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INFLUENCE FACTORS IN THE PERFORMANCE IN A TRACING OF A FRIENDLY FISH TURBINE HYDRAULIC CHANNEL

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Abstract. *This research study is based in a development of a design methodology for tracing the geometry of hydraulic channel for a friendly-fish turbine. The hydrodynamic performance characteristics are obtained, through Computational Fluids Dynamics techniques, considering the operating conditions and geometrical factors that may influences significantly in the efficiency and rotor performance. For the analysis of the hydrodynamic performance of the turbine, criteria such as turbine drowning levels, angular velocity, and the use of two types of draft tubes and their influence on the performance of the turbine; were considered. The types of draft tubes considered are a simple conical draft tube and the parameterized draft tube, based on the original geometry of the GAMM Francis Turbine. The GAMM (Gesellschaft für Angewandte Mathematik und Mechanik - Mathematical and Mechanics Applied Society) Francis turbine is a normal Francis turbine model that was tested in the Hydraulic Machines Laboratory IMH-EPFL in Lausanne, Switzerland. The elbow draft tube modified over the original geometry draft tube of the GAMM Francis turbine, has the characteristic that the generatrix line that defines its contour in the plane, is a curve in hyperbolic spiral format, denominated in the current paper as HIP-DT. In the HIP-DT draft tube, at the outlet and at the inlet of the cone and the diffuser respectively, the curvature is zero, thus allowing the transition of the draft tube geometry from the cone to the diffuser to be smooth, this allows a better hydrodynamic performance of the flow in the draft tube, and consequently in the turbine.*

Keywords: *Fish Friendly Turbine, Logarithmic-Spiral, Drowning turbine, Draft Tube, Hyperbolic-spiral.*

1. INTRODUCTION

Due to the necessity and the rise interests over the environment preservation, that have the most of nations; about the care of natural sources and mitigation on the environment impact for a sustainable development, many governments as also different industries that are focused in the hydropower sector generation, have developed researches about turbines that would be friendly with the fishes. These researches about the friendly fish turbines projects have taking in an account the project requirements and therefore the operations conditions (i.e. the hydraulic heads, the flow capacity, etc.), without present a significant lost or reduction on its efficiency at the Power generation.

In this moment, there is a great number of turbines operating in all hydraulic head ranges with high efficiencies, however many of which, do not have an adequate design that will be friendly with the fishes, causing an environmental damage by the high mortality fish rate occasioned, due to the injuries caused to them. Čada G. (2001). Therefore being of transcendental importance to develop and improve hydraulic turbines that satisfices the environmental criteria and reach the high efficiencies.

2. METHODOLOGY

For the design methodology of a hydraulic channel of a friendly fish turbine was taking into account the environmental requirements established by Odeh (1999), and that are presented below as follow:

- Peripheral runner velocities should be less or equal than 12 m/s,
- Minimum pressure through the runner should not be significantly less than 69 kPa ,

- The rate of pressure change through the runner $V\dfrac{dP}{dS}$ should be less than 550 kPa/s,
- Shear Stress Indicator $\tau = \dfrac{dV}{dS}$ should be less or equal to 180 m/s/m
- The clearance between the rotating and stationary components should be less than 2 mm,
- The flow passage opening in the runner should be as large as be possible.
- The number and length of the runner blade leading edges should be minimized.

2.1 Hydraulic channel and dimensions for a fish friendly rotor

For establishment of the dimensions for a fish friendly rotor, was applied the classical one-dimensional approach design for radial and mixed flow turbomachines at the inlet of the hydraulic channel.

The operational conditions chosen for the purpose of the generation of the hydraulic channel, were established, according to the physical criteria about the design for a fish friendly turbine obtained from Odeh (1999), and the information reported in Dixon D. and Dham R. (2011). Within the chosen parameters were:

- The head hydraulics of 20 m, a medium height water turbine project.
- A flow of water for turbine project were established in 28m3/s.
- β4 angle of the relative velocity at the inlet adopted, was 18º.
- The peripheral velocity at the inlet taken was u4=20 m/s, without choking turbine consideration.

This last parameter is over the value established for Odeh (1999) of 12m/s, however for the project design of a friendly fish turbine in the cited reference, was considered an u_4 velocity of 19,51 m/s with bigger diameters.

With these conditions and for a two low rotational speed (150 and 180 rpm) adopted, was determined the diameter at the inlet rotor D_4 and the N_{qA}. The outcome indicated by the N_{qA} obtained, was the corresponding to the Francis rotor's performance.

For the establishment of the cone dimensions, were adopted the geometrical parameters given by Eq. (1), and Eq. (2) and Fig. 1:

$$\frac{D_4}{D_{5i}} = 2{,}775 \tag{1}$$

$$D_{5e} = 0.85 D_4 \tag{2}$$

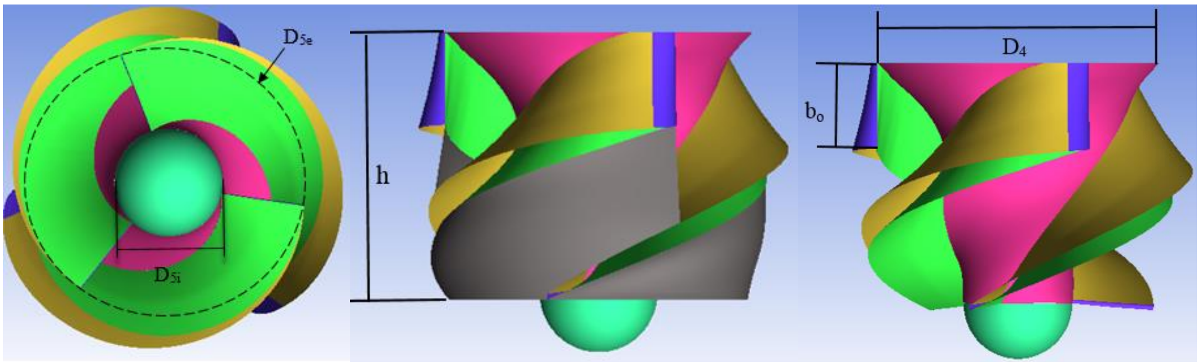


Figure 1: Frontal and lateral views of a turbine's rotor generated with a Göetingem 474 profile.

The rotor dimensions for D_{5i} and the D_{5e} are obtained using Eq. (2). Taking into account the data supplied by Sousa and Bran (1969) in the ratio (bo/D5e) and N_{qA} previously calculated see Fig.2, was established the height of the blade at the inlet of hydraulic channel bo, satisfying the range among $0{,}85\ D_4 \leq D5e < D_4$. The blade height at the inlet of hydraulic channel bo, using de abode procedure mentioned was $bo=0.757\ m$.

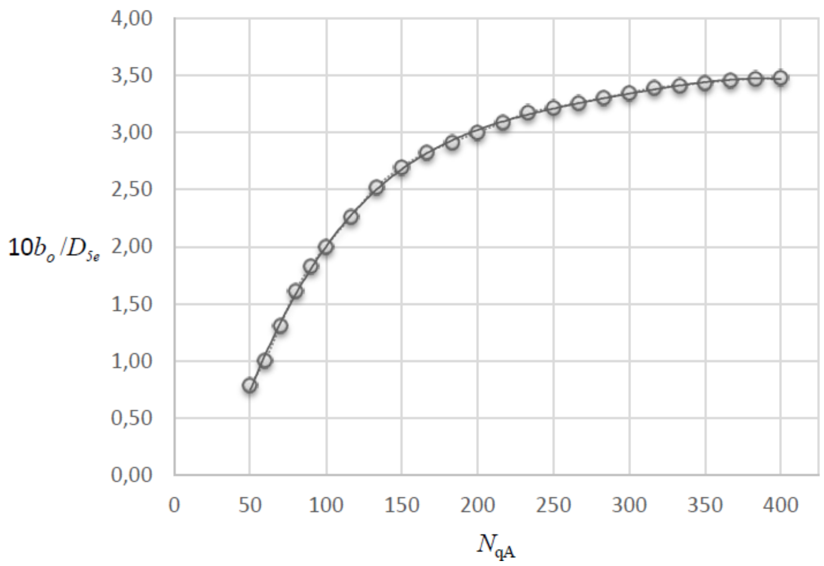


Figure 2: Elements of preliminary Francis rotors project. Figure adopted of Bran e Sousa. (1969).

Then by the Eq. (3) it's possible to determine the meridian velocity at the inlet of the channel, and after, all components velocities triangle at the inlet, see Table 1 and Fig. 3.

$$C_{m4} = {}^{Q}\!/_{\pi D_{4m} b_o} \tag{3}$$

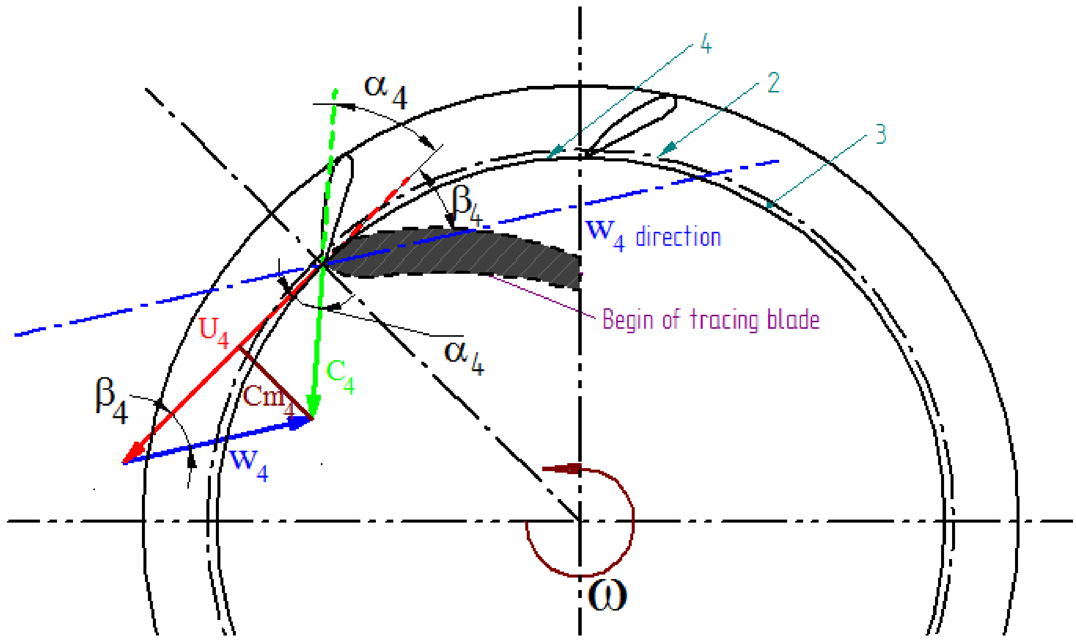


Figure 3: Schematic velocity triangles at the rotor inlet.

Table 1- Velocities components triangle at the inlet rotor.

Velocities components at the inlet rotor	**Magnitude**
C_{m4}	4,62 m/s
$w_4 = C_{m4}/\sin\beta_4$	14,95 m/s
$w_{u4} = C_{m4}/\tan\beta_4$	14,22 m/s
$C_{u4} = u_4 - w_{u4}$,	5,81 m/s
$C_4 = \sqrt{u_4^2 + w_4^2 - 2u_4 w_4 \cos\beta_4}$	7,42 m/s
$\alpha_4 = \tan^{-1}(C_{m4}/C_{u4})$	38,5°
$\beta 4$	18°

2.2 Tracing of hub and the generation of the blades

It was taken a conical hub, it has a smoothed curve revolution's profile given by e second order polynomial equation that pass among the two points generated by r4 and r5i in the plane XZ see Fig.5. Niño del Rio (2015). See Fig. 4.

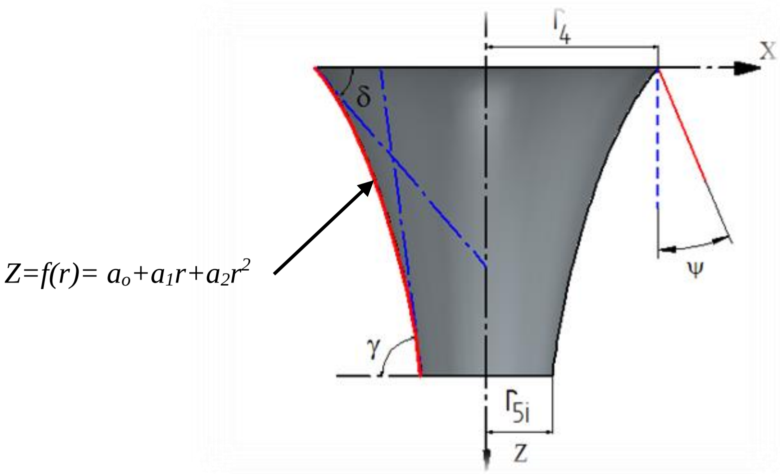


Figure 4: hub rotor form and its construction variables.

Where, δ and γ conforms the primary inlet and outlet hub angles, ψ is the aperture blade angle with respect to the vertical axis Z. Niño del Rio (2015)

In the Table 2, are showed the established values for the other geometrical variables used for the fish friendly turbine rotor generation.

Table 1 - Established values geometrical variables for the fish friendly turbine rotor generation.

Blade lenght, [m]	Hub's parameters	Angle θ	Angle β	Göettingen	N (blades number at the rotor)
0,757	h=2,27 m δ=47°; γ=78°	180°	18°	474	3

For the tracing of the channel were used a logarithm spiral represented by the Eq. (4). See Fig. 5. Where the beta angle is the angle of the relative velocity at the rotor inlet, holding a constant magnitude throughout its tracing, and theta is the rotational sweep along the helix trajectory in radians.

$$r = \left(r_4 e^{(\tan\beta)\theta} \cos\theta ; r_4 e^{(\tan\beta)\theta} \sin\theta \right) \quad (4)$$

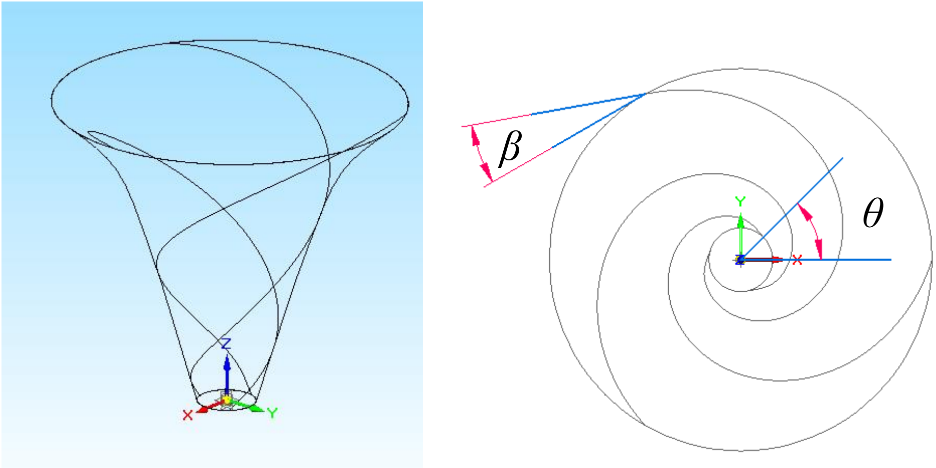


Figure 5: Rotor hub geometry elaborated with a logarithmic spiral curve with β angle constant.

For the hydraulic performance the following criteria were considered: turbine drowning, 150 rpm and 180 rpm rotations, and draft tube configuration using two types of draft tubes.

2.3 Draft tube configuration criteria

Were considered, a simple conical draft tube and elbow draft tube parameterized based on the geometry of the GAMM Francis turbine model, which was tested and designed in the IMH-EPFL, Lausane Switzerland.

The parameterized draft tube is defined in this paper as HIP-DT, see Fig 6. It has the characteristic, among others, that the generatrix curve that defines the elbow contour in the plane, is given by a curve in hyperbolic spiral format (T. M. Arispe Angulo, 2016), which allows the curvature in the outlet of the cone and the inlet of the diffuser of the draft tube to be zero. This characteristic is important, since the geometrical transition of cone, elbow and diffuser, influences pressure gradients; which impacts on the recovery of static pressure at the outlet of the draft tube and consequently on the hydrodynamic performance of the whole turbine.

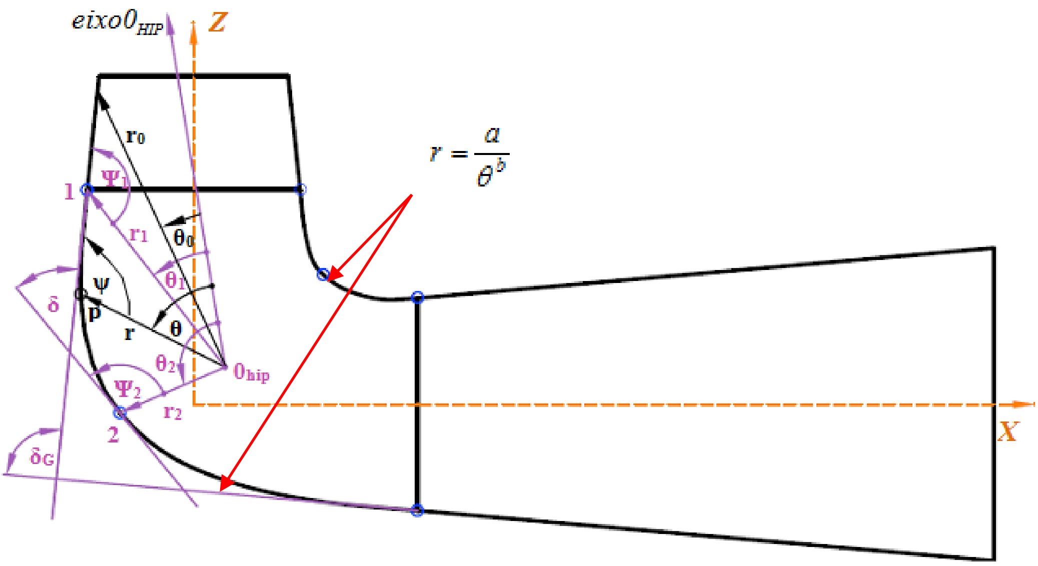
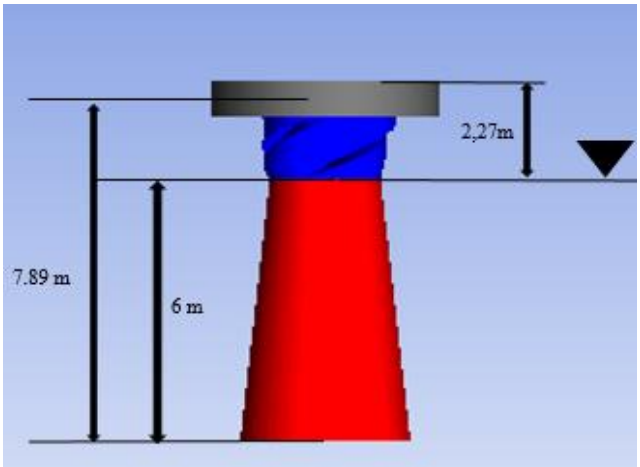


Figure 6: Elbow draft tube in hyperbolic spiral format

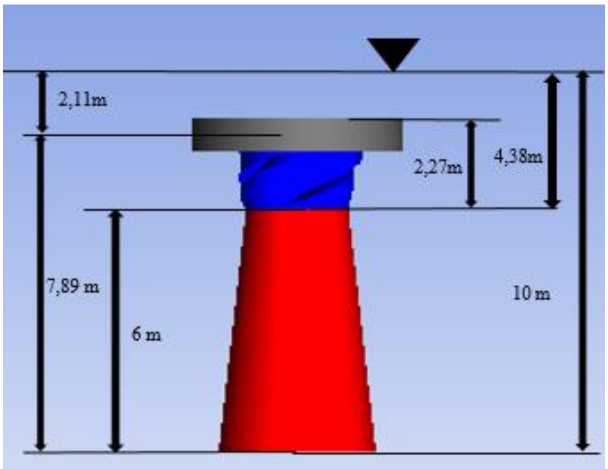
Where, r_n represent the radius at any point on the curve, θ_n are their corresponding angles, δ_n are the angles that define the tangency at any point of the curve.

2.4 Turbine drowning

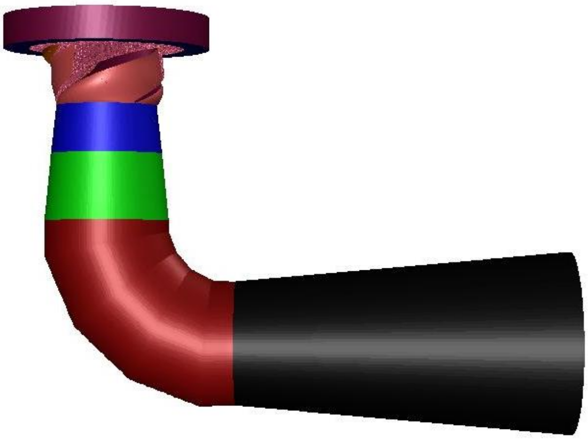
The turbine drowning is one of the most relevant factors in the operating conditions that avoid the cavitation and influences to reach a better performance. To analyses the influence of the drowning in the fish friendly turbine proposed, were considered different cases varying the drowning level of the turbine. See Fig. 7. Niño Del Rio (2015).



(a)



(b)



(c)

Figure 7: (a) Turbine with draft tube drowned, (b) Full drowned Turbine with simple conical draft tube, (c) Full drowned Turbine with HIP-DT

For being similar to the Francis turbine rotor characteristics, at the inlet of the rotor was considered the use de Eq. (5) to determine Thoma coefficient, and the Eq. (6) to determine the minimum suction height in the turbine for the all cases.

$$\sigma = 0{,}0245\ e^{0{,}00833\ n_{qA}} \tag{5}$$

$$h_s < h_b - \Delta h - h_v \tag{6}$$

Being; hs the suction height, hb, the barometric height, Δh the additional decrease of pressure and hv the steam pressure.

3. NUMERICAL SIMULATION

For the numerical simulation of the fish friendly turbine projected, 4 cases were considered: rotor without drowning, turbine with simple conical draft tube drowned, full drowned turbine (with simple conical draft tube), full drowned turbine with HIP-DT draft tube.

The CFD simulation was done using Fluent Version 14® wich resolve the RANS equations in combination with the turbulence modeling equation for (3D). Was used the k-ω SST two equation turbulence model to calculate the turbulent kinetic energy k and its specific dissipation rate ω, being k and ω used to determine the turbulent eddy viscosity *υt*.

The SST k-ω turbulence model is suitable to use in situations when are involved adverse gradients of pressure and presence of separating flows (Dixon and Dham 2011).

3.1 Boundary conditions.

For the determination of the maximum power and performance of the turbine, considering a constant angular velocity, was varied the volumetric flow at the inlet to inertial domain (director system).

The flow was considered incompressible, in permanent regimen with a water dynamic viscosity and density values of the 1,003E-3, ρ=998 kg/m^3, taken to 20°C. At the same time were included the gravity effects with a value of 9,81m/s^2.

The boundary condition at the inlet was given through absolute velocity C4 in the director system in the tangential and radial components and the static pressure given in function of the liquid height 196200 Pa.

The boundary condition at the outlet to the draft tube was configured through a static pressure (Outlet Pressure), at the value which was fixed the atmospheric local pressure, considering the turbine at the first instance without drowning, with a barometric relative pressure equal to zero Pa (7,89 m). Is to outline that the cavitation calculus was not done until will be known the volumetric flow for which was obtained the maximum efficiency.

The rotation was fixed in 150 rpm and 180 rpm, an acceptable value to reduce the fish mortality rate Dixon and Dham (2011).

4. RESULTS AND DISCUSSION

Taking into account two rotations, full drowned turbine and a simple conical draft tube, was obtained the hydraulic efficiency vs volumetric flow curves for the fish friendly turbine with a hydrodynamic profile Göettingem 474. See Fig. 8.

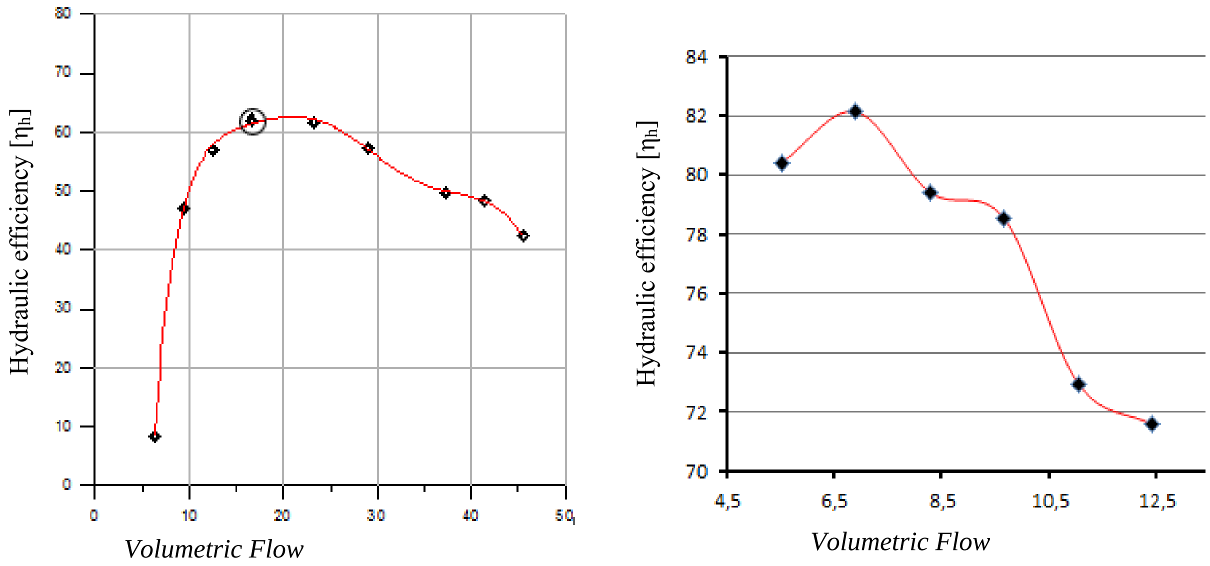


Figure 8- Hydraulic Efficiency Vs Volumetric Flow curve for the fish friendly turbine with profile Göettingem 474 a) 150 rpm, b)180 rpm

In order to improve the hydrodynamic performance of the turbine, the HIP-DT draft tube was added, considering the conditions for the BEP and 180 rpm rotation. The global results for the cases are showed in the Table 4.

Table 2- Global results values at the best performance point with different criteria

	Turbine with the draft-tube drowned (150 rpm)	*Full drowned turbine 150 (rpm)*	*Full drowned turbine 180 (rpm)*	*Full drowned turbine with HIP-DT 180 (rpm)*
η_h [%]	67,48	69,78	82,14	82,27
T [kN-m]	537,223	553,949	329,140	317,072
P_e [kW]	8438,80	8701,40	6202,12	5975,96
P_h [kW]	12505,6	12469,8	7550,67	7263,84

It can be seen, that the turbine drowning, increased rotation and use of the DT-HIP draft tube; Influence positively in turbine performance, increasing the hydraulic efficiency.

With reference to the path lines, it observes a progressive and gradual improve over the guiding on the flow through the hydraulic channel. See Fig.9

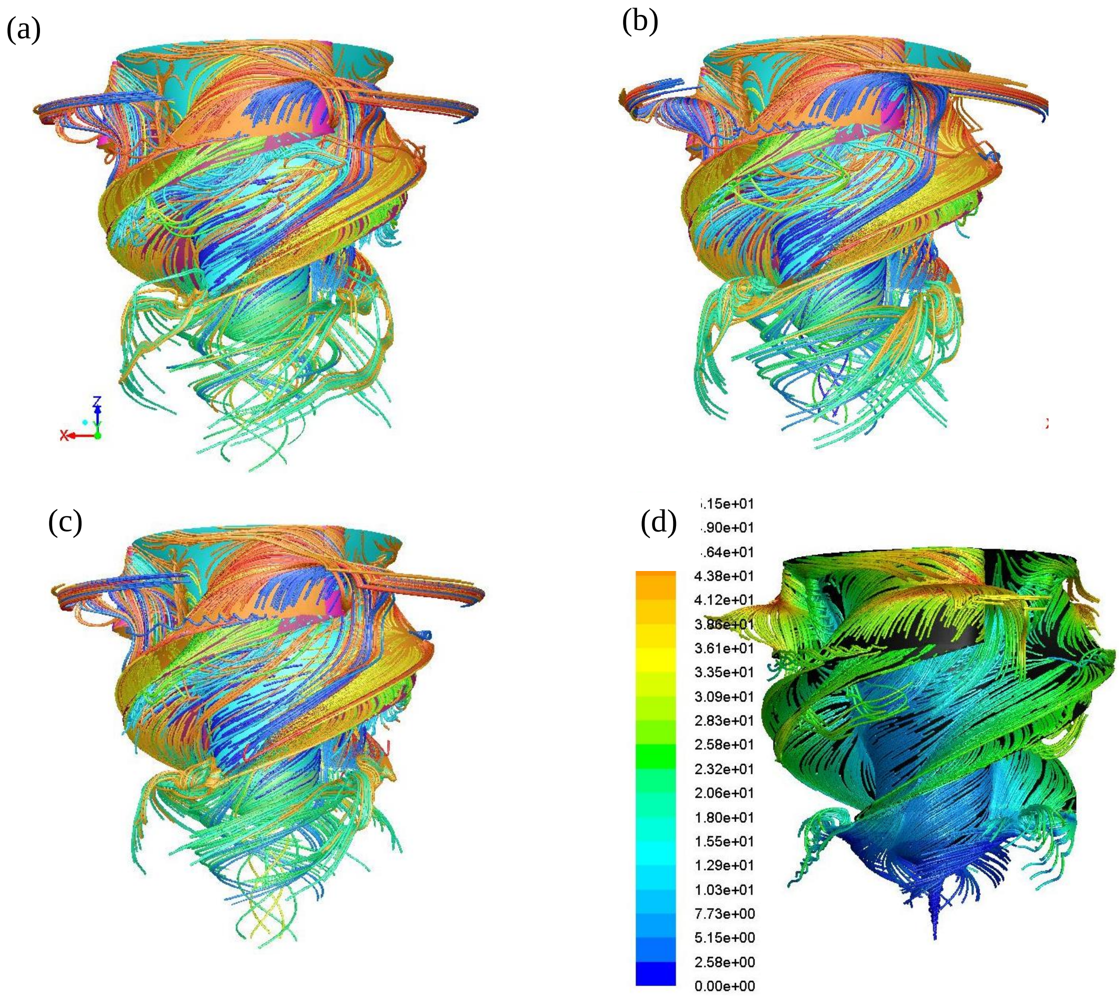


Figure 9- Path lines for the turbine rotor. (a) Turbine rotor without drowing; (b) Turbine rotor with the draft-tube drowned; (c) Full drowned turbine rotor with conical DT; (d) Full drowned turbine rotor with HIP-DT

Despite having a better guiding in the flow through in the hydraulic channel of the rotor in the turbine cases with drowning (turbine with the draft-tube drowned and the full drowned turbine), persists the presence of flow separation regions, secondary fluxes in the rotor at hub.

The located zones, where are presented these characteristics in the flow behavior, is due to the presence of negative pressures at the inlet and outlet of the rotor channel and at the hub and that is verified by the contours of static pressure the both cases above mentioned. See Fig. 10

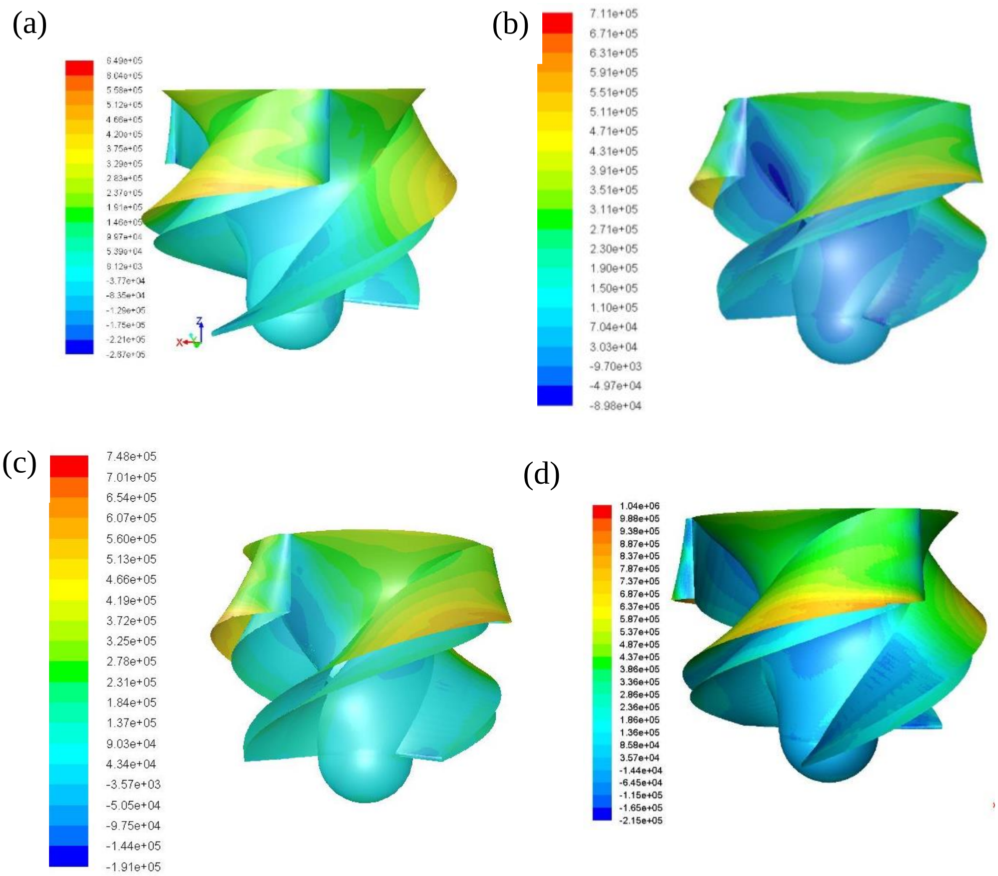


Figure 10-static pressure contours of the turbine rotor. (a) Turbine rotor without drowing; (b) Turbine rotor with the draft-tube drowned; (c) Full drowned turbine rotor with conical DT; (d) Full drowned turbine rotor with HIP-DT

5. CONCLUSIONS

With the full-drowned turbine using a HIP-DT case were obtained the best results in the concern to the Hydraulic efficiency. However must be considered the full drowning of the turbine imply major costs in the civil infrastructure that can influence on the economic viability of the project in a hydropower central with this type of turbines.

In the other hand, for investigate the reason of the presence of the strong stagnation on the edge of the pressure surface of the blade at inlet rotor, will be done a factorial experiment of one factor on the variation over the ψ angle that controls the aperture blade angle. This with the purpose to decrease the big energy dissipation due to the stagnation in this region, affecting the performance of the turbine rotor and therefore its hydraulic efficiency.

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