i and y_j are given by

$x_i = i\cdot\Delta x$, $y_j = j\Delta l\cdot\cos\beta$

As a consequence, the distributed captured flow by the intake becomes

$$Q_d = \frac{\pi\sqrt{2g}}{4}\mu d^2\sum_{i=1}^{n}\sum_{j=1}^{m}\left(\Delta l\cdot\cos\beta\cdot tg\beta\cdot j - \Delta x tg\alpha_2\cdot i\right)^{1/2}.$$

After summation the flow becomes:

$$Q_d = \frac{\pi\sqrt{2g}}{4}\mu d^2(\sqrt{\Delta l\sin\beta - \Delta xtg\alpha_2} + \ldots + \sqrt{\Delta l\sin\beta - n\Delta xtg\alpha_2} +$$

$$+\sqrt{2\Delta l\sin\beta - \Delta xtg\alpha_2} + \ldots + \sqrt{2\Delta l\sin\beta - n\Delta xtg\alpha_2} + \ldots$$

$$+\sqrt{m\Delta l\sin\beta - \Delta xtg\alpha_2} + \ldots + \sqrt{m\Delta l\sin\beta - n\Delta xtg\alpha_2}) \quad (5)$$

The result becomes more precise if μ is considered variable with the depth *z*, but thus the calculus becomes more complicated.

The calculus can be effectuated both with the method which applies the integral and with the method which utilize the two sums, as long as the positive term under the radical is bigger than the negative one. This thing is justified from the physical point of view by the existence of a positive depth of the water. One obtains the transit flow through the intake with the difference $Q_t = Q - Q_d$.

6. Conclusions

Both installations presented in this paper are new and original. Furthermore, the experimental results are new and the theoretical approaches are also new and original. So we consider that the paper brings a great added value to what is known already in this field of knowledge.

The intake is very useful because a great part of the sediments are transported downstream [5]. This intake has two advantages: a smaller part of the sediments enter in the intake and they are retained inside with proper systems; the sediments which arrive again in the river after the intake prevent the erosion, so the morphology of the river is almost unchanged.

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