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STUDIES AND RESEARCH ON THE TRAJECTORY OF STREAMLINES IN E.O.S. (HORIZONTAL KAPLAN) TURBINES

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Abstract: *The paper presents a detailed hydromechanical analysis of the flow in horizontal Kaplan turbines, with a focus on the trajectory of the streamlines in the essential areas of the installation. The three-dimensional structure of the flow, the formation of vortices, the velocity distribution and the influence of the constructive parameters on the hydraulic performance are investigated. The study combines analytical methods with CFD simulations to identify the areas with energy losses and cavitation potential, providing hydromechanical optimization solutions. The results contribute to improving the design and operation of horizontal Kaplan turbines, with a direct impact on the efficiency and functional stability.*

Keywords*: Kaplan turbines, flow lines, hydromechanical analisys*

1. INTRODUCTION

Kaplan-type hydraulic turbines are one of the most widely used solutions for converting potential and kinetic energy of water into mechanical energy in hydroelectric power plants with low head and high flow rates. Due to their ability to operate efficiently in a wide range of hydraulic regimes, Kaplan turbines have become essential in the sustainable exploitation of hydropower resources. Horizontal construction variants, known as E.O.S. (Elbow Outlet System), are preferred in modern designs due to their compactness, accessibility and possibility of integration into hydrotechnical infrastructures with limited space. In the context of mechanical and hydraulic engineering, the analysis of the trajectory of streamlines inside a horizontal Kaplan turbine is a fundamental element for optimizing hydrodynamic performance. The complex three-dimensional flow, influenced by the geometry of the distributor, the orientation of the rotor blades and the fluid-structure interaction, determines the pressure distribution, the appearance of recirculation zones and the formation of vortices, phenomena that directly affect the efficiency and stability of the turbine operation. Modern studies show that a detailed understanding of streamlines allows for the reduction of hydraulic losses, the limitation of cavitation and the increase of the durability of mechanical components [1], [2]. Recent advances in computational fluid dynamics (CFD) have allowed for the accurate modeling of velocity and pressure fields in Kaplan turbines, providing a deep insight into the flow behavior in critical areas such as the diffuser, the rotor hub and the exhaust duct. Numerical models based on RANS, LES or DES equations are used to reproduce phenomena such as boundary layer

separation, rotor–stator interaction and tail vortex formation, contributing to the optimization of mechanical and hydraulic design [3], [4]. In this context, the present work aims to investigate the trajectory of streamlines in E.O.S. turbines. (Horizontal Kaplan) by analytical and numerical methods, with emphasis on identifying areas with high potential for hydraulic losses and evaluating the influence of constructive parameters on internal flow. The results obtained can contribute to improving the mechanical design, optimizing the operation and increasing the energy efficiency of this type of turbine [5].

2. EXPERIMENTAL STUDY

The test stand was designed in two versions, in a simple and inexpensive execution. However, after carrying out the tests, the conclusions were extremely clear and convincing. The first version of the stand models turbines in their real constructive form (Figure 1).
The basic components of the stand, in this version, are: the inlet hose (1) that connects the water network and the turbine inlet, the pressure gauge (2) that measures the pressure value of the agent at the turbine inlet, the turbine (3) in miniaturized construction, the pressure paint injection device (4), the connection for the turbine rear bearing (5) and the turbine outlet hose to the sewer (6).
The turbine body (3) as well as the connection for the turbine rear bearing (5) are made of transparent Plexiglas tubes and glued with soft glue. To maintain the shape, the turbine body is fixed to a metal support using clamps. The tests are carried out at a pressure of one atmosphere (1.2

bar), corresponding to 12.000 mm of water column which is the maximum height of the water column at which this type of turbine is used. Thus, the deeply turbulent flow of the agent at the connection for the rear bearing of the turbine can be easily observed [6].

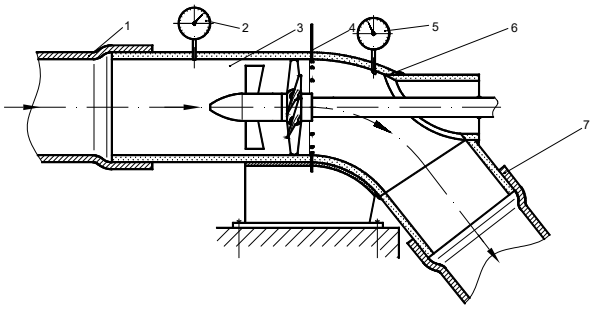


Figure 1. Experimental stand for studying flow lines in turbines
1-inlet hose (from the network); 2-upstream pressure gauge; 3-turbine; 4-pressure paint injection device; 5-downstream pressure gauge; 6-solder; 7-outlet hose.

The profile of the streamlines has been modeled and is shown in Figure 2. It can be seen that at the entrance to the director the flow of the agent is almost laminar, and after entering the director and the turbine propeller the agent acquires a swirling flow. Finally, at the rear bearing connection, the flow becomes sharply turbulent.

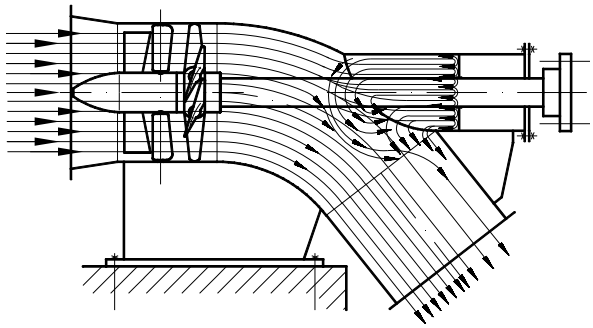


Figure 2. Modeling of the experimental distribution of streamlines in E.O.S.-1100 turbines with record for the rear bearing

As can be seen in the image, this behavior is due to the penetration and then the return of the working agent from inside the rear bearing connection of the turbine.
The return of the agent inside the turbine produces in the respective area a throttling of the fluid jet section (Fig.2). This leads to a decrease in the values of the speed and the motor torque of the shaft, and implicitly, to a decrease in the power and efficiency of the turbine [6].
Figure 3 shows the construction of the test stand with a turbine without the rear bearing connection.
The construction elements and dimensions are the same, except that the rear bearing is placed exactly in the wall of the turbine elbow, without a record. In practice, however, from a technical point of view, this is not possible, because the rear bearings must be mounted in a housing.
From the modeling in Figure 4, it can be seen that, in this case, the profile of the streamlines differs fundamentally.

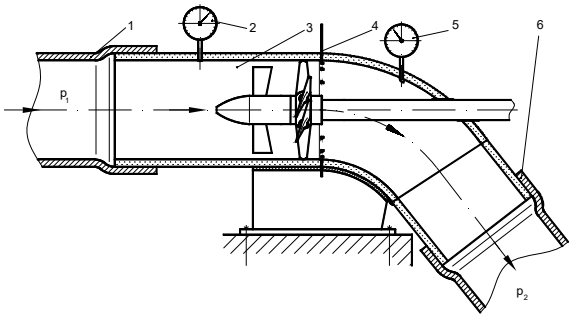


Figure 3. Experimental stand for studying the streamlines in E.O.S.-1100 turbines without rear bearing housing
1-inlet hose (from the network); 2-upstream pressure gauge; 3-turbine; 4-pressure paint injection device; 5-downstream pressure gauge; 6-outlet hose.

Thus, after passing the director and the turbine propeller, the agent has a slightly turbulent motion but very close to a laminar motion. A non-negligible increase in the speed and torque of the turbine shaft is observed. Logically, the power and efficiency of the turbine will also increase.

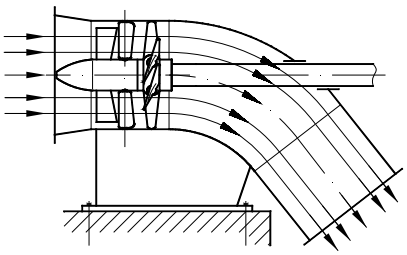


Figure 4. Modeling streamline distribution in turbines without rear bearing record

3. PERFORMING TESTS ON THE PROTOTYPE TURBINE AND EVALUATING THE RESULTS

a) Description of the turbine prototype

The axial projection of the prototype turbine of the E.O.S.-1100 type (horizontal Kaplan type) is presented in figure 5.

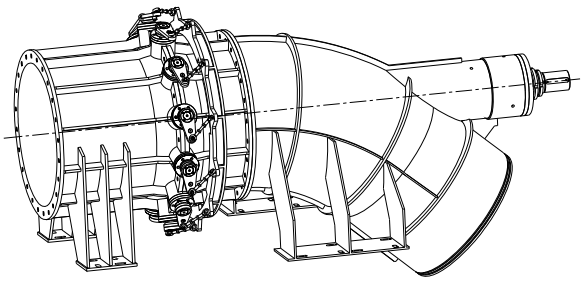


Figure 5. Spatial view of the prototype turbine E.O.S.-1100 type

In figures 6, 7 and 8 all the constructive details of such a turbine can be observed.In figures 6, 7 and 8 all the constructive details of such a turbine can be observed.

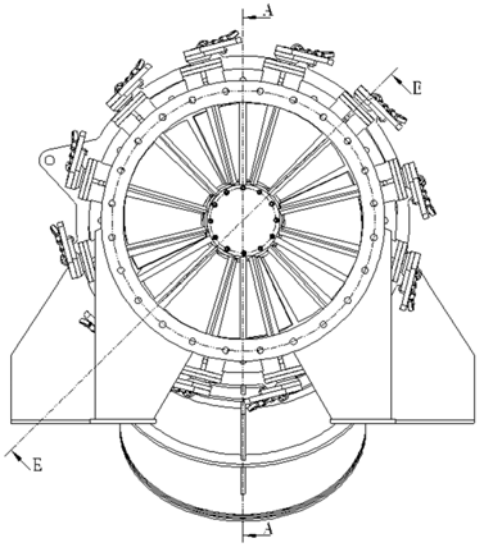


Figure 6. Front view of the prototype turbine of the E.O.S.-1100 type

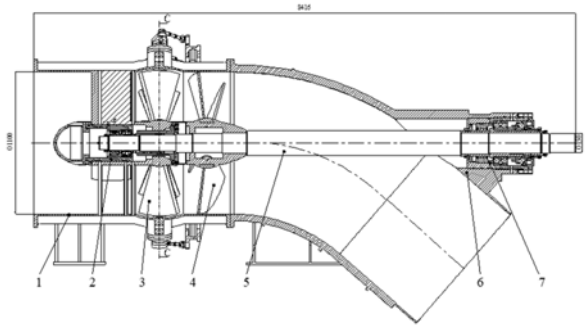


Figure 7. Section A-A of the prototype turbine of the E.O.S.-1100 type

1-turbine body; 2-front bearing; 3-control device; 4-turbine propeller; 5-shaft; 6-rear bearing connection; 7-rear bearing.

As can be seen from the figures above, the main subassemblies of the turbine are:
- the turbine body (1) which is also provided with support supports and fixing on the foundation;
- the front bearing (2) which is a bearing with radial oscillating bearings with two rows of spherical rollers, bearings that take up the slight non-coaxialities of the very long shaft;
- the director apparatus (3) which directs the fluid jet so as to obtain an optimal impact on the propeller blades (4);
- the turbine shaft (5);
- the rear bearing connection (6) and the rear bearing (7) formed by a radial oscillating bearing with two rows of spherical rollers and a special axial oscillating bearing with spherical rollers that takes up the axial force from the turbine shaft.

Both the front bearing and the rear bearing are provided with specially constructed sealing boxes, very safe in operation.

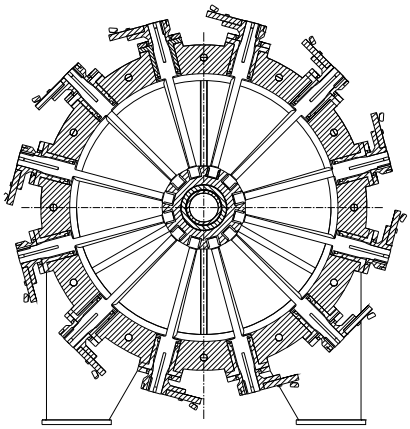


Figure 8. Section E-E through the director apparatus

b) Carrying out tests and drawing up the graphs of the director blade angle - speed and director blade angle - power

The tests were carried out on an E.O.S.-1100 turbine (horizontal helical turbine with S-shaped rotor blades), and consisted of changing the value of the inclination angle of the director blade from 0º to 90º (0º angle being corresponding to the distribution system blades in a completely closed position, therefore perpendicular to the turbine axis, and 90º is corresponding to the completely open position of the distribution system blades, therefore the blades are parallel to the turbine axis).
During the tests, the values of the speed and power supplied by the generator are read.
The values obtained as a result of the tests carried out, with different angles of inclination of the distribution system blades, are listed in Table 1.

Table 1

α [º]	0	10	20	30	40	50	60	70	80	90
v[rot/min]	0	85	154	205	238	274	288	282	273	264
P[kW]	0	62	92	110	134	149	160	151	144	143

4. EXPERIMENTAL RESULTS

Based on these, the two graphs in figure 9 were drawn: graph of inclination angle of the director's blades – speed, and variation of inclination angle of the director's blades - power.

a) Proposals for modifying the prototype turbine construction

From the study of the behavior of the two constructive variants of turbines in figure 2 and fig 4, it is clearly observed that the variant in fig.4 operates at higher performance parameters.
Thus, the following constructive solutions can be adopted for the prototype of the new turbine:

- Closing the rear bearing connection, between the shaft and the casing, using a removable metal cover consisting of two sectors attached to the casing with screws (1 in Figure 10).
- On the shaft, the cover does not have to be airtight, it must only prevent the formation of vortices in the rear bearing connection area.
- In the working agent outlet area, the turbine will be provided with an aspirator (a suction area) which has the role of increasing the pressure difference between the inlet and outlet of the turbines.

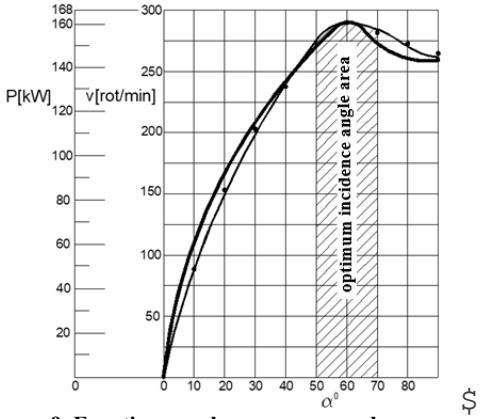


Figure 9. Function graphs $v = f(\alpha)$ and $P = f(\alpha)$ for the classic E.O.S.-1100 turbine

In Figure 10 a section through the proposed new variant is represented. The cover (1) that closes the rear bearing connection space, as well as the suction area (2), can be observed.

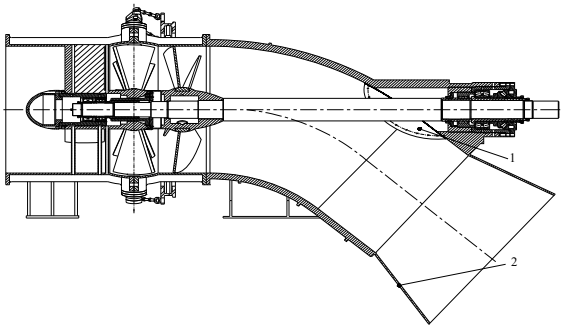


Figure 10. Section through the modified turbine
1-removable cover; 2-vacuum cleaner

b) Carrying out the tests and drawing the graphs of the steering gear angle - speed and the steering gear angle - power, for the modified turbine.

The tests were carried out on the same E.O.S.-1100 turbine, after the two half-covers were mounted and after the vacuum cleaner was welded, the turbine reassembled in the same place, with the same drop of the working fluid column, therefore with the same inlet pressure.
The results listed in Table 2 were obtained, and the function graphs $v = f(\alpha)$ and $P = f(\alpha)$ were also drawn for the improved E.O.S.-1100 turbine from Figure 11.

Table 2

α [^{0}]	0	10	20	30	40	50	60	70	80	90
v[rot/min]	0	90	145	205	241	275	292	284	275	270
P[kW]	0	62	94	118	136	152	165	153	146	145

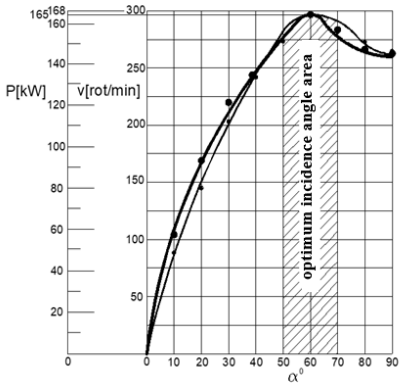


Figure 10. Function graphs $v = f(\alpha)$ and $P = f(\alpha)$ for the improved E.O.S.-1100 turbine

5. CONCLUSION

Both by following the values in Table 2 and the function graphs and represented in Figure 11, it can be seen that the improved E.O.S.-1100 turbine variant, presented in Figure 10. has much higher functional parameters and efficiency than the variant presented in Figure 7.
At the same time, the new turbine variant also has a quieter operation, free of vibrations.
Since the highest efficiency specified in the specialized literature for such a turbine is 94%, it can be easily concluded that the proposed measures are very good.

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